Development Services Department
Environmental Coordinator
450 110th Avenue NE
Bellevue, WA 98009-9012

DETERMINATION OF NON-SIGNIFICANCE

PROPOSAL NAME:	Emergency Water Supply Master Plan
LOCATION:	City-Wide
FILE NUMBERS:	22-118651-LM
PROPONENT:	Douglas Lane, City of Bellevue

DESCRIPTION OF PROPOSAL:

Application for preliminary SEPA review of the City of Bellevue's Emergency Water Supply Master Plan. This is a non-project action.

The Environmental Coordinator of the City of Bellevue has determined that this proposal does not have a probable significant adverse impact upon the environment. An Environmental Impact Statement (EIS) is not required under RCW 43.21C.030(2)(C). This decision was made after the Bellevue Environmental Coordinator reviewed the completed environmental checklist and information filed with the Land Use Division of the Development Services Department. This information is available to the public on request.

This DNS is issued after using the optional DNS process in WAC 197-11-355. There is no further comment period on the DNS. Only persons who submitted written comments before the DNS was issued may appeal the decision. This DNS is only appealable as part of the City's action on this proposal. In order to comply with requirements of SEPA and the State of Washington Growth Management Act for coordination of hearings, any appeal of the SEPA threshold determination herein will be considered by the Growth Management Hearings Board along with an appeal of the City Council's action. the DNS was issued may appeal the decision.

DATE ISSUED: March 16, 2023

This DNS may be withdrawn at any time if the proposal is modified so as to have significant adverse environmental impacts; if there is significant new information indicating a proposals probable significant adverse environmental impacts (unless a non-exempt license has been issued if the proposal is a private project): or if the DNS was procured by misrepresentation or lack of material disclosure.

Issued By: ***Reilly Pittman***
Planning Manager **for**
Elizabeth Stead, Environmental Coordinator
Development Services Department

Date: 3/16/2023

Development Services

See attached supplemental email at the end of this SEPA checklist which clarifies specific measures and BMPs to mitigate and remedy anticipated impacts.

Leticia Wallgren, Associate Land Use Planner

Non-project Action SEPA Checklist

These questions pertain to land use actions that do not involve building and construction projects, but rather pertain to policy changes, such as code amendments and rezone actions.
Because the questions are very general, it may be helpful to read them in conjunction with the Environmental Checklist. When answering these questions, be aware of the extent to which the proposal, or the types of activities likely to result from the proposal, would affect the item at a greater intensity or at a faster rate than if the proposal were not implemented.

Respond briefly and in general terms.

1. How would the proposal be likely to increase discharge to water; emissions to air; production, storage, or release of toxic or hazardous substances; or production of noise?

   The Emergency Water Supply Master Plan (Master Plan) itself would cause no discharge. Master Plan recommendations would result in hypochlorite storage at well site(s), and small, short discharges of groundwater (to storm or sewer) to flush well(s) at pump startup. Other impacts would be temporary during construction only.

   Indicate proposed measures to avoid or reduce such increases.

   Any impacts would be addressed during a project-specific SEPA. Hypochlorite storage would include double containment to mitigate spill risks. Well flushing duration would be kept short to limit flow to the storm or sewer system.

2. How would the proposal be likely to affect plants, animals, fish or marine life?

   One groundwater well option considered (Alternative #3 - normal potable supply), but not recommended by the Master Plan (page 44) could potentially impact stream flow due to continuous pumping at maximum allowed flows. Detailed analysis is in Attachment 2E.

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Secondary Review by Leticia Wallgren 2/27/23

Indicate proposed measures to protect or conserve plants, animals, fish or marine life.

The Master Plan considers but does not recommend Alternative #3. Rather, Alternative #2 is recommended, along with further hydrogeological study to understand potential risks.

3. How would the proposal be likely to deplete energy or natural resources?

The Master Plan itself would not deplete energy or natural resources. Recommended actions would require electrical energy (for well pumps), groundwater pumping, and resources typical to municipal project construction.

Indicate proposed measures to protect or conserve energy and natural resources.

The Master Plan considers but does not recommend pumping continuously at the maximum rate allowed. Rather, very low flows are recommended (local non-potable use) to maintain readiness, with max flows only in an emergency. See page 44.

4. How would the proposal be likely to use or affect environmentally sensitive areas or areas designated (or eligible or under study) for governmental protection; such as parks, wilderness, wild and scenic rivers, threatened or endangered species habitat, historic or cultural sites, wetlands, floodplains or prime farmlands?

The Emergency Water Supply Master Plan proposes to designate additional sensitive areas for wellhead protection (will benefit sensitive areas).

Indicate proposed measures to protect such resources or to avoid or reduce impacts.

The proposal recommends creating new sensitive area designations to protect well head areas.

5. How would the proposal be likely to affect land and shoreline use, including whether it would allow or encourage land or shoreline uses incompatible with existing plans?

Shoreline use would be unaffected under normal circumstances, and could be reduced during and after a major emergency.

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Indicate proposed measures to avoid or reduce shoreline and land use impacts.

During an emergency, the use of shoreline water drafting by fire trucks (locations on Figure 21) would be reduced as proposed by the Master Plan, due to additional resilient emergency water supply points away from shorelines. See pages 41-42.

6. How would the proposal be likely to increase demands on transportation or public services and utilities?

The proposal would add resilience to the drinking water system. Some flow may be added to the stormwater system during well pump maintenance. The proposal does not involve any increased demands on tranportation networks.

Indicate proposed measures to reduce or respond to such demand(s).

Flows discharged to the storm system would be brief, and would be dechlorinated if applicable.

7. Identify, if possible, whether the proposal may conflict with local, state, or federal laws or requirements for the protection of the environment.

There are no known legal conflicts proposed with the Master Plan. In fact, elements of the Master Plan are required by Bellevue City Code, Washington Administrative Code (WAC 246-290-420.5) and America's Water Infrastructure Act of 2018.

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Development Services

SEPA Environmental Checklist

The City of Bellevue uses this checklist to help determine whether the environmental impacts of your proposal are significant. This information is also helpful to determine if available avoidance, minimization or compensatory mitigation measures will address the probable significant impacts or if an environmental impact statement will be prepared to further analyze the proposal.

Instructions

The checklist asks you to describe some basic information about your proposal. Please answer each question accurately and carefully and to the best of your knowledge. You may need to consult with an agency specialist or private consultant for some questions.

You may respond with “Not Applicable” or "Does Not Apply" only when you can explain why it does not apply and not when the answer is unknown. You may also attach or incorporate by reference additional studies and reports. Please make complete and accurate answers to these questions to the best of your ability in order to avoid delays. For assistance, see SEPA Checklist Guidance on the Washington State Department of Ecology website.

The checklist questions apply to all parts of your proposal, even if you plan to do them over a period of time or on different parcels of land. Attach any additional information that will help describe your proposal or its environmental effects. The city may ask you to explain your answers or provide additional information reasonably related to determining if there may be significant adverse impact.

Background

1. Name of proposed project, if applicable Emergency Water Supply Master Plan
2. Name of applicant City of Bellevue Utilities Department
3. Contact person Doug Lane Phone (425) 452-6865
4. Contact person address PO Box 90012, Bellevue, WA 98009-9012
5. Date this checklist was prepared 9/28/2022
6. Agency requesting the checklist City of Bellevue

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7. Proposed timing or schedule (including phasing, if applicable)

The Emergency Water Supply Master Plan (Master Plan) is a non-project action that proposes water system resilience improvements over the next 50-years, to mitigate earthquake impacts.

8. Do you have any plans for future additions, expansion or further activity related to or connected with this proposal? If yes, explain.

The Master Plan proposes improvements over the next 50-years.

9. List any environmental information you know about that has been prepared or will be prepared, that is directly related to this proposal.

1) Appendix 2E evaluates the local aquifer-stream interface and how groundwater pumping may affect streamflow. 2) The City has performed environmental assessments, remediation and monitoring resulting from a former underground fuel tank at the Crossroads well site.

10. Do you know whether applications are pending for governmental approvals of other proposals directly affecting the property covered by your proposal? If yes, explain.

The Master Plan covers the entire cities of Bellevue, Clyde Hill, Medina, Hunts Point and Yarrow Point, and does not cover any specific property(ies).

11. List any government approvals or permits that will be needed for your proposal, if known.

No government approvals are required for the proposal.

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12. Give a brief, complete description of your proposal, including the proposed uses and the size of the project and site. There are several questions later in this checklist that ask you to describe certain aspects of your proposal. You do not need to repeat those answers on this page. (Lead agencies may modify this form to include additional specific information on project description.)

The Master Plan intends to mitigate a months-long water supply disruption and catastrophic damage to the local community and economy that will occur following a major earthquake with existing infrastructure. It proposes pipeline, pump station and reservoir improvements, groundwater wells, and ancillary work. Most of this is already proposed in Bellevue's renewal & replacement programs; well installation is new.

13. Location of the proposal. Give sufficient information for a person to understand the precise location of your proposed project, including a street address, if any, and the section, township and range, if known. If a proposal would occur over a range of area, provide the range or boundaries of the site(s). Provide a legal description, site plan, vicinity map and topographic map, if reasonably available. While you should submit any plans required by the agency, you are not required to duplicate maps or detailed plans submitted with any permit applications related to this checklist.

The Master Plan covers the entire cities of Bellevue, Clyde Hill, Medina, Hunts Point and Yarrow Point, and does not cover any specific property(ies).

Environmental Elements

Earth

1. General description of the site:
   - ☐ Flat
   - ☐ Rolling
   - ☐ Hilly
   - ☐ Steep Slopes
   - ☐ Mountainous
   - ☑ Other Bellevue's water service area is located between two lakes, with 1,400-ft of elevation range.

2. What is the steepest slope on the site (approximate percent slope)? N/A

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3. What general types of soils are found on the site (for example, clay, sand, gravel, peat, muck)? If you know the classification of agricultural soils, specify them and note any agricultural land of long-term commercial significance and whether the proposal results in removing any of these soils.

The Master Plan covers the entire cities of Bellevue, Clyde Hill, Medina, Hunts Point and Yarrow Point, with many types of soils. Soil would only be removed as needed to pipeline trenching.

4. Are there surface indications or history of unstable soils in the immediate vicinity? If so, describe.

Yes. The Master Plan proposes to mitigate the impacts of unstable soils (existing risk of main breaks).

5. Describe the purpose, type, total area and approximate quantities and total affected area of any filling, excavation and grading proposed. Indicate the source of the fill.

The Master Plan covers the entire cities of Bellevue, Clyde Hill, Medina, Hunts Point and Yarrow Point, with many types of soils. Filling, excavation and grading quantities cannot be estimated at this time, and will be addressed on a project basis when applicable.

6. Could erosion occur as a result of clearing, construction or use? If so, generally describe.

The Master Plan does not involve any clearing or construction. Potential erosion from proposed future projects would be mitigated when applicable.

7. About what percent of the site will be covered with impervious surfaces after project construction (for example, asphalt or buildings)? N/A

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8. Proposed measures to reduce or control erosion, or other impacts to the earth, if any.

The Master Plan would benefit (not impact) the earth, and reduce erosion. The proposed added water system resilience proposed by the Master Plan would reduce the number of water main breaks throughout the system by hundreds, particularly after an earthquake, and eliminate the associated erosion from those main breaks.

Air

1. What types of emissions to the air would result from the proposal during construction, operation and maintenance when the project is completed? If any, generally describe and give approximate quantities if known.

The Master Plan would not cause emissions to the air. Future projects proposed by the Master Plan would involve temporary increases of emissions associated with construction work, and would be addressed on a project basis.

2. Are there any off-site sources of emissions or odor that may affect your proposal? If so, generally describe.

No.

3. Proposed measures to reduce or control emissions or other impacts to air, if any.

N/A

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Water

1. Surface Water
   a. Is there any surface water body on or in the immediate vicinity of the site (including year-round and seasonal streams, saltwater, lakes, ponds, wetlands)? If yes, describe type and provide names. If appropriate, state what stream or river it flows into.

The Master Plan covers the entire cities of Bellevue, Clyde Hill, Medina, Hunts Point and Yarrow Point, bordering and including several lakes and over 80 miles of streams.

   b. Will the project require any work over, in or adjacent to (within 200 feet) the described waters? If yes, please describe and attach available plans.

No, the Master Plan would not result in additional work over, in or adjacent to these waters. Existing pipelines that cross streams will already require replacement under existing renewal & replacement programs, but the Master Plan would simply require more resilient types of piping be installed when replaced.

   c. Estimate the amount of fill and dredge material that would be placed in or removed from surface water or wetlands and indicate the area of the site that would be affected. Indicate the source of the fill material.

N/A

   d. Will the proposal require surface water withdrawals or diversions? Give a general description, purpose and approximate quantities, if known.

No.

   e. Does the proposal lie within a 100-year floodplain? N/A
   If so, note the location on the site plan.

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f. Does the proposal involve any discharges of waste materials to surface waters? If so, describe the type of waste and anticipated volume of discharge.

The Master Plan itself would not involve any discharges of waste materials. If new groundwater wells are installed as recommended (future), some untreated groundwater may be discharged to the storm and/or sewer system(s) during exercise and maintenance of well pump equipment to flush the well at startup. Anticipated volume would be roughly 5,000 gallons per location, per startup.

2. Ground Water

a. Will groundwater be withdrawn from a well for drinking water or other purposes? If so, give a general description of the well, proposed uses and approximate quantities withdrawn from the well. Will water be discharged to groundwater? Give general description, purpose, and approximate quantities if known.

The Master Plan recommends continued withdrawals from existing WD97 Wells No. 3, 5, 6 and 7 (see Fig. 12, p. 16). In normal conditions, only non-potable use is recommended (0 to 20,000 gal/day), but in temporary conditions (1-12 weeks) after a major earthquake, potable use is recommended up to the existing water rights (3,816,000 gal/day). In addition, approx 6 new emergency-only wells are proposed (locations to be determined), for use only in a declared emergency at less than 1,000,000 gal/day (each). No water would be discharged to groundwater.

b. Describe waste material that will be discharged into the ground from septic tanks or other sources, if any (for example: Domestic sewage; industrial, containing the following chemicals…; agricultural; etc.). Describe the general size of the system, the number of such systems, the number of houses to be served (if applicable), or the number of animals or humans the system(s) are expected to serve.

None.

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3. Water Runoff (including stormwater)
   a. Describe the source of runoff (including storm water) and method of collection and disposal, if any (include quantities, if known). Where will this water flow? Will this water flow into other waters? If so, describe.

The Master Plan would not result in any anticipated additional runoff.

   b. Could waste materials enter ground or surface waters? If so, generally describe.

Waste materials would not enter ground or surface waters as a result of the Master Plan.

   c. Does the proposal alter or otherwise affect drainage patterns in the vicinity of the site? If so, describe.

N/A

   Indicate any proposed measures to reduce or control surface, ground and runoff water, and drainage pattern impacts, if any.

N/A

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Plants

1. Check the types of vegetation found on the site:

- ☐ deciduous tree: alder, maple, aspen, other _____
- ☐ evergreen tree: fir, cedar, pine, other _____
- ☐ shrubs
- ☐ grass
- ☐ pasture
- ☐ crop or grain
- ☐ orchards, vineyards or other permanent crops
- ☐ wet soil plants: cattail, buttercup, bulrush, skunk cabbage, other _____
- ☐ water plants: water lily eelgrass, milfoil, other _____
- ☑ other types of vegetation N/A

2. What kind and amount of vegetation will be removed or altered?

The Master Plan would not involve removal or alteration of vegetation. If there are anticipated vegetation impacts from any subsequent projects, those impacts would be addressed with the project-specific SEPA.

3. List any threatened and endangered species known to be on or near the site.

N/A

4. Proposed landscaping, use of native plants or other measures to preserve or enhance vegetation on the site, if any.

N/A

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5. List all noxious weeds and invasive species known to be on or near the site.

N/A

Animals

1. List any birds and other animals which have been observed on or near the site or are known to be on or near the site. Examples include:

   Birds: ☐hawk, ☐heron, ☐eagle, ☐songbirds, ☐other N/A

   Mammals: ☐deer, ☐bear, ☐elk, ☐beaver, ☑other N/A

   Fish: ☐bass, ☐salmon, ☐trout, ☐herring, ☐shellfish, ☑other N/A

2. List any threatened and endangered species known to be on or near the site.

N/A

3. Is the site part of a migration route? If so, explain.

N/A

4. Proposed measures to preserve or enhance wildlife, if any.

N/A

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5. List any invasive animal species known to be on or near the site.

N/A

Energy and Natural Resources

1. What kinds of energy (electric, natural gas, oil, wood stove, solar) will be used to meet the completed project's energy needs? Describe whether it will be used for heating, manufacturing, etc.

Proposed improvements to existing wells, and new (future) wells would require electrical energy for pumping.

2. Would your project affect the potential use of solar energy by adjacent properties? If so, generally describe.

N/A

3. What kinds of energy conservation features are included in the plans of this proposal? List other proposed measures to reduce or control energy impacts, if any.

N/A

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Secondary Review by Leticia Wallgren 2/27/23

Environmental Health

1. Are there any environmental health hazards, including exposure to toxic chemicals, risk of fire and explosion, spill or hazardous waste, that could occur as a result of this proposal? If so, describe.

The Master Plan would not involve any environmental health hazards. If any subsequent projects have potential related hazards (e.g. hypochlorite stored at well locations for water treatment), those would be addressed with the project-specific SEPA and conform to OSHA/WISHA rules and best practices.

a. Describe any known or possible contamination at the site from present or past uses.

At the Crossroads wells site, an underground fuel storage tank was removed in the 1990s. Contaminated soil and perched groundwater was subsequently remediated. The lower, confined aquifer used by the wells was not affected, but the City regularly monitors soil composition and groundwater chemistry.

b. Describe existing hazardous chemicals/conditions that might affect project development and design. This includes underground hazardous liquid and gas transmission pipelines located within the project area and in the vicinity.

See above question and response.

c. Describe any toxic or hazardous chemicals that might be stored, used, or produced during the project's development or construction, or at any time during the operating life of the project.

Hypochlorite (either liquid sodium hypochlorite and/or solid calcium hypochlorite) may be stored at existing or new (future) well locations, for use in treating groundwater prior to use.

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Secondary Review by Leticia Wallgren 2/27/23

d. Describe special emergency services that might be required.

No special emergency services would be required for the Master Plan. However, the Master Plan recommendations would augment and support emergency services in the future.

e. Proposed measures to reduce or control environmental health hazards, if any.

The City would continue to monitor soil and groundwater chemistry at the Crossroads wells site, due to the former underground fuel tank. If applicable, double containment would be provided for future hypochlorite storage at well sites, to mitigate spill risks.

2. Noise

a. What types of noise exist in the area which may affect your project (for example: traffic, equipment, operation, other)?

None.

b. What types and levels of noise would be created by or associated with the project on a short-term or a long-term basis (for example: traffic, construction, operation, other)? Indicate what hours noise would come from the site.

The Master Plan itself would not create noise. Groundwater well improvements recommended by the Master Plan may require on-site power generation to mitigate power outages after earthquakes. Generators would require regular exercise (likely weekly) on a long-term basis.

c. Proposed measures to reduce or control noise impacts, if any.

The Master Plan would not create noise. If recommended projects such as groundwater well improvements created noise, that would be addressed on a project-specific basis. Mitigation measures may include generator noise dampeners and enclosures.

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Land and Shoreline Uses

1. What is the current use of the site and adjacent properties? Will the proposal affect current land uses on nearby or adjacent properties? If so, describe.

The Master Plan would not affect land use. If new emergency-only wells are installed as recommended (locations to be determined), those would likely change land use on their specific sites, and require a wellhead protection area that limits land use within a limited radius (possibly affecting adjacent properties). Future siting studies would identify these sites and address land use issues, but sites are not known at this time.

2. Has the project site been used as working farmlands or working forest lands? If so, describe. How much agricultural or forest land of long-term commercial significance will be converted to other uses as a result of the proposal, if any? If resource lands have not been designated, how many acres in farmland or forest land tax status will be converted to non-farm or non-forest use?

N/A

   a. Will the proposal affect or be affected by surrounding working farm or forest land normal business operations, such as oversize equipment access, the application of pesticides, tilling and harvesting? If so, how?

N/A

3. Describe any structures on the site.

N/A

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4. Will any structures be demolished? If so, what?

N/A

5. What is the current zoning classification of the site? N/A

6. What is the current comprehensive plan designation of the site? N/A

7. If applicable, what is the current shoreline master program designation of the site?

N/A

8. Has any part of the site been classified as a critical area by the city or county? If so, specify.

N/A

9. Approximately how many people would reside or work in the completed project? 150,000+

10. Approximately how many people would the completed project displace? None known (zero)

11. Proposed measures to avoid or reduce displacement impacts, if any.

Resident displacement is not likely as a result of the Master Plan. If the siting of future emergency-only groundwater wells might displace any residents, those impacts would be mitigated at that time, when known (locations to be determined).

12. Proposed measures to ensure the proposal is compatible with existing and projected land uses and plans, if any.

N/A

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13. Proposed measures to ensure the proposal is compatible with nearby agricultural and forest lands of long-term commercial significance, if any.

N/A

Housing

1. Approximately how many units would be provided, if any? Indicate whether high, middle, or low-income housing.

0

2. Approximately how many units, if any, would be eliminated? Indicate whether high, middle, or low-income housing.

None known (zero). If future, emergency-only groundwater wells might eliminate any housing, those impacts would be mitigated at that time, when known (locations TBD).

3. Proposed measures to reduce or control housing impacts, if any.

N/A

Aesthetics

1. What is the tallest height of any proposed structure(s), not including antennas; what is the principal exterior building material(s) proposed?

N/A

2. What views in the immediate vicinity would be altered or obstructed?

N/A

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3. Proposed measures to reduce or control aesthetic impacts, if any

N/A

Light and Glare

1. What type of light or glare will the proposal produce? What time of day would it mainly occur?

N/A

2. Could light or glare from the finished project be a safety hazard or interfere with views?

N/A

3. What existing off-site sources of light or glare may affect your proposal?

N/A

4. Proposed measures to reduce or control light and glare impacts, if any.

N/A

Recreation

1. What designated and informal recreational opportunities are in the immediate vicinity?

WD97 Well #3 is located in an un-named park at 1028 151st Ave SE.

2. Would the proposed project displace any existing recreational uses? If so, describe.

None known.

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3. Proposed measures to reduce or control impacts on recreation, including recreation opportunities to be provided by the project or applicant, if any.

The Master Plan proposes augmenting irrigation at Crossroads Park as a non-potable use for the existing Crossroads wells. If improvements at WD97 Well #3 might affect the local park, those impacts would be mitigated on a project-specific basis.

Historic and Cultural Preservation

1. Are there any buildings, structures or sites located on or near the site that are over 45 years old listed in or eligible for listing in national, state or local preservation registers located on or near the site? If so, specifically describe.

None known (or N/A)

2. Are there any landmarks, features or other evidence of Indian or historic use or occupation? This may include human burials or old cemeteries. Are there any material evidence, artifacts or areas of cultural importance on or near the site? Please list any professional studies conducted at the site to identify such resources.

None known (or N/A)

3. Describe the methods used to assess the potential impacts to cultural and historic resources on or near the project site. Examples include consultation with tribes and the department of archeology and historic preservation, archaeological surveys, historic maps, GIS data, etc.

N/A

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4. Proposed measures to avoid, minimize or compensate for loss, changes to and disturbance to resources. Please include plans for the above and any permits that may be required.

N/A

Transportation

1. Identify public streets and highways serving the site or affected geographic area and describe proposed access to the existing street system. Show on site plans, if any.

N/A

2. Is the site or affected geographic area currently served by public transit? If so, generally describe. If not, what is the approximate distance to the nearest transit stop?

N/A

3. How many additional parking spaces would the completed project or non-project proposal have? How many would the project or proposal eliminate?

N/A

4. Will the proposal require any new or improvements to existing roads, streets, pedestrian, bicycle or state transportation facilities, not including driveways? If so, generally describe (indicate whether public or private).

N/A

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5. Will the project or proposal use (or occur in the immediate vicinity of) water, rail or air transportation? If so, generally describe.

N/A

6. How many vehicular trips per day would be generated by the completed project or proposal? If known, indicate when peak volumes would occur and what percentage of the volume would be trucks (such as commercial and non-passenger vehicles). What data or transportation models were used to make these estimates?

N/A

7. Will the proposal interfere with, affect or be affected by the movement of agricultural and forest products on roads or streets in the area? If so, generally describe.

N/A

8. Proposed measures to reduce or control transportation impacts, if any.

N/A

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Public Service

1. Would the project result in an increased need for public services (for example: fire protection, police protection, public transit, health care, schools, other)? If so, generally describe.

No, public services would not be impacted. In fact the Master Plan explicitly prioritizes public services such as hospitals, Fire Stations, etc for service restoration after an earthquake. See policies in Chapter 2.

2. Proposed measures to reduce or control direct impacts on public services, if any.

N/A

Utilities

1. Check the utilities currently available at the site:

- ☐ Electricity
- ☐ natural gas
- ☐ water
- ☐ refuse service
- ☐ telephone
- ☐ sanitary sewer
- ☐ septic system
- ☐ other

2. Describe the utilities that are proposed for the project, the utility providing the service and the general construction activities on the site or in the immediate vicinity which might be needed.

The Master Plan proposes improvements over 50-years that will enhance water system resilience, reducing the likelihood and duration of service disruptions. Construction activities would be addressed in project-specific SEPA processes as applicable.

Original Review by Lauren Anderson 11/22/22
Secondary Review by Leticia Wallgren 2/27/23

Signature

The above answers are true and complete to the best of my knowledge. I understand that the lead agency is relying on them to make its decision.

Signature Douglas J Lane

Name of signee Doug Lane

Position and Agency/Organization Utilities Planning Manager, City of Bellevue

Date Submitted 9/30/2022

Original Review by Lauren Anderson 11/22/22
Secondary Review by Leticia Wallgren 2/27/23

Wallgren, Leticia

From: Wallgren, Leticia
Sent: Monday, February 27, 2023 2:54 PM
To: Wallgren, Leticia
Subject: FW: Comments regarding Emergency Water Supply Master Plan, file number: 22-118651-LM

From: Lane, Douglas <DLane@bellevuewa.gov>
Sent: Monday, February 27, 2023 7:45 AM
To: Wallgren, Leticia <LWallgren@bellevuewa.gov>
Subject: RE: Comments regarding Emergency Water Supply Master Plan, file number: 22-118651-LM

General

Most future projects recommended by the Master Plan are already included in existing capital programs (e.g. pump station rehabilitation or water main replacement), so the Master Plan doesn't change what is proposed for those projects. Other recommended projects, particularly groundwater wells and new backbone piping, would be new projects, although the extent and location of those projects cannot be determined at this time (a separate groundwater well siting study is proposed for 2028). It is not appropriate at this point to speculate on future emergency well locations, because public engagement and further technical analysis needs to occur first. The Master Plan recommends emergency well capacity and general neighborhood-level improvements, without detailing precisely where or how this should occur.

Earth

- Erosion: There are no known erosion impacts of the Master Plan. Proposed future construction projects would implement temporary erosion control and other measures to mitigate environmental impacts during construction, and would be permitted through a future project-specific SEPA and/or a programmatic SEPA when appropriate. Although not enough information is known at this time (e.g. including locations) about potential future projects, in general all projects will perform erosion control best management practices (BMPs) in conformance with the City's NPDES permit, Washington State Department of Ecology requirements, the Western Washington Stormwater Manual, the City's Storm & Surface Water Engineering Standards, and future grading permit conditions. Such BMPs include:
    - Seasonal construction to avoid the rainy season
    - Silt fencing, straw wattles, and other physical barriers
    - Temporary sedimentation ponds
    - Catch basin liners
    - Covering soil piles and bare slopes
    - Restoration planting and post-construction monitoring to ensure plant survival
- Filling, Excavation and Grading: No changes to surface contours are proposed by the Master Plan. Grading quantities for potential future projects cannot be determined at this time, and will be addressed on a project basis when applicable. For new emergency wells, it is not possible to estimate quantities and not appropriate to speculate on locations. For pump station rehabilitation, grading quantities would not be known until an alternatives analysis is conducted to determine the type of future pump (e.g. may require no excavation, or installation of buried "cans", or a vault, etc). For water main replacement projects, excavation and imported fill would both be roughly 0.7 cubic yards per lineal foot of pipeline replaced, although the specific routes and lengths/locations are not dictated by the Master Plan. In general, impacts due to earthwork would be mitigated through numerous measures:

- Traffic control and route planning approved by the City's ROW reviewer (when in right-of-way).
- Erosion control BMPs indicated above.
- Daily limits on the length of pipe to be installed (to avoid trenches left open longer than required).
- Spill control and response plans for heavy equipment fuels and lubricants.
- Limits on working hours to mitigate noise.
- Avoiding critical areas wherever possible, or mitigation described below.

Critical Areas

- In general, well sites need to be flat, and it is not feasible or appropriate to locate any well (particularly an emergency well relied on for resilience) in a steep slope, flood plain, or any other geological hazard or critical area. Critical areas will be explicitly avoided when selecting future emergency well sites.
- The Master Plan recommends replacing some existing pipelines to improve community resilience. A small portion of these existing pipes may pass through critical areas as required to provide drinking water service (e.g. crossing a stream or providing service to customers on a steep hill). These water main replacement projects will benefit the environment by reducing the likelihood of a main break and subsequent steep slope erosion and/or release of chlorinated water to streams. During construction, the standard BMPs listed above would be used, in addition to measures specific to critical areas:
  - Restrained joints or earthquake-resistant pipeline materials would be used to accommodate for ground settlement in liquefaction-prone soils (to further reduce the likelihood of main breaks).
  - Anchor blocks are required in steep slopes per the City's Water Engineering Standards.
  - Trenchless installation would be considered to eliminate some open trench work.

Environmental Health

- Hypochlorite storage at potential well locations would not pose a general environmental or public health hazard. These water treatment chemicals, either liquid sodium hypochlorite (a.k.a. bleach) and/or solid calcium hypochlorite are commonly available on retail store shelves for household use (e.g. laundry, bathroom/kitchen cleaning, pools, etc). These chemicals do pose some occupational safety risks to staff who handle the chemicals and to first responders, so they are generally regulated by OSHA/WISHA and by Fire Code rather than environmental regulators. This is in contrast to the alternative, chlorine gas (which is not proposed), which is highly hazardous during transport and storage.
  - For liquid hypochlorite (also known as bleach), secondary containment (in case of tank or pipe/tubing failure) would be required so that any leakage is fully contained.
  - Calcium hypochlorite comes in solid briquettes and does not require special handling other than dry, secure storage away from the public. It would be stored inside secured, above ground buildings.

Groundwater

- Groundwater Withdrawal: Alternatives proposed by the Master Plan would not withdraw enough groundwater to appreciably impact stream flows or ground water levels, as demonstrated by modeling documented in Attachment 2E. At existing well sites, regular withdrawals in small quantities (< 20,000 gal/day) are proposed to provide some non-potable water supply and maintain readiness for emergencies. Only during declared emergencies when no drinking water is available and life safety is at risk would the Master Plan propose groundwater withdrawals at up to 1,000,000 gal/day (each) at existing wells, however modeling (attachment 2E) indicates that even this will not affect stream flows due to the short duration (only pumping until normal water service is restored in 3+ weeks). Only one alternative (fully on-line potable water supply), which the Master Plan does not recommend, would draw enough water for sufficient duration to affect flows to some tributary streams that feed Lake Sammamish. Despite findings that the recommended alternatives would not affect stream flows, the Master Plan still recommends further groundwater modeling to assess groundwater affects in more detail for existing well locations, and to assess potential impacts at future emergency well locations (to be determined). This future modeling would recommend additional actions to protect the environment.
- Groundwater Disposal: Each time a well pump is turned on, water inside the existing well would need to be flushed, plus an additional 2-3 times the well volume (estimated 5,000 gallons total). Flushing at well startup is necessary due to sediment buildup and chemical or biological activity that may take place as microbes and

natural compounds react to well casing materials while a well is dormant. Flushing purges this water that could potentially cause aesthetic problems (taste, odor or staining) if provided to customers for use. Well flushing discharge typically contains naturally-occurring iron, manganese, sulfates, and minerals. Although these are non-toxic and naturally-occurring chemicals and bacteria, they do vary somewhat from typical surface water chemistry, so some mitigation may be appropriate to avoid impacts to aquatic animals, depending on site-specific water quality. If appropriate for any location, discharge to on-site water quality swales and/or a retention pond would be proposed to allow settling, filtering and/or infiltration of these natural compounds and bacteria back into the ground prior to discharge into the storm water system.

EMERGENCY WATER SUPPLY MASTER PLAN

2022

Draft

CITY OF BELLEVUE WASHINGTON

UTL-22-6747

City of Bellevue

Emergency Water Supply Master Plan

DRAFT – October 2022

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Many staff and consultants contributed leadership, expertise, and other valuable assistance in developing this Master Plan:

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Cover Photos

From Bottom Left to Top Right: Nisqually Earthquake Damage; Installation of new distribution mains with tee and "3-pack" of isolation valves; Parksite Reservoir; Installation of Earthquake-Resistant Ductile Iron Pipe on West Lake Sammamish Pkwy; Newport Pump Station

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Attachment 1: Bellevue Water System Seismic Vulnerability Assessment. Jacobs, 2021.

- Appendix A. Geotechnical Data Refinement and Seismic Vulnerability Assessment Scenario Selection
- Appendix B. Seismic Analysis Methodology
- Appendix C. System Modeling Methodology
- Appendix D. Existing System Performance
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- Appendix G. Post-Earthquake Level of Service Goals
- Appendix H. Improvements Alternatives
- Appendix I. Recommended Seismic Resilience Improvements

Attachment 2: Bellevue Emergency Water Supply Planning. HDR & Stantec, 2019

- Appendix A. Well Condition Assessment (Golder Associates, 3/13/2018)
- Appendix B. Aquifer Characterization and Well Yield Assessment (Golder Associates, 9/18/2019)
- Appendix C. Water Quality Analysis (Confluence Engineering Group LLC, 2/28/2018)
- Appendix D. Economic Losses Due to Potential Water Outage (HDR, 5/4/2018)
- Appendix E. Aquifer-Stream Delineation and Assessment (Golder Associates, 4/9/2019)
- Appendix F. Emergency Water Needs Assessment (HDR, 5/14/2019)
- Appendix G. Bellevue Emergency Water Alternatives Analysis (HDR, 12/20/2019)

Attachment 3: Public Engagement Survey Report

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Abbreviations

AC	Asbestos Cement
BCP	Bellevue Comprehensive Plan
BSD	Bellevue School District
BV400	Bellevue 400 Pressure Zone
CCUD	Coal Creek Utility District
CESSL	Cedar Eastside Supply Line
CIP	Capital Improvement Plan
CPOD	Community Point of Distribution (a.k.a. POD)
CSZ	Cascadia Subduction Zone
DI	Ductile Iron
DOH	Department of Health
EOC	Emergency Operations Center
ERDIP	Earthquake resistant Ductile Iron Pipe
FEMA	Federal Emergency Management Agency
gpm	Gallons per minute
HGL	Hydraulic Grade Line
LH520	Lake Hills 520 Pressure Zone
MGD	Million Gallons per Day
NIMS/ICS	National Incident Management System / Incident Command System
PE-LOS	Post-Event (or Post-Earthquake) Level of Service
Plan	Emergency Water Supply Master Plan
POD	Point of Distribution (a.k.a. CPOD)
PR	Pressure Reducing Valve
PSE	Puget Sound Energy
R&R	Renewal and Replacement
RJ	Restrained Joint Pipe
SBCC	??
SCADA	Supervisory Control and Data Acquisition

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SFZ	Seattle Fault Zone
SOP	Standard Operating Procedure
SPU	Seattle Public Utilities
SS850	Somerset 850 Pressure Zone
SVA	Water Distribution System Seismic Vulnerability Assessment (Attachment 1)
TESSL	Tolt Eastside Supply Line
UASI	Urban Area Security Initiative
USEPA	United States Environmental Protection Agency
Utilities	City of Bellevue Utilities Department
WA DNR	Washington State Department of Natural Resources
WAC	Washington Administrative Code
WA-WARN	Washgington Water/Wastewater Agency Responce Network
WD97	King County Water District 97
WSDOT	Washington State Department of Transportation
WSP	City of Bellevue 2016 Water System Plan
WTPO	Water Treatment Plant Operator

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1. Executive Summary

This Emergency Water Supply Master Plan (Master Plan) addresses severe and long-lasting community impacts anticipated from disasters in Bellevue's service area (shown yellow in Figure 1). It fulfills Federal law (America's Water Infrastructure Act) and Bellevue Comprehensive Plan (BCP) policy requirements for resilience planning, while increasing public awareness of water system resilience and documenting emergency levels of service as required by Washington Administrative Code (WAC) 246-290-420.5.

The Master Plan summarizes water supply vulnerabilities, estimates risks to residents and businesses, proposes new policies specific to water supply emergencies, and recommends short- and long-term mitigation, including capital investments. The Master Plan is not intended to address emergency response, nor localized brief impacts to water service (e.g. water main breaks), which are addressed in the Bellevue Utilities Emergency Management and Response Plan.

New policies are established in Chapter 2. Policies address prioritizing service to certain customers who directly support community recovery, such as hospitals, first responders, designated shelters, and essential businesses. Post-Earthquake Level of Service (PE-LOS) performance goals are established, to define expectations for how long it should take to restore service. Finally, mitigation policies to achieve those goals are proposed, including a risk-based capital investment strategy, personal preparation encouragement, and expansion of existing groundwater usage for independent supply.

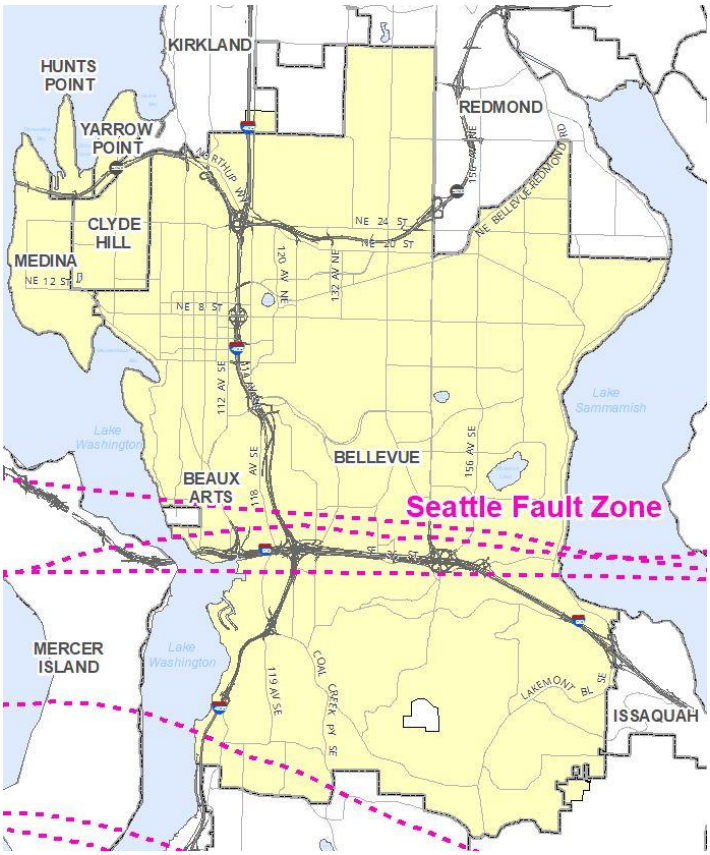


Figure 1: Bellevue's Water Service Area with Seattle Fault Zone (Source: WA DNR)

The primary hazards addressed by the Master Plan are severe earthquakes along the Seattle Fault Zone (SFZ; see Figure 1) and the Cascadia Subduction Zone (CSZ). As discussed in Chapter 3, there is less apparent risk to Bellevue's water supply from other hazards such as floods, wildfires, volcanic eruption, terrorism, etc., and many of the actions to mitigate earthquake damage would also address those hazards.

The existing water system's performance during and after the SFZ and CSZ events was simulated, based on the industry's current knowledge and observations from recent worldwide earthquakes. Results predicted over 500 main breaks and 3+ months recovery for the SFZ event in Bellevue, and over 200 main breaks with 2+ month recovery for CSZ event. The economic impacts to Bellevue solely due to water service disruption were estimated to be $8.3 and $2.3 billion for the SFZ and CSZ events, respectively.

Annualized community risk based on these impacts and the recurrence of each event is estimated at $5.2 and $4.6 million per year, respectively. Because both events will reoccur based on geologic records, the total is a cumulative annual risk of $9.8 million per year. Additional detail is provided in Chapter 3.

Impacts and Risks with Existing Infrastructure:

200-500 Main Breaks

↓

3+ Month Recovery

↓

$9.8M/year Annual Risk

Figures 2 and 3 show the simulated time to restore water service following the SFZ and CSZ earthquake events. Existing performance is represented in blue, demonstrating a complete loss of water supply for up to 3 weeks, and 2 to 3 months for full system recovery. Red, green and purple lines show the shortened restoration time following improvements recommended in the short-term (2035), mid-term (2050) and long-term (2070), consistent with the PE-LOS goals in Chapter 2.

In developing the PE-LOS goals, various improvement timeframe strategies were evaluated. Improvements will take time, as they require replacing a substantial amount of infrastructure. An aggressive timeframe (< 20 years) exceeds local industry norms, and does not appear to be feasible due to community impacts, availability of contractors and materials, and questions of affordability with extra-ordinary rates of construction work. A more generational approach (100 years) would leverage already planned spending with little to no added costs, but benefits would not be fully realized in our lifetimes. A targeted, risk-based approach with prioritized improvements over 50 years is recommended, as it balances optimized risk reduction, attainable goals and affordability, consistent with other utilities in Washington and Oregon.

Figure 2 – Simulated Seattle Fault Earthquake Restoration Time with Proposed Improvements

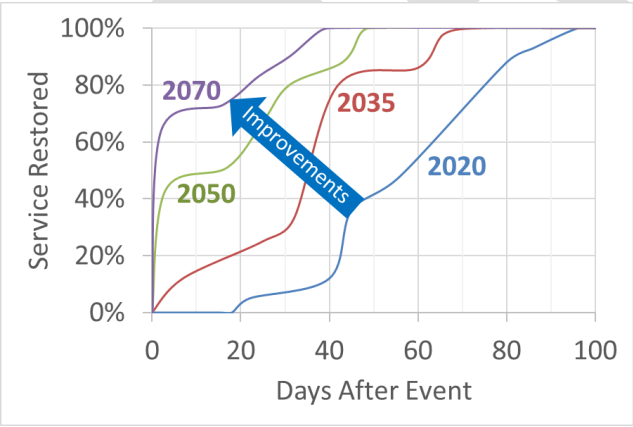
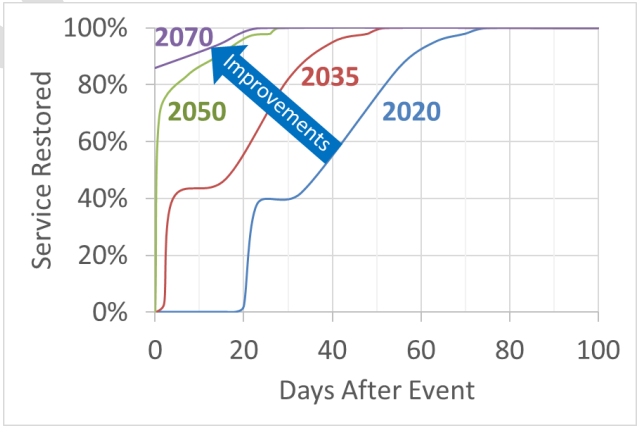


Figure 3 – Simulated Cascadia Earthquake Restoration Time with Proposed Improvements



Recovery Period*, with Proposed Improvements

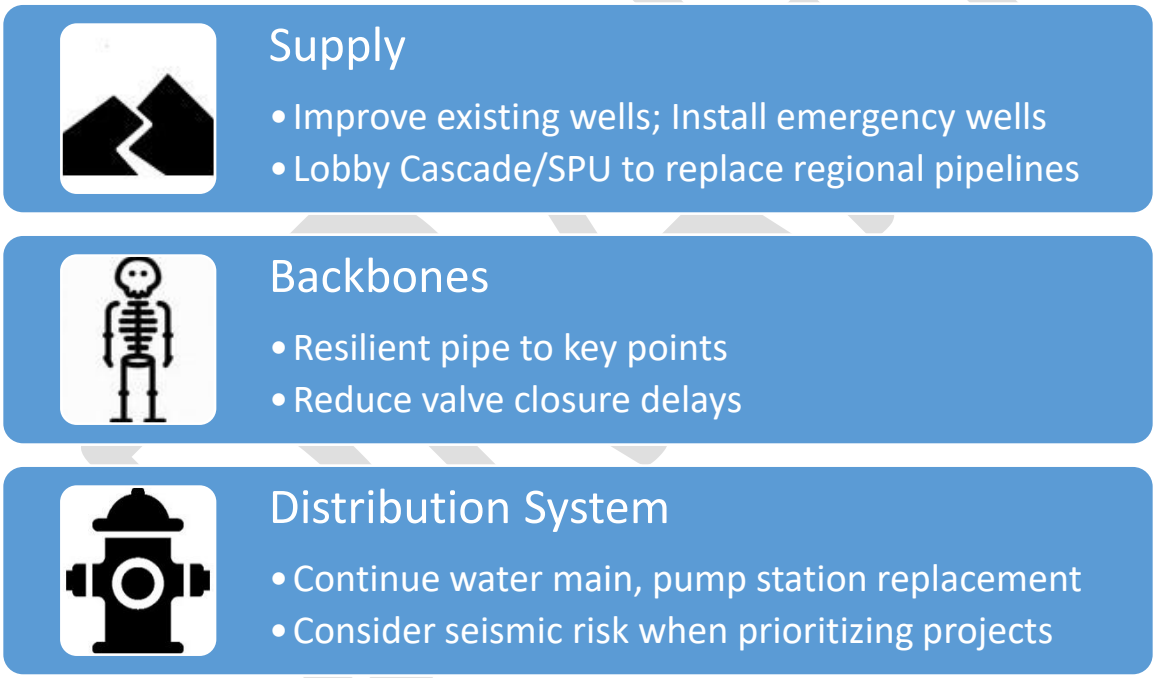
2020	2035	2050	2070
2-3 Months	1-2 Months	1-4 Weeks	1-21 Days

*Time to 80% - 90% of service restored, following SFZ or CSZ event

Emergency water supply needs are evaluated in Chapter 4, to provide criteria for planning. Anticipated emergency water demands were evaluated, and a public engagement process provided insights to customer values, sensitivities, personal preparedness and ancillary needs (e.g. physical access and language translation). Estimated emergency water needs vary based on type of use, urgency, location, water volume, customer vulnerability, and other relevant factors. Immediate needs focus on life safety and first response, such as hospital operations, fire fighting and support for vulnerable populations. Short-Term needs that would be met with emergency supplies (while infrastructure is being repaired) include hygiene, basic domestic needs, and business continuity, with the goal of avoiding widespread evacuation due to unlivable conditions. Long-Term needs, after the normal water supply is restored, include ongoing maintenance and training to ensure readiness.

Coordination between City departments and across agencies in multiple levels of government is essential for responding to any catastrophic emergency. Chapter 5 addresses roles and responsibilities, agreements, inter-dependencies and shared resources across agencies, and how these factors can affect mitigation and response activities.

Recommended improvements are described in three categories:

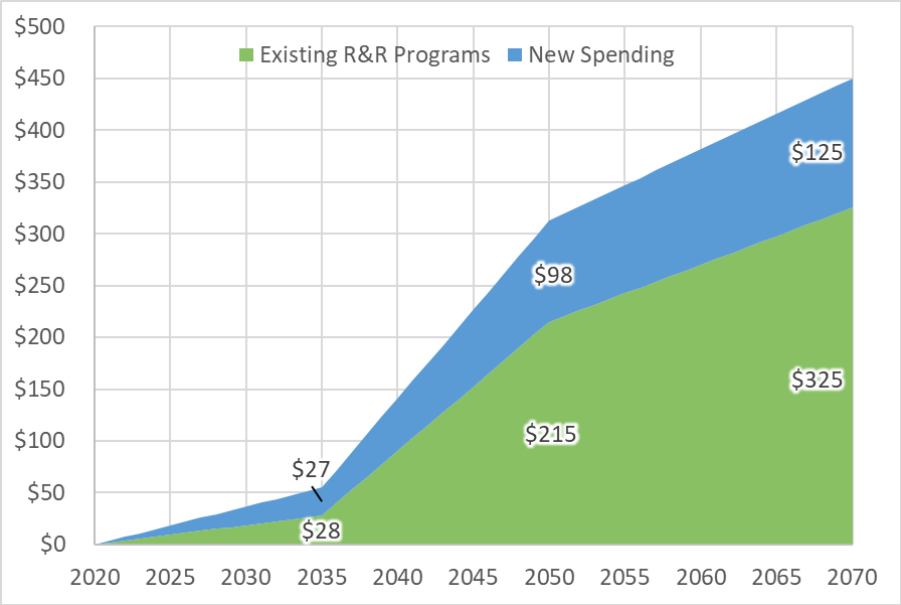


Most of the recommended improvements involve replacement of existing, aging infrastructure such as water mains, pump stations and reservoirs. These improvements are already included in the City's existing renewal and replacement (R&R) programs, so will not represent new spending (only re-prioritizing) relative to current long-term plans. In addition to the existing drivers of maintaining reliable service and minimizing long-term, life-cycle costs, these R&R programs should more heavily consider seismic resilience as part of prioritization and planning.

New proposed spending includes resilient backbone piping, improvements to the City's existing municipal water supply wells (currently used for non-potable supplies and standby service), and the siting and construction of new, emergency-only wells. In the near-term (15-year) timeframe,

improvements to the City's Crossroads Wells are recommended to improve readiness in a neighborhood with numerous critical customers, essential businesses and vulnerable populations, while also making more effective use of this existing water resource. Figure 4 shows recommended spending over time, including existing R&R programs (already budgeted), and proposed new spending for groundwater wells and backbones.

Figure 4: Estimated Cumulative Recommended Spending ($ Millions)*



$125M* Total New Spending

$325M* Total Already Planned

50-Year Period

$9.5M*/year Less Risk

* Costs presented are in 2019 dollars, prior to COVID-related inflation

To quantify the basis for recommended projects, benefit/cost ratios specific to earthquake mitigation were estimated, as discussed in Chapter 7. For new spending, benefits exceed cost by ratios of 2.5:1 (over 50-years) to 5.2:1 (over 15-years). For existing programs, spending is already justified and budgeted for R&R purposes, but seismic benefits alone provide additional benefits at ratios of 0.7:1 (50-year) to 2.6:1 (15-year).

The Master Plan recommends mitigation of community impacts due to real potential disasters, using a risk-based, customer-focused rationale. The recommended actions are proposed with the goal of balancing responsiveness, attainability and affordability within a reasonable timeframe.

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2. Emergency Water Supply Policies

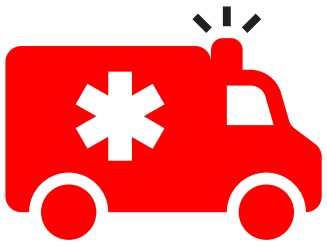
Emergency water supply policies have been developed based on seven guiding principles:

- Public Safety: Support first responders and the community to help save lives in the aftermath of a disaster.
- Social Equity: Support the City's Diversity Advantage Plan to provide access, equity, inclusion, opportunity and cultural competency.
- Economic Vitality. Support the economic health of the community during recovery from a disaster through business continuity and by allowing employees to get back to work.
- Regional Preparedness: Coordinate mitigation actions with other infrastructure sectors, adjacent water utilities, and emergency responders.
- Value: Make investments where risk reduction benefit exceeds the cost.
- Resilience. Maintain operations through resilient critical infrastructure.
- Resource Conservation. Protect and continue to use available groundwater sources .

Emergency water supply policies are listed below in **bold**, followed by the applicable guiding principle(s) and explanations to provide context. References to the City of Bellevue Comprehensive Plan (BCP) show consistency with City-wide policies

2.1 Health Care Providers

Invest in resiliency with the goal to provide uninterrupted water service at emergency rooms, and prioritize service restoration to other health care providers.



Guiding Principles: Public Safety, Regional Preparedness, Resilience

Emergency room hospitals depend on water to stay in operation, and play an immediate and crucial role in saving lives at all times, and particularly after a disaster such as a severe earthquake. Regional[1,2], and national[3] industry guidance recognizes that the highest level of service is justified for these facilities.

Other health care providers such as dialysis centers and urgent care clinics are important and necessary for supporting public health and safety, and should be prioritized. These facilities do not typically provide immediate care for life-threatening situations, and are distributed broadly throughout the City, making it impractical to ensure uninterrupted service to them all. Long-term resiliency improvement plans should prioritize improving resiliency to all medical facilities.

[1] *Regional Water Supply Resiliency Project, Phase 2 Summary Report*. Water Supply Forum, July 2018.
[2] *Resilient Washington State*. Washington State Seismic Safety Committee, Emergency Management Council, 2012.
[3] *Community Resilience Planning Guide for Buildings and Infrastructure Systems (NIST Special Publication 1190)*. National Institute of Standards and Technology, US Dept of Commerce, May 2016.

2.2 Alternative Fire Fighting Methods

Coordinate, facilitate and develop alternative fire-fighting strategies identified by the Fire Department for use during disaster recovery, prior to full system restoration.

Guiding Principles: Public Safety

This policy acknowledges that the water system's normal capacity to support firefighting will be compromised following a water supply emergency. Fires can occur anywhere in the water service area, making it impractical to prioritize service restoration based on fire response.

The Utilities Department should communicate and review water supply risks with the Fire Department, understand post-disaster firefighting tactics, and develop ways to support firefighters with access to water when appropriate during periods of limited service. The Fire Department employs numerous strategies in response to fire events, many (but not all) of which require water. Examples of water-based tactics may include hydrants directly connected to reservoirs or resilient pipelines, groundwater fill sites, and siting of such facilities where surface water drafting (e.g. boat ramps, pools) are unavailable..

2.3 Personal Preparedness

Encourage residents to store 14 days of water.

Guiding Principles: Public Safety, Resilience

This policy is consistent with current guidance from the Washington State Emergency Management Division[4], and with City of Bellevue Comprehensive Plan policy N-3[5].

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[4] https://mil.wa.gov/preparedness

[5] BCP N-3: "Equip residents, businesses, and community service providers through education and training to be active participants in public safety (including, but not limited to, emergency preparedness, crime prevention, first aid and fire prevention)."

2.5 Shelters and Points of Distribution

Prioritize mitigation and response efforts to support the readiness of pre-identified shelters and points of distribution.

Guiding Principles: Social Equity, Resilience

Pre-identified Community Points of Distribution (CPODs) and/or shelters are locations where basic supplies of water can be provided to residents who lack the means or ability to store or obtain water following a disaster. Currently such locations include some City-operated facilities such as specific parks or community centers[6], some schools[7], and other locations as identified by the City's Office of Emergency Management. By supporting the readiness of CPODs and shelters, the City supports community stability.

Depending on the extent of infrastructure damage, water might be supplied to a CPOD or shelter via the normal water distribution system, trucks carrying bulk water from other locations, an on-site groundwater supply or reservoir, or some other method, and then distributed in suitable individual containers. Pre-bottled water might also be supplied following a disaster, but would typically be procured through the Emergency Operations Center from outside the City, while the City works to restore normal supplies. This policy supports investment in a more resilient water distribution system and faster restoration of normal service to CPODs.

2.6 Business Continuity

Establish water service restoration goals to support business continuity.

Guiding Principles: Economic Vitality, Resilience

Non-essential businesses should be a lower priority than critical customers such as hospitals, or community recovery facilities such as schools. However, consistent with BCP policies[8,9,10], businesses based in Bellevue should be confident that water service will be restored in a timely manner. Historical disaster events in the United States and worldwide have shown that if service recovery does not occur steadily or sufficiently, businesses may permanently relocate out of the impacted area, with long-term negative consequences to the local economy.

[6] *Community Points of Distribution Annex (Draft)*. City of Bellevue, 2011.
[7] *Emergency Assistance Mutual Aid Agreement*. The City of Bellevue and Bellevue School District, 2017.
[8] BCP ED-1: "Maintain a business climate that supports the retention and expansion of the city's economic base."
[9] BCP ED-32: "Continue to identify, construct and maintain infrastructure systems and facilities required to promote and sustain a positive economic climate. Anticipate needs and coordinate city infrastructure investments with economic development opportunities."
[10] BCP ED-33: "Maintain and improve communications, electric utility, and other infrastructure needed to support the city's economic needs and growth."

2.7 Inter-Dependent Sector Coordination

Coordinate and optimize emergency preparation with inter-dependent infrastructure sectors (power, transportation, communications, etc).

Guiding Principles: Public Safety, Economic Vitality, Regional Preparedness

The regional nature of risks posed to Bellevue's water distribution system necessitate a coordinated approach to disaster mitigation and response. Efforts to restore water service following a regional disaster such as a severe earthquake will be complicated by impacts to other sectors such as transportation, power, communications, etc. Conversely, efforts to restore health care services, schools, wastewater service, local construction and other economic activity will be impeded by lack of water service.

2.8 Emergency Mitigation Investments

Identify and invest in water system reliability and resiliency improvements where the benefits of reduced risk to the community exceed the costs of the improvement. Prioritize improvements with the highest benefit per cost.

Guiding Principles: Value

Economic, social and environmental risks to the broader community, not merely direct risks to the water system, should all be used to estimate risks, event impacts, and the benefits (reduced risk) of mitigation projects. In situations where one customer or a group of customers benefit disproportionately, the City may partner with those customers for joint-funded improvements.

The City should also identify and pursue grant funding opportunities to mitigate water supply emergencies and improve the benefit/cost for rate payers.

This policy conforms to industry best practices, including AWWA Standard J100[11].

[11] Standard J100: Risk and Resilience Management of Water and Wastewater Systems. AWWA, 2010. "Calculate the net benefits and benefit-cost ratio (and/or other criteria that are relevant in the utility's resource decision-making) to estimate the total value and risk-reduction efficiency of each option."

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2.10 Post-Event Level of Service Goals

The City will establish short-term (2035), medium-term (2050) and long-term (2070) post-event level of service (PE-LOS) goals, and invest as needed in resiliency to meet those goals.

Guiding Principles: Regional Preparedness, Resilience

This policy acknowledges that with existing infrastructure, widespread water service disruption is likely in the event of a severe earthquake. Significant investments are required to improve anticipated performance of the water system during and after such an event.

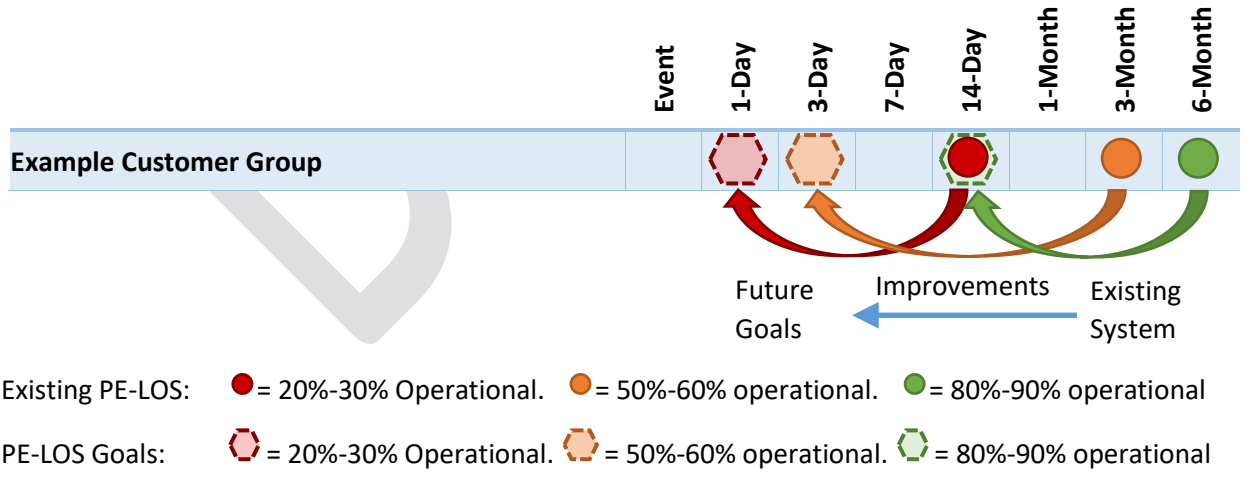
Washington Administrative Code (WAC) does not establish minimum levels of service for emergency conditions. WAC stipulates that the level of reliability during emergency conditions shall be "in accordance with consumer expectations" (WAC 246-290-420.5). Therefore it is required that PE-LOS goals be understood and agreed upon by the community.

This policy conforms to and implements BCP Policies N-4[12], CF-8[13], CF-12[14], UT-2[15] and UT-41[16].

Short-term (2035), medium-term (2050) and long-term (2070) PE-LOS goals are shown on the following pages. More information on the development of these goals, including the alternatives considered, is provided in Section 6.4. Further detail is in Attachment 1-G.

The figure below provides an example of how PE-LOS goals are illustrated, and how improvements reduce the time required to restore service after the event.

Figure 5: PE-LOS Goals – Example



[12] BCP N-4: "Plan and prepare for the response, recovery, and mitigation of potential disasters and hazards."
[13] BCP CF-8: "Use adopted Level of Service, operating criteria or performance standards to evaluate capital facilities' needs."
[14] BCP CF-12: "Maintain the post-disaster Response and Recovery Plan that ensures the city's capability to recover and reconstruct from a disaster."
[15] BCP UT-2: "Build and manage city-owned utility infrastructure assets to reduce the likelihood of risks to public safety, property and environment, and disruption due to asset failure."
[16] BCP UT-41: "Provide reliable water service for domestic use, fire flow protection, and emergencies."

Figure 6: Seattle Fault Zone Event – 2035 PE-LOS Goals

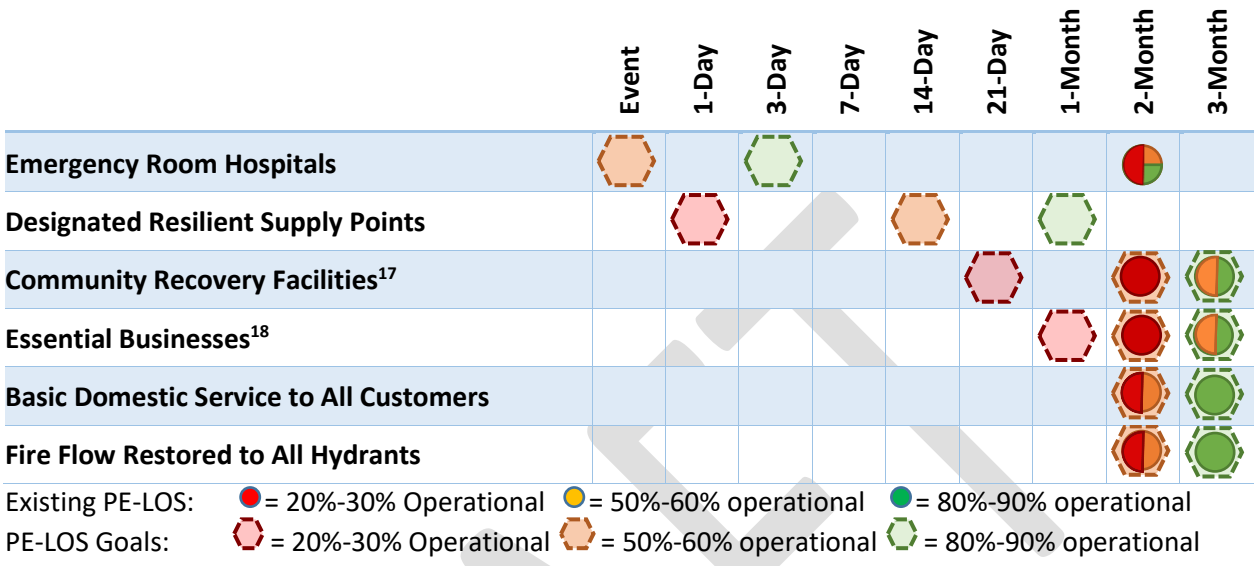
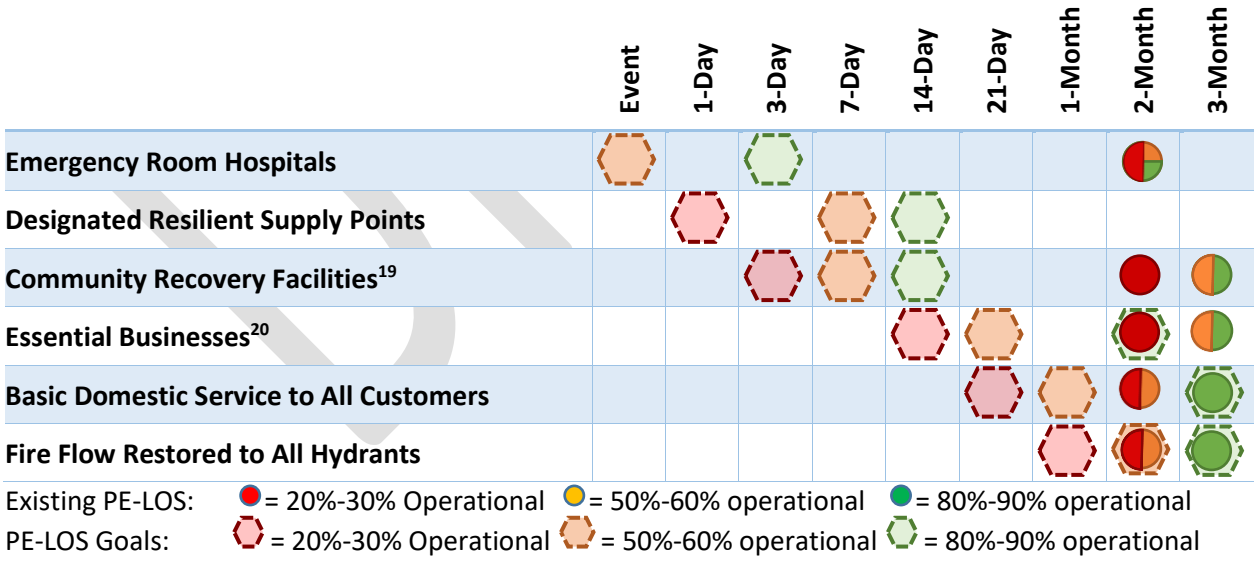


Figure 7: Seattle Fault Zone Event – 2050 PE-LOS Goals



[17] Designated shelters, schools, urgent care and dialysis clinics, other emergency services, vulnerable housing, etc
[18] Grocery stores, pharmacies, etc
[19] Designated shelters, schools, urgent care and dialysis clinics, other emergency services, vulnerable housing, etc
[20] Grocery stores, pharmacies, etc

Figure 8: Seattle Fault Zone Event – 2070 PE-LOS Goals

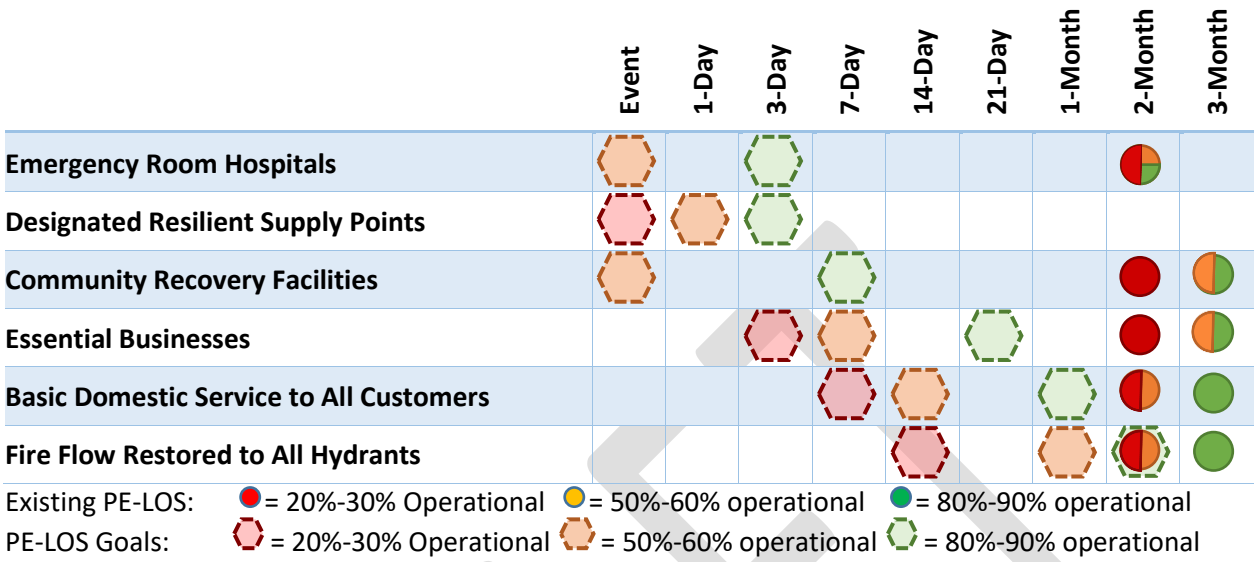
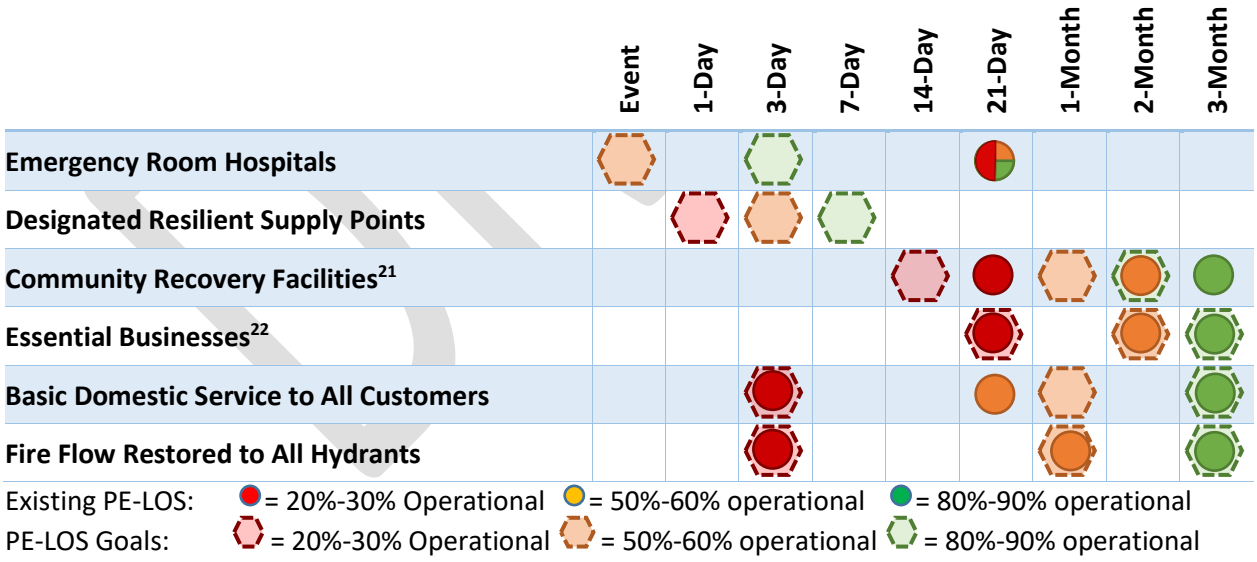


Figure 9: Cascadia Subduction Zone Event – 2035 PE-LOS Goals



[21] Designated shelters, schools, urgent care and dialysis clinics, other emergency services, vulnerable housing, etc
[22] Grocery stores, pharmacies, etc

Figure 10: Cascadia Subduction Zone Event – 2050 PE-LOS Goals

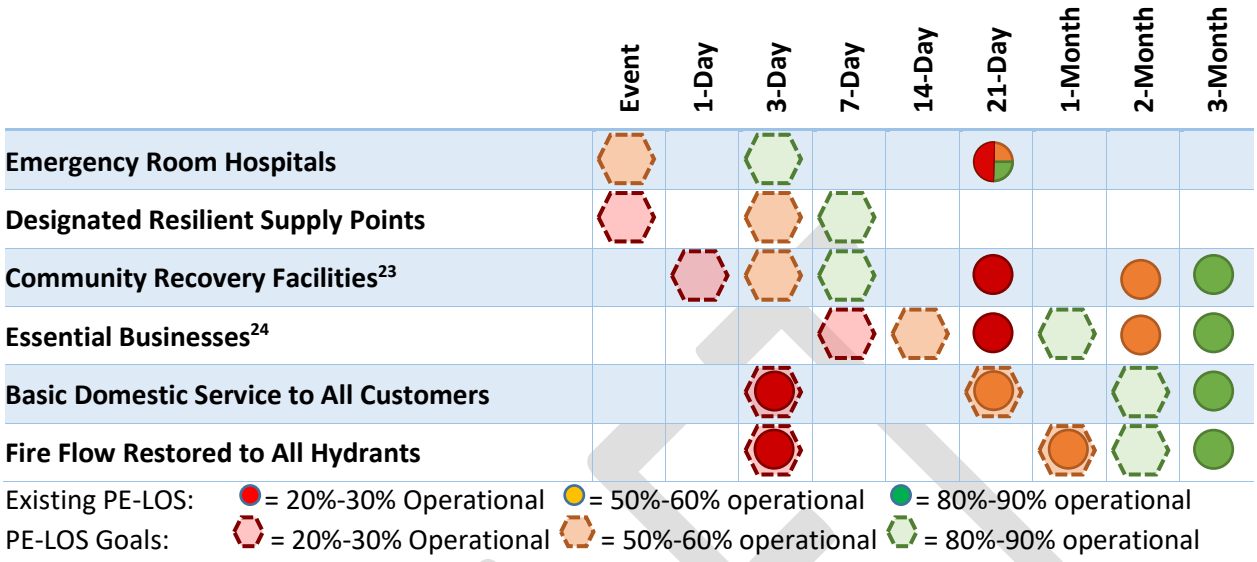
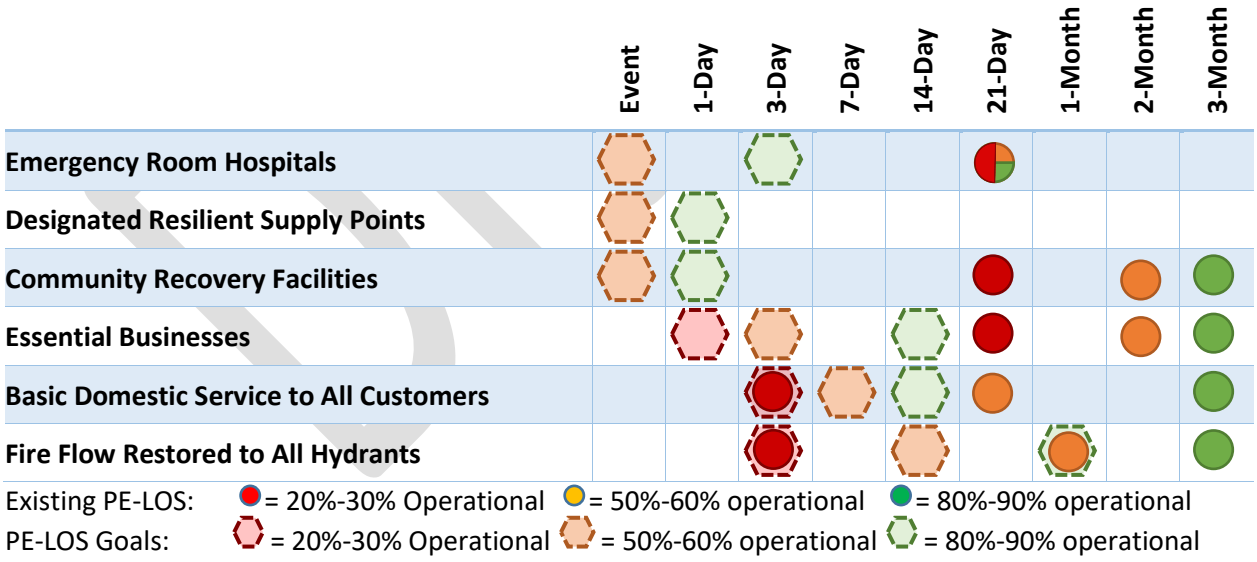


Figure 11: Cascadia Subduction Zone Event – 2070 PE-LOS Goals



[23] Designated shelters, schools, urgent care and dialysis clinics, other emergency services, vulnerable housing, etc
[24] Grocery stores, pharmacies, etc

2.11 Groundwater Supplies

The City should invest continued capital and maintenance to provide reliable and resilient wells.

Guiding Principles: Resilience, Resource Conservation

Groundwater wells provide viable, local and independent water supply redundancy to support the community following a disaster. Wells require investment to maintain capacity and readiness.

2.12 Well Head Protection

Restrict land use and establish Critical Areas near wells to preserve water quality.

Guiding Principles: Public Safety, Resource Conservation

WAC 246-290-135 requires certain source water protection measures, including a sanitary control area of at least 100-feet radius around the well, and a Well Head Protection Area. Sanitary controls generally include restrictions on land use, and must be recorded by covenant to the property. Well head protection areas are larger (ten-year groundwater travel distance) but less restrictive, and may still require agreements pertaining to use of potential contaminants such as pesticides, fertilizers, or industrial chemicals.

This policy should be considered and communicated when siting new wells, and when improving existing well sites. It augments and supports BCP critical area policies.[25,26,27,28]

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[25] BCP EN-81: "Use the best scientific information available in an adaptive management approach to preserve or enhance the functions and values of critical areas through regulations, programs, and incentives."
[26] BCP EN-83: "Recognize critical area function in preparing programs and land use regulations to protect critical areas and to mitigate the lost function due to unavoidable impacts."
[27] BCP EN-88: "Develop partnerships with land conservation organizations to acquire critical areas and buffers to protect and restore critical areas functions."
[28] BCP EN-89: "Explore opportunities for public acquisition and management of key critical areas of valuable natural and aesthetic resources, and fish and wildlife habitat sensitive to urbanization through a variety of land acquisition tools such as conservation easements and fee-simple purchase."

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3. Hazards and Impacts

Numerous hazards threaten the reliability of the City's water supply and distribution network, and create risks for the local community.

3.1 Existing Infrastructure

The City's water service area (shown in Figure 1) includes the Cities of Clyde Hill and Medina, the Towns of Hunts Point and Yarrow Point, and the entire City of Bellevue except the Hilltop Community. The City serves a population of roughly 150,000 residents and over 150,000 jobs. The distribution system includes over 600 miles of pipe, approximately 72 pressure zones, 150 pressure-reducing valve (PRV) stations, 6,000 fire hydrants, 10,500 main isolation valves, over 41,000 customer meters, 24 active reservoirs, and 21 pump stations. Bellevue also owns a share of 4 additional reservoirs that are maintained by neighboring utilities. More information on the City's water system is provided in Chapter 1 of the 2016 Water System Plan (WSP).

The City's Infrastructure, particularly buried piping, was planned and constructed prior to an understanding of the relevant hazards, resulting in significant vulnerabilities.

Currently, the regular supply of water comes from Seattle Public Utilities' (SPU's) Tolt and Cedar watersheds. After treatment, this water is delivered to the City's service area by transmission mains owned and operated by SPU.

Originally, the sole supply of water to Bellevue's service area was wells, shown in Figure 12. Although the City's primary supply of water today comes from SPU, the Water District #97 (WD97) wells 3, 5, 6 and 7 are still controlled and maintained by the City. These wells are not currently equipped to provide potable water, but are approved by Washington State Department of Health (DOH) for emergency use.

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Existing Water Supply Facilities

Figure 12

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3.2 Hazards

A cursory assessment of numerous potential hazards has been performed, including floods, source water quality problems, terrorism, and others. As described below, earthquakes appear to be the highest-risk hazard by far for Bellevue, based on known information.

Flood

Despite Bellevue having over 19 miles of shoreline[29], including lakes, sloughs and other water bodies, flooding does not appear to be a significant risk to the City's water distribution system due to local topography. As shown in Figure 13, local floodplain areas are limited, and do not include any reservoirs, pump stations, pressure-reducing valves or inlet stations.

The City does have approximately 10 miles of water mains, 20 fire hydrants and 8 blow-offs in flood plain areas.

Earthquake

Recent geological discoveries in Western Washington have revealed hazards that were not understood during development of regional and local water infrastructure. SPU has estimated[30] a 15% to 20% likelihood in next 50-years of losing all water supply due to either a Seattle Fault Zone (SFZ) or Cascadia Subduction Zone (CSZ) earthquake.

As part of the SVA, the City's consultants evaluated local seismic threats and defined the highest-risk seismic event scenarios to be evaluated. This evaluation is documented in Attachment 1-A, including maps of shaking intensity, liquefiable soils, and seismically-induced landslide risks.

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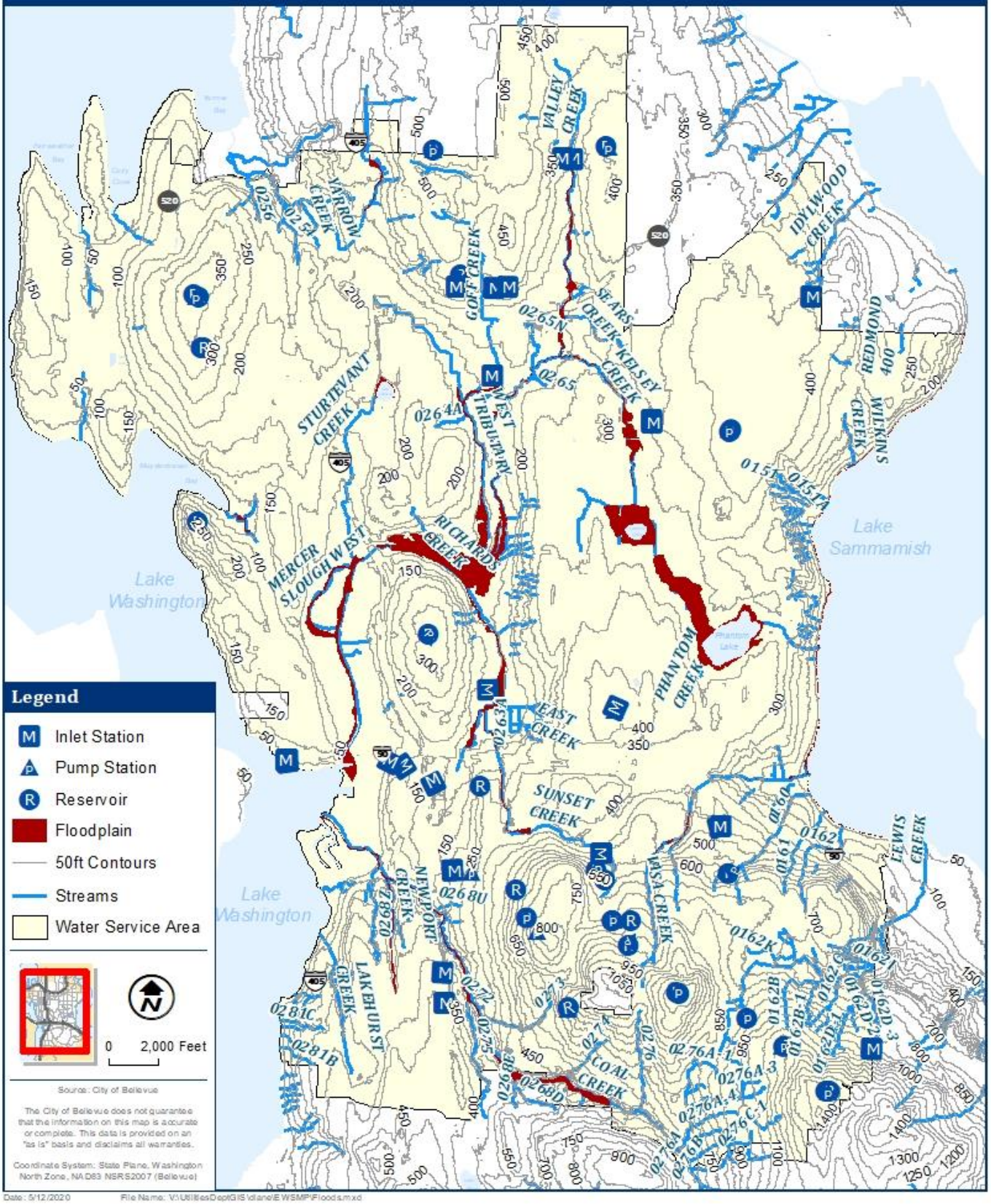
[29] City of Bellevue Comprehensive Shoreline Master Program Update – Conditional Approval, Resolution Number 8922. June 1, 2017 letter from Washington State Department of Ecology.
[30] *Water System Seismic Study Summary Report*. Seattle Public Utilities, 2018

Flood Plains and Elevation

Figure 13



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Landslides and Erosion

The primary landslide risks to Bellevue's water supply are along regional water transmission pipelines managed by Seattle Public Utilities, outside of Bellevue's jurisdiction or control. Within Bellevue, although singular landslides present risks to nearby infrastructure and property, they are not a threat to overall water supply. For these reasons, this Plan focuses on landslides only in the context of a major earthquake, where multiple seismically-induced landslides could occur simultaneously.

Seismically-induced landslide hazards specific to the SFZ and CSZ earthquakes are mapped in Attachment 1-A. Water infrastructure potentially vulnerable to seismically-induced landslides in Bellevue include some water distribution mains, and the following major facilities:

- Factoria Reservoir, due to its location on sand fill atop a 25%-30% slope
- Forest Hills Reservoir and Pump Station, due to their location atop a steep slope (>40%) critical area
- Parksite Reservoir and Pump Station, due to being at the base of a steep slope (>40%) critical area

Actions to mitigate risks to the facilities listed above are discussed in chapter 6. Local distribution mains are less critical than major facilities, and will be mitigated according to the risk-based water main replacement program prioritization.

Source Water Quality Event

Bellevue's primary source water supplies (managed by Seattle Public Utilities) are in protected watersheds and generally not susceptible to contamination from industrial pollution or other unnatural contamination. However, algae blooms, forest fires, volcanic ash, and other natural events do pose some risk to SPU's supplies.

Occasional algae events occur in SPU's unfiltered Cedar water supply, typically with only minor impacts to system operations in Bellevue. Such events would generally only impact service if severe enough that SPU determined its facilities could not effectively treat the source water, and a source shutdown was required. In that instance, it is unlikely that the Tolt and Cedar supplies would both be impacted.

Mitigation measures for a severe source water quality event that impacts supply would be common with those for a seismic event, because Bellevue only manages water distribution (not treatment). Therefore, for Bellevue's planning, water quality events should represent some additional level of risk (and greater benefit from mitigation), but likely not result in additional types of mitigation measures. Some specific response actions are appropriate (e.g. accelerated cleaning of strainers in PRV stations), but beyond the scope of the Master Plan.

Intentional Acts

The City evaluated the threat of intentional acts of sabotage as part of America's Water Infrastructure Act (AWIA) compliance. This included physical sabotage and cyber attacks.

Physical attacks are generally expensive, difficult to execute, and have limited, localized impacts. They are also considered to be very unlikely except during war or rebellion. One of the best mitigation actions for physical attacks is to reduce criticality through robust physical and operational redundancy, allowing continuous operation even if a facility is destroyed. Redundancy improvements are logical to mitigate a wider disaster (such as a severe earthquake), and simply to provide operational flexibility for

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maintenance activities, but threat reduction from physical attacks should also be considered as one of the benefits to add redundancy.

Physical security at above-ground facilities is another mitigation tactic. The City has already adopted and continues to implement physical security measures.

The threat of cyber attacks is increasing, due to the widespread availability of sophisticated cyber-warfare technologies on the open market, and the lowering cost, effort and knowledge required to mount an attack. Cyber attacks are a pervasive financial threat, but that is outside the scope of this Master Plan. The potential water supply operational impacts of cyber attacks vary widely, but can be mitigated by many of the same network security measures used to mitigate financial threats, and by the infrastructure improvements used to impacts of power outages or other emergencies.

Other Events

A health crisis such as a global pandemic can have significant impacts to Bellevue's Utilities Department, such as illness, mandatory social distancing, and demands on staff for City-wide response (e.g. the Emergency Operations Center). In addition, the increased emphasis on sanitation during such a crisis makes reliable water service even more important. However, this type of event does not pose a direct threat to water infrastructure. Although concurrent pandemic during another type of emergency would severely hamper the City's ability to respond to both, the likelihood of simultaneous catastrophic events is unreasonably small. Pandemic response is addressed in the City's Continuity of Operations Plan.

3.3 Impacts

Community impacts due to severe earthquakes have been evaluated. Impacts due to other hazards have not been analyzed in detail, because they carry significantly lower risk as described above, and because those impacts would be mitigated by the same actions taken to mitigate earthquake impacts.

Service Impacts

As part of the SVA, post-earthquake customer service levels in Bellevue have been simulated based on known geological hazards, current system information, and observed water system response from past worldwide earthquake events. For the CSZ and SFZ events, separate probabilistic, 10,000-iteration "Monte Carlo" simulations were performed to estimate the most likely failures and service impacts throughout the system. Another simulation was then performed to estimate the service restoration time after the event, based on available labor and prioritized main break repairs to benefit the maximum number of customers. Table 1, Figure 14 and Figure 15 show anticipated impacts to the existing water system following either of these two severe local earthquake scenarios.

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Table 1: Simulated Earthquake Customer Service Impacts with Existing Infrastructure

Event	Frequency	Pipe Repairs	Customer Service Restored (%) after: 3 days	30 days	45 days	70 days	90 days
Cascadia Subduction Zone	500 yr	220	35%	40%	70%	100%	100%
Seattle Fault Zone East	800 yr*	540	0%	5%	22%	60%	100%

* Estimated 50% likelihood of full Seattle Fault eastern rupture during 800-year event

Economic Impacts

The economic impacts to the community of a complete loss of water supply would be severe and long-lasting. [Cite references with sensitivity factors; potential for permanent business relocation; indirect vs. direct to exclude losses due to other factors].

As shown in Figure 16, HDR Engineering, Inc estimated[31] a cumulative $960,000,000 system-wide loss in wages and business activity in Bellevue from only a 3-week water supply disruption (not based on any specific event). SPU estimates a 15% to 20% likelihood of such an event to occur in next 50-years[32] (0.3% to 0.4% chance each year).

Subsequently, as part of the SVA a more detailed evaluation of both the SFZ and CSZ earthquake impacts was performed, with results shown in Table 1. Cumulative annual risk to the community is estimated at $9.8 Million per year. This evaluation considered the restoration times shown in Figures 14 and 15, and estimated economic impacts using population (for residents) or tax revenues and water dependency (for businesses).

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[31] *Bellevue Emergency Water Supply Master Plan – Economic Losses Due to Potential Water Outage*. HDR, 5/4/2018.

[32] *Water System Seismic Study Summary Report*. Seattle Public Utilities, 2018

Figure 14: CSZ Event Simulated Service Restoration Time with Existing Infrastructure

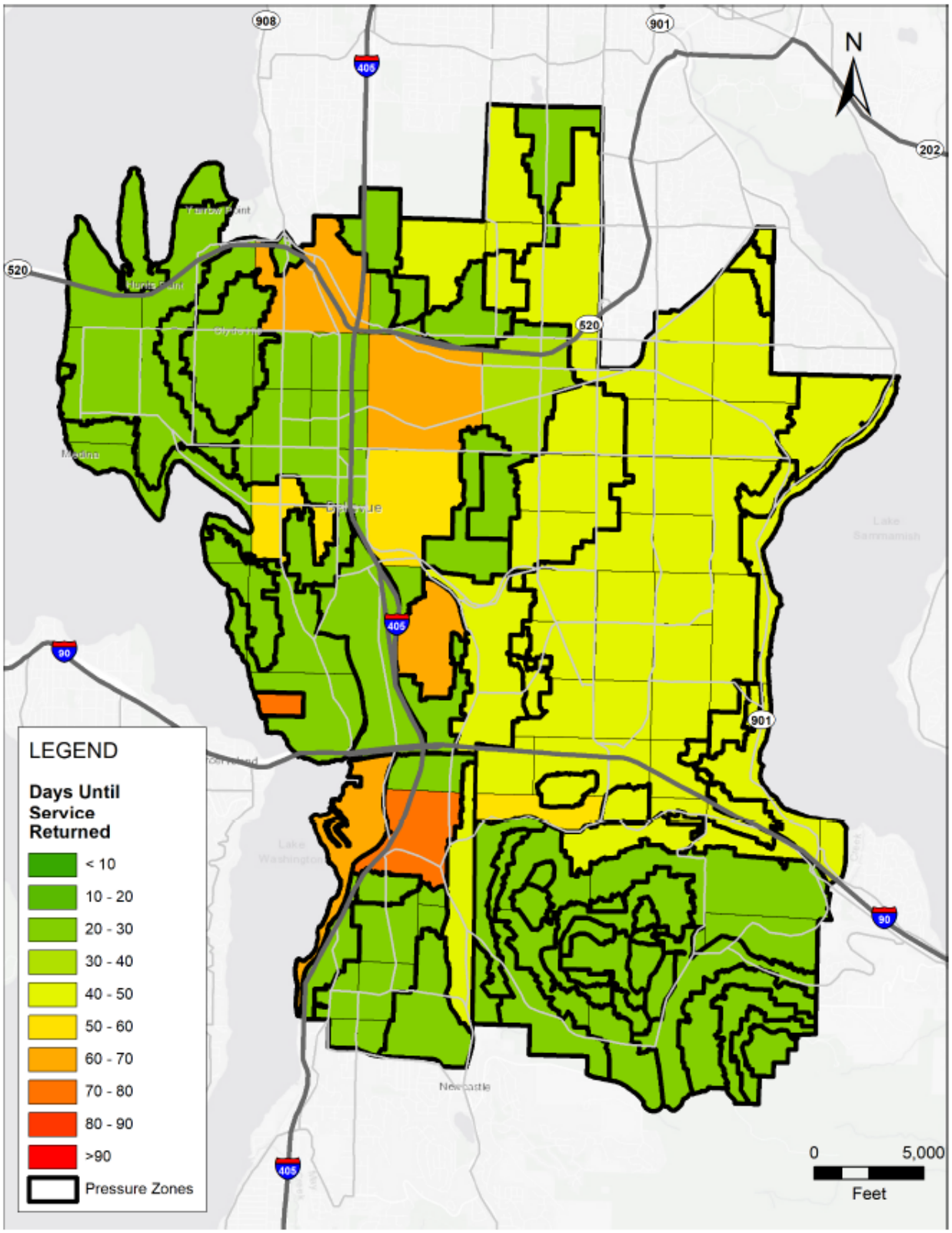

Figure 15: SFZ Event Simulated Service Restoration Time with Existing Infrastructure

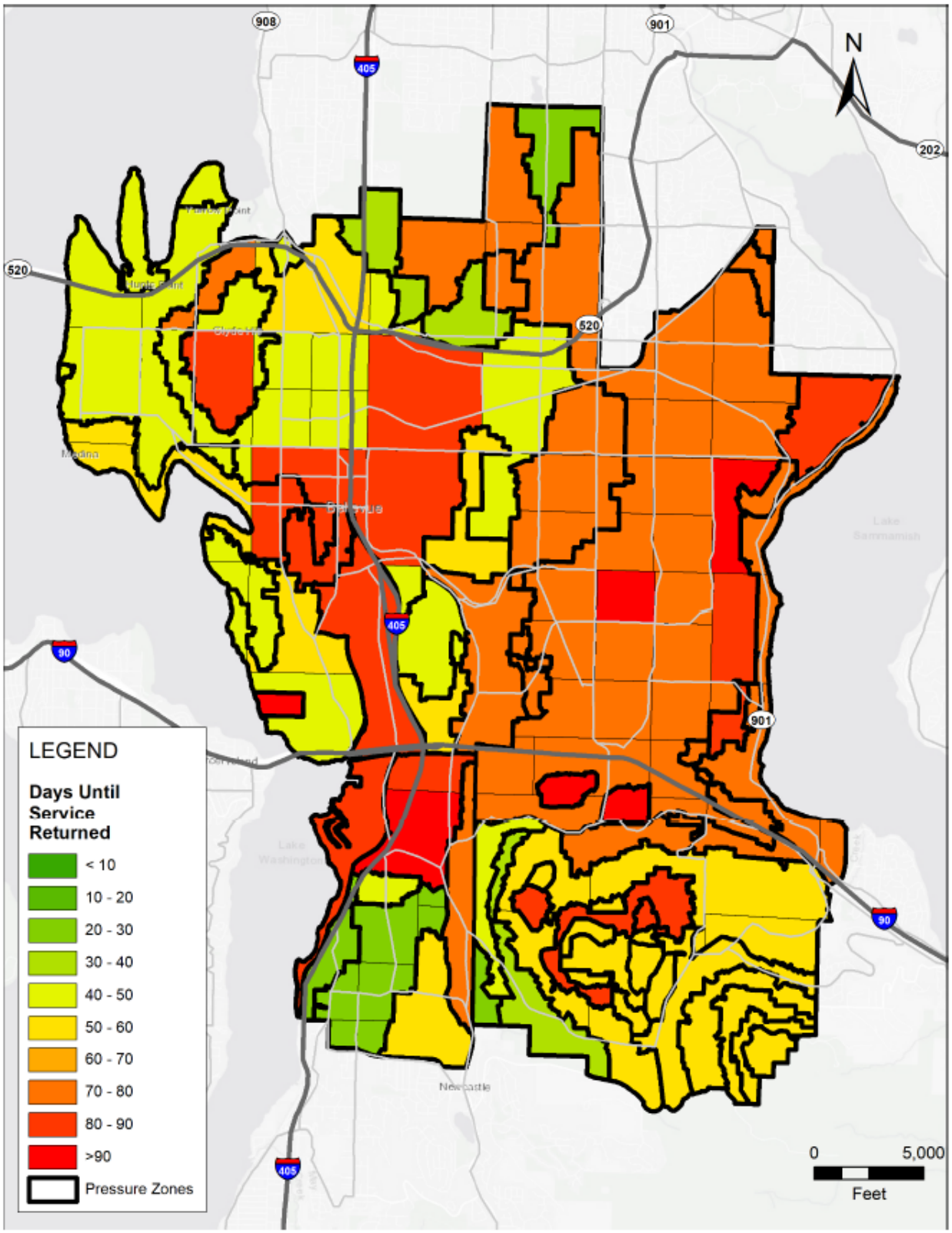

Figure 16–- Economic Impact of Complete Water Supply Disruption to Bellevue (2019 dollars)

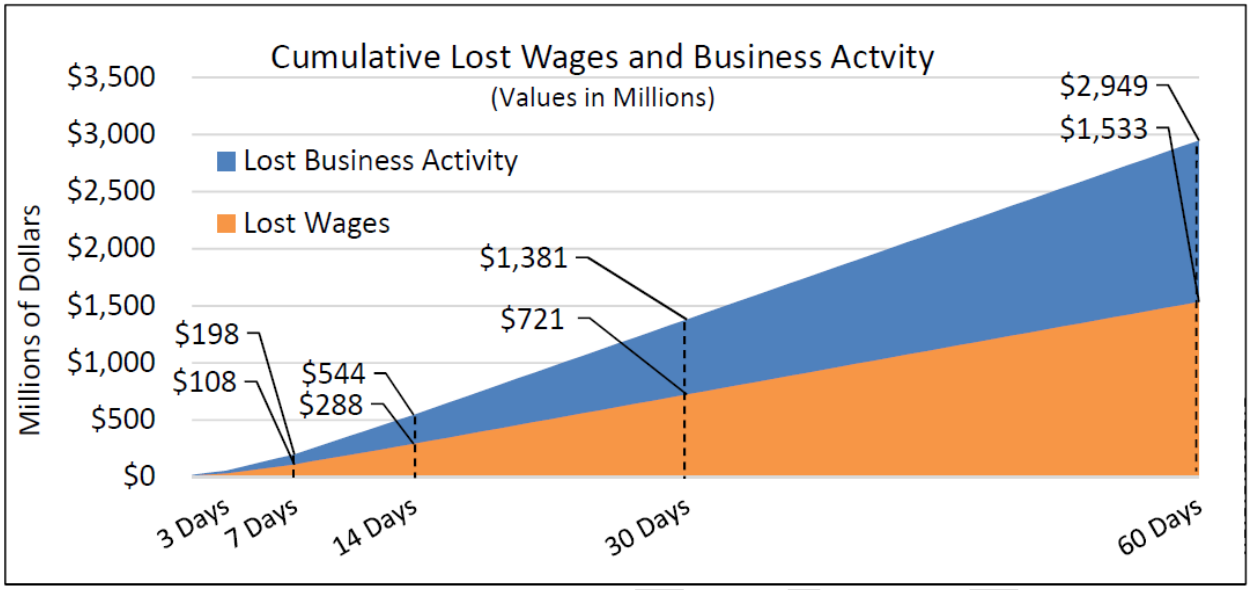

Table 2: Simulated Earthquake Economic Impacts with Existing Infrastructure

Event	Frequency	Economic Damage	Annualized Risk
Cascadia Subduction Zone	500 yr	$2.3 Billion	$4.6 Million/year
Seattle Fault Zone East	800 yr*	$8.3 Billion	$5.2 Million/year
Cumulative			$9.8 Million/year

* Estimated 50% likelihood of full Seattle Fault eastern rupture during 800-year event

Both the CSZ and SFZ events are anticipated to re-occur, so the annualized risk of these separate events is cumulative, for a total annualized risk of $9.8 Million/year.

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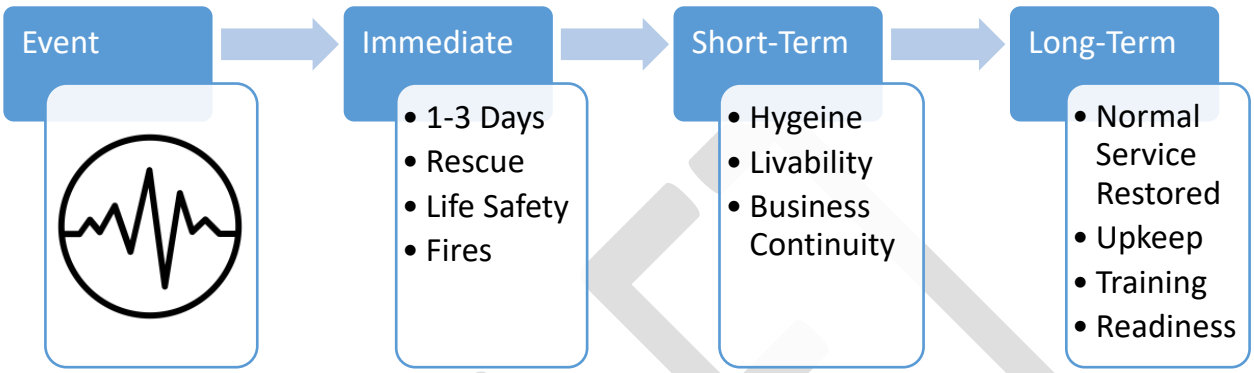
4. Emergency Water Needs

Bellevue's emergency water supply needs have been evaluated based on type of use, urgency, location, quantity, and other relevant factors. For the purpose of planning, needs have been categorized by time periods – Immediate, Short-Term and Long-Term – as shown in Figure 17 and described below.

Figure 17: Summary of Emergency Water Needs



4.1 Public Engagement

To understand customer values, assess personal preparedness, and inform development of the Master Plan, the City created an on-line open house and survey in late 2021. The survey was promoted system-wide via social media, press release, and the Cit''s website, and was translated into several languages. While the survey was open to all, postal invitations were also mailed to a randomized sub-set of 5,000 customers. A detailed summary of survey results is provided in Attachment 3.

In late 2021, the City held a workshop with staff from several community-based organizations, representing historically under-served populations, including immigrant, minority, youth and senior services. Feedback included several lessons learned during the COVID-19 response, as opportunities for the City and other government agencies to improve coordination and service:

- Some COVID-19 vaccination sites were difficult to access for residents who do not own a personal vehicle. This problem would be exacerbated for distributing heavy emergency supplies (especially water), which would need to transported from the site. By siting emergency water supply distribution points in neighborhoods with relatively low car ownership, the City can provide better access to services.
- Some translation of COVID-19 public messaging was either missing (impeding access to information) or redundant with CBO staff (needlessly diverting their limited resources). The demand for translation resources was demonstrated by the Cit''s survey itself based on the use of translated versions (e.g. 7% of respondents completed the survey in Chinese). By improving coordination and offering greater translation services, the City can improve cultural competency and access to emergency services.

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4.2 Immediate Needs

Immediate needs are life safety related, and primarily driven by the needs of first responders and vulnerable populations. These water demands may be directly caused by the event, though not necessarily (e.g. unrelated medical emergencies).

Hospitals provide emergency and ongoing life-saving care, and require water to stay in operation. For this reason, emergency room hospitals are considered critical customers by the Water Supply Forum, Oregon Resilience Plan, etc., and are recommended as a priority for Bellevue (see Chapter 2). As an example of the importance of water supply, following Hurricane Katrina multiple hospitals were forced to evacuate due to loss of water pressure and/or indirect water-related failure (e.g. impacted wastewater service)[33]. Interviews with local medical facility staff in Bellevue

Firefighting is another immediate need, as demonstrated by numerous historical examples of conflagrations caused by earthquakes[34]. Documented number of ignitions include 149 after the 1971 San Fernando earthquake, 58 following the 1989 Loma Prieta earthquake, 92 after the 1994 Northridge earthquake, and approximately 100 following the 1995 Hanshin (Kobe) earthquake. Major observed causes of ignition have been electric arcing (due to short circuits or normal activity) combined with natural gas leaks, flame from gas appliances, and cooking activity during the earthquake. In all of these events, firefighting was severely impaired by depressurization caused by water main breaks and leaks in local water systems.

Vulnerable populations include residents who may be unable to help themselves following an emergency. Some characteristics recognized as increasing the likelihood that an individual will suffer diminished access to life-sustaining commodities are[35]:

- Age 65 years and older, or 4 years and younger
- Functional needs
- Serious chronic health condition or multiple conditions (including heart disease, high blood pressure, psychiatric, or cognitive disorders)
- Living near, on, or below the poverty line
- Language barriers

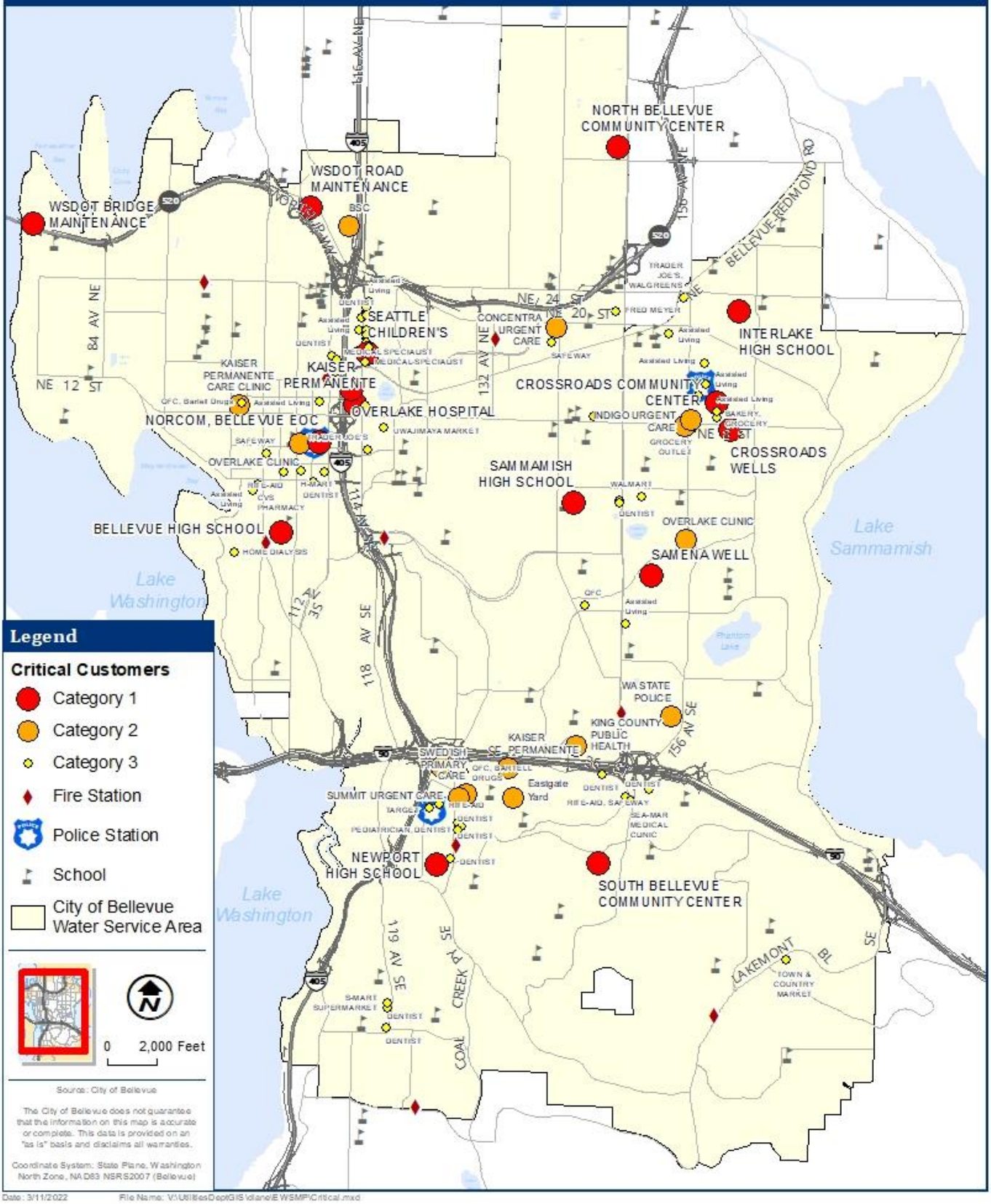
Based on these criteria, assisted living facilities, urgent care and dialysis facilities, and community shelters have been identified as critical customers. Higher prioritization to mitigating impacts is also recommended in areas with relatively higher poverty rates.

Figure 18 shows critical customers identified during the development of the Plan.

[33] Gray and Hebert. *After Katrina – Hospitals in Hurricane Katrina: Challenges Facing Custodial Institutions in a Disaster*. The Urban Institute, 2006.
[34] Charles Scawthorn, John M. Eidinger, Anshel Schiff. *Fire Following Earthquake*. ASCE Publications, 2005.
[35] *Disaster Logistics: Point of Distribution Manual*. Bay Area Regional Logistics Program, February 2014.

Critical Water Customers

Figure 18



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4.3 Short-Term Needs

Short-term needs support community recovery, to avoid cause for widespread evacuation while the normal system is repaired. The short-term period of emergency water needs begins as immediate concerns abate (e.g. fire suppression), and ends with restoration of the normal regional water supply. This is estimated to take 2 to 3 months with existing infrastructure, or 2 to 4 weeks based on proposed PE-LOS goals.

During this short-term period, the City would be reliant on emergency water supplies. Priorities include basic service for hygiene and sanitation, general livability and community recovery, and business continuity. To support these priorities, water-sensitive "essential businesses" (e.g. grocery stores, non-urgent medical facilities, etc.) as defined by Washington State Governor Inslee's COVID-19 "Stay Home, Stay Healthy" Proclamation 20-05 are identified as Category 3 critical customers (see Figure 18).

Water Quality

Following a disaster, with normal supplies unavailable, customer expectations for water quality are likely to change. For instance, non-potable supplies are sufficient for many essential uses such as toilet flushing, and could be treated at the point of use (boiling or personal filtration) for cooking and drinking. Typical emergency water supply planning assumes temporarily reduced water quality while the normal potable water supplies are being repaired[36].

Water Quantity

The City performed a needs assessment of system-wide water demands following a catastrophic emergency[37]. This estimated a reduced, post-event system-wide domestic water demand of 9 million gallons per day (MGD), compared to a typical winter day demand of 12 MGD, and average day demand of 16 MGD. This assumes:

- 12 MGD represents the current basic domestic needs (no irrigation) for all customers
- Emergency per capita demands are curtailed through public messaging after an event
- Water demand is further reduced by lower occupancy, due to building damage or because some portion of the population leaves the area

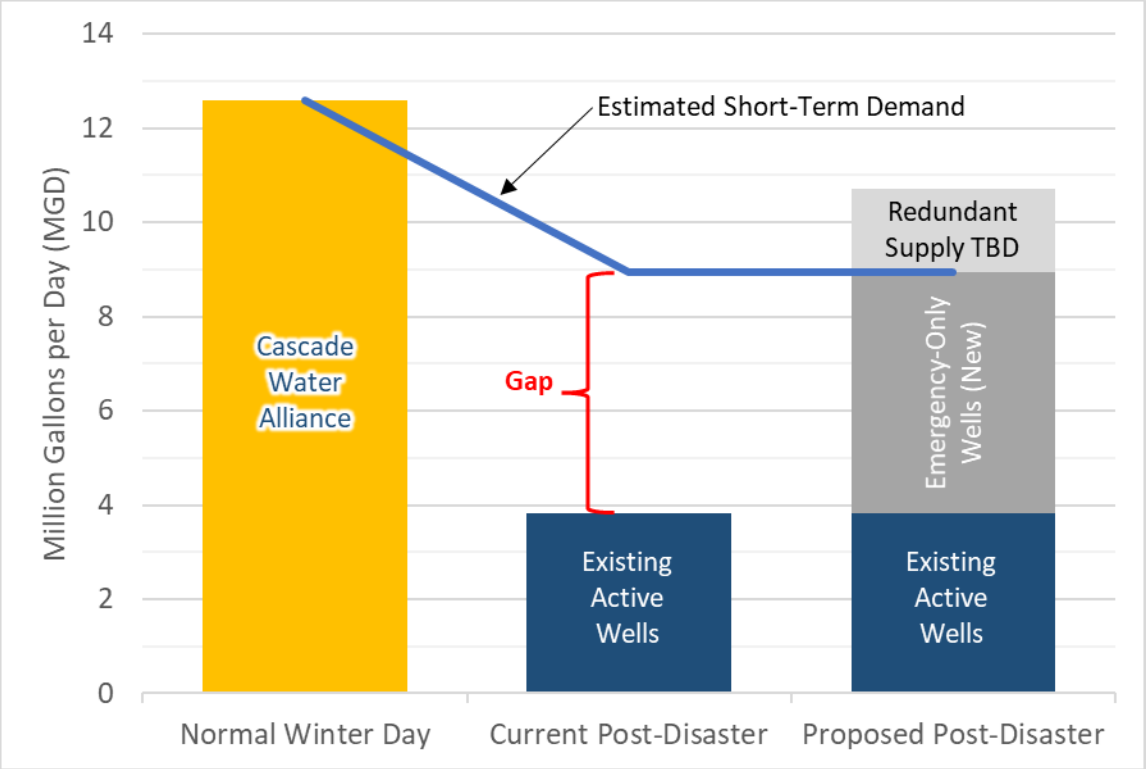
In addition to domestic demands, the City should also consider the following when considering the appropriate amount of emergency supply:

- Future population growth
- Increased leakage and other non-revenue water demands (e.g. pipe flushing)
- Redundancy (additional capacity in case one or more supply is inoperable)

To account for these additional factors, a "firm" capacity (assuming the largest emergency supply is inaccessible or out of service) of 9 MGD is recommended. If the largest emergency supply is 1 MGD (e.g. Crossroads Well #7), then the total installed capacity would be 9 + 1 = 10 MGD.

[36] *Regional Water Supply Resiliency Project, Phase 2 Summary Report – Appendix A: PE-LOS and Mitigation Measure Assessment*. Water Supply Forum, July 2018.
[37] *Bellevue Emergency Water Needs Assessment Technical Memorandum*. HDR, 5/14/2019.

Figure 19: Estimated Short-Term Emergency Supply Needs



4.4 Long-Term Needs

After normal water supply is restored, long-term needs begin. The long-term emergency water supply needs described here are not actually water demands, but are ongoing tasks necessary to maintain readiness for future emergencies. It is important to recognize, plan for and budget these tasks.

Equipment Maintenance

Equipment maintenance and exercise is a required, ongoing cost that should be considered when evaluating mitigation alternatives. This is true for portable equipment (jumper hoses, bulk delivery, portable treatment) and permanent facilities such as groundwater supplies.

Exercise is particularly challenging for new wells that cannot be used for municipal purposes, because the City would not be able to make any beneficial use of the equipment except during an emergency. The inability to regularly use a well may affect the feasibility of installing permanent equipment, including treatment systems and pumps at these locations.

Staffing

The City would need to have Washington State certified Water Treatment Plant Operators (WTPO) on staff to operate any treatment system that might be used to supply potable water. This is true even when operating as a non-potable supply (as proposed for the Crossroads wells), if potable water is to be supplied during an emergency. Uncertified operators can gain experience towards WTPO certification by assisting with regular maintenance.

Storage and Land

Spare parts and portable emergency-response equipment added to the City's inventory will require additional storage. The cost of real estate and building square footage should be considered during space planning and while evaluating alternatives for procuring equipment.

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5. Regional Coordination

Coordination between City departments and across agencies in multiple levels of government is essential for planning and responding to any catastrophic event. All infrastructure sectors, including transportation, communications, power supply, and others will all be impacted in different, but intersecting ways.

The City's Emergency Operations Center (EOC) uses the NIMS/ICS[38] structure, which treats all staffing, equipment, supplies, etc. as modular and shared, allowing for the most effective use of resources. During a water supply emergency, this means that the Utilities Department can and should remain focused on the objective of restoring normal water service, while relying on others to meet some community needs (e.g. bottled water distribution). This approach is also recommended by the USEPA:

> "One of the primary goals of utilities in the aftermath of an emergency should be to restore piped water service. A good Emergency Drinking Water Plan should avoid resource allocation conflicts (i.e., personnel and equipment) during a disaster in order to allow the utility to focus on restoring piped water service expeditiously."[39]

Roles and responsibilities for distributing commodities is discussed more in Chapter 6, under the context of community points of distribution (CPODs or PODs).

5.1 Adjacent Water Utilities

Bellevue coordinates with regional water suppliers and adjacent water utilities as part of normal operations and as part of long-term planning, including water system plans and emergency response plans.

Regional Water Supplies

Bellevue frequently coordinates with SPU and Cascade Water Alliance regarding pressure, flow, shutdowns, metering/billing, and other operational needs at supply inlets. In addition, Bellevue participates with SPU and Cascade as part of the Water Supply Forum and other regional efforts.

Influencing or incentivizing SPU to prioritize the TESSL and CESSL through Bellevue would improve Bellevu''s resilience and allow for faster accomplishment of the PE-LOS goals (see Chapter 6).

Local Interties

Bellevue has ongoing coordination with adjacent water utilities regarding local interties, primarily in the context of water audits for non-revenue flow or other normal operations. For emergency purposes, there are limited opportunities to add resilience with interties, as discussed in Chapter 6.

During an emergency, Bellevue will need to coordinate public messaging with adjacent utilities to provide consistent and accurate information. Bellevu''s Emergency Response Plan includes provisions for this coordination.

[38] National Incident Management System / Incident Command System

[39] *Planning for an Emergency Drinking Water Supply*. USEPA (600/R-11/054), 2011.

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5.2 Mutual Aid

Pre-arranged mutual aid contracts improve resiliency and response time, by having a framework in advance to allow rapid sharing of resources. Mutual aid contracts are also required for successful cost reimbursement from the Federal Emergency Management Agency (FEMA).

WA-WARN

The City is a member of the Washington Water/Wastewater Agency Response Network (WA-WARN). This network provides for rapid mutual aid and assistance between utilities in Washington, through a pre-established agreement. WA-WARN's structure is consistent with the National Incident Management System (NIMS), and mutual aid through WA-WARN is eligible for FEMA disaster reimbursement.

Bellevue School District

The City has a mutual aid agreement[40] with Bellevue School District (BSD), which allows for the use of schools as shelters and other limited sharing of equipment and facilities. Some schools have also been designated as CPODs, as discussed in Chapter 6. Due to the role of shelters and CPODs in meeting basic housing needs in an emergency, followed by the ongoing role of schools in supporting community recovery and restoring normal routines, public high schools have been identified as critical water customers. Middle schools and in particular elementary schools are more numerous and distributed widely in lower-density areas farther from water sources (see Figure #), so restoration time at these smaller facilities will vary.

5.3 Infrastructure Sector Inter-Dependencies

The Cybersecurity and Infrastructure Security Agency (U.S. Department of Homeland Security) defines 16 critical infrastructure sectors. These sectors have varying degrees of inter-dependency with Bellevue's water system, as shown in Table 3.

Table 3: Sixteen Critical Infrastructure Sectors

Critical Water Customers	Less Water Sensitive	In Bellevue, but not Water-Sensitive	No Significant Presence in Bellevue
Emergency Services, Healthcare, Water & Wastewater	Commercial, Financial, Food, Government, Info Technology, Transportation*	Communications*, Energy*	Chemical, Dams, Defense, Manufacturing, Nuclear

* Bellevue's water system is highly dependent on these sectors

Coordination as part of the Master Plan has focused on sectors that are highly water-sensitive, or will most impact the water system during a failure.

Related facilities identified as critical water customers below, despite not being high-volume water consumers, because they could be impacted by loss of fire suppression (Fire Code and occupancy rules), and by limited sanitation during a water outage.

[40] Emergency Assistance Mutual Aid Agreement. The City of Bellevue and Bellevue School District. 6/14/2017.

Logistics will be impacted due to transport and delivery disruption, supply chain interruption, and a spike in demand for labor, supplies, parts and equipment as other utilities cope with the impacts of the same event.

Healthcare

All healthcare facilities have been identified as critical customers, with varying tiered Categories depending on function. As shown in Figure 18, most healthcare providers are clustered along 11^{6t}h Ave NE, Crossroads, or Eastgate/Factoria, such that improved service would be shared, regardless of category. Emergency room hospitals are the most critical "Category 1" due to their role in providing immediate life-saving care, and their requirement to stay in operation. Urgent care, dialysis centers, and similar facilities are designated "Category 2", because they meet urgent medical needs, but may not be open following an event, and are less sensitive to a loss of supply compared to hospitals. Providers of elective procedures and non-urgent care such as pharmacies and dentists have been assigned "Category 3", as important customers that support community recovery, but not in an urgent, life-saving capacity.

Early in Master Plan development, the City met with multiple health care providers to better understand their water needs and emergency preparation. Dialysis centers are completely water-dependent. Hospitals with inpatient services have sterilization boilers for surgical equipment, laboratory needs, and other highly water-sensitive functions, in addition to normal domestic water uses. Urgent care facilities have fewer water needs, but would still require water for normal hygiene and sanitation. All providers could have building occupancy challenges with non-functioning fire suppression systems, depending on post-event enforcement of Fire Code.

Emergency Services

Emergency services include EOCs, 911 dispatch (e.g. Norcom), law enforcement, fire response, emergency medical services (part of Bellevue Fire Department), and other services. Hospitals and medical facilities are discussed above as part of the healthcare sector.

Bellevue City Hall plays a role in all aspects of emergency services, and the City also maintains a backup EOC at Bellevue Service Center. Both facilities have been identified as critical customers.

Police stations are clustered along with healthcare facilities in Downtown, Crossroads and Factoria (see Figure 18), so will benefit from mitigation to improve service at surrounding critical customers. Washington State Patrol also has a facility in Bellevue that includes 911 dispatch, and is identified as a critical customer.

Power

Bellevue's electricity provider is Puget Sound Energy (PSE). PSE has its own backup EOC located in Bellevue, which has been identified as a critical water customer due to PSE's role in supporting community recovery and water service restoration.

PSE has performed their own seismic evaluations to identify earthquake hazards, and has also identified lessons learned and sector inter-dependencies observed during widespread power outages in 2006. For instance, during that event, power failure at traffic signals in Bellevue caused traffic backups that blocked I-405, which then impeded PSE's crews ability to get to damaged locations to perform repairs. These same power and transportation impacts would also affect the ability of Bellevue's water crews to get to work, and to reach water main repair sites.

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Following a future widespread regional outage, PSE would seek to restore the maximum number of customers to power, beginning with transmission lines, then substations, and then the local circuits, depending on the situation. Bellevue is not assuming that PSE would prioritize water pump stations because power restoration activities would focus on the locations of highest impact and benefit (e.g. density), and due to competing sectors (healthcare, corrections, etc) and the needs of the regional economy. To mitigate the loss of power to the water system, Bellevue's strategy is to provide local, independent backup power.

Although most of Bellevue's water supply is gravity-fed (does not require pumping), roughly 20% of local water demands do require pumping. For electrical reliability, the City has receptacles at each pump station to connect a portable generator. The City's water utility shares backup generators with the wastewater utility, and in a declared emergency under NIMS/ICS protocols, generators may be shared with other City departments or even other agencies. Transporting and operating backup generators also requires significant labor that may not be available in a widespread disaster. To help mitigate these limitations, permanent on-site backup generators are being added at key stations as they are rehabilitated, including Horizon View 1 (complete 2017), Horizon View 2 (planned for 2023) and Parksite (planned after 2030) along backbone route "O" (see Chapter 6).

At gravity-fed facilities with no pumps and therefore low power demands (e.g. inlet stations, reservoirs), 24V batteries provide backup power for local monitoring and control equipment. For SCADA-connected valves with solenoid controls (pressure-reducing valves, flow control valves, etc), backup hydraulic controls that do not require power will take over during an extended power outage, and maintain predetermined, manual default settings.

Communications

Cellular communication sites are critical infrastructure, but often (e.g. towers) are unstaffed and have no water demands, so are not considered to be critical water customers. Cellular sites typically have limited backup power supplies, but are vulnerable to extended electrical outages, so are inter-dependent with the electric grid.

Bellevue monitors and controls water distribution through a supervisory control and data acquisition (SCADA) system. Bellevue's water system SCADA is being transitioned to a private cellular network, which will be reliant on local telecommunications infrastructure. However, impacts to water facilities are mitigated or avoided by programming the local controls equipment to revert to default settings during a loss of communications. Although water system operators would be unable to monitor or control local equipment, pre-determined operational settings will be maintained while cellular service is unavailable.

The City also coordinates emergency preparation and response with telecommunications providers as part of the Bellevue Utilities Emergency Management and Response Plan.

Transportation

Washington State Department of Transportation (WSDOT) has two maintenance facilities in Bellevue's water service area, including a bridge maintenance office, and a roadway maintenance facility that also functions as a backup EOC. The Bellevue Transportation Department shares its major facilities with the Utilities Department (e.g. City Hall and Bellevue Service Center). All of these locations have been identified as critical water customers due to their role in supporting community recovery.

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Local streets are not as important as freeways for City-wide recovery, but local streets are critical for access to specific water system facilities. The Utilities and Transportation Departments regularly coordinate operations and planning, as well as emergency preparation and response through the City's EOC.

The highway system is critical for every aspect of overall water system restoration. WSDOT maintains three freeways through Bellevue (I-405, I-90 and SR-520) that are critical for moving emergency workers, materials, and equipment. In the 1990s, WSDOT identified seismic lifeline routes state-wide and is retrofitting bridges along the lifeline to mitigate earthquake impacts over time. I-405 through Bellevue was chosen as the north-south seismic lifeline through the Seattle area instead of I-5, due to the relative high cost to retrofit I-5 through Seattle.

After an event, WSDOT performs tiered inspections based on apparent level of damage prior to opening a bridge. For the CSZ and especially SFZ earthquakes, it is anticipated that some number of bridges may need to be closed for an extended time for repairs, or demolished and rebuilt. A Transportation Recovery Annex is maintained to provide predetermined detour routes. These impacts will slow the recovery of the water system.

As part of the City's SVA, emergency response information gathered from WSDOT informed development of the iterative models used to estimate water service restoration time (See Chapter 3).

Bellevue also coordinates with WSDOT and the City's Transportation Department to improve water system resilience opportunistically with transportation projects. For instance, the City is partnering with WSDOT to install an earthquake-resistant 16" water main crossing I-405 at the new Main Street bridge in 2022-2023, as part of a proposed backbone pipeline route "M" (See Chapter 6). Seismically-resilient pipe is also proposed for a new bridge over Sunset Creek along SE 3^{6t}h Street, as part of backbone route "C". The Utilities Department routinely replaces aging pipes with more resilient water mains as part of local paving or sidewalk projects managed by the City's Transportation Department.

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6. Mitigation Alternatives

The SVA evaluated a variety of improvement packages to achieve the desired PE-LOS goals.

Several potential alternative water supplies and distribution methods are discussed below.

Industry standards[41] recommend that any emergency preparedness measure have Standard Operating Procedures (SOPs), initial & refresher training, and periodic exercises to establish and maintain readiness.

Most mitigation measures are equally effective in reducing risk for all hazards.

SPU has water supply redundancy, such that some level of water supply could be maintained with the loss of one watershed.

6.1 Water Supply

As described in Chapter 3, the regional water transmission system may be disrupted for weeks following a SFZ or CSZ earthquake. Reducing the duration of this outage and/or meeting short-term demands with temporary, alternative water supplies would mitigate community and economic impacts.

Regional Water Supply Resilience

Bellevue does not control the regional transmission system, but can exert influence and lobby regional partners as part of Cascade Water Alliance.

SPU developed a risk-based 50-year resilience plan[42] similar to the strategy recommended in this Plan. Their plan prioritizes resilience along the Cedar supply to maximize the benefit for SPU's overall regional customer base, since the Cedar has higher capacity and provides roughly 2/3 of SPU's total wholesale and retail water volumes. SPU's Tolt supply provides the remainder of SPU's normal water supply.

The Cedar source supplies roughly 20% of Bellevue's water volumes under normal system configurations (80% typically Tolt supply). However, SPU has facilities in Bellevue to pump water from the Cedar to the Tolt system, so the relative prioritization of SPU's supplies may or may not have significant effects on Bellevue's service area in an emergency.

Bellevue would benefit most from replacement of the TESSL and CESSL pipelines through Bellevue. These are bar-wrapped concrete pipes installed circa 1960, which are particularly susceptible to corrosion and seismically vulnerable. It is recommended that the City and other local partners (e.g. Cascade, Redmond, Kirkland, etc) lobby SPU for prioritized mitigation or improvement of the TESSL and CESSL pipelines that benefit local customers.

[41] AWWA Standard G440-17. *Emergency Preparedness Practices*. AWWA, 2017.
[42] *Water System Seismic Study Summary Report*. Seattle Public Utilities, 2018.

Portable Surface Water Treatment Systems

Portable emergency surface water treatment equipment is commercially available to provide potable water, and is also maintained by some emergency response agencies such as FEMA. These systems can treat a limited capacity of surface water for on-site pickup.

Challenges associated with portable treatment systems include:

- Capacity: Portable surface water treatment systems can typically treat tens of gallons per minute (gpm). Bellevue's reduced water demands following a regional disaster are estimated to be roughly 10 MGD (see Chapter 4), or about 7,000 gpm. Hundreds of small portable systems would be needed to replace the volume lost following a total water supply disruption.
- Storage and hauling: Permanent indoor storage space and dedicated trucks would be required.
- Maintenance, exercise and training: Regular use and testing of the system is necessary to maintain functionality and readiness.
- Access to Source Water: The system would need to have clear access to surface water, so may only be usable at boat ramps or similar locations.
- Proximity to Customers: Portable systems would rely on customers to be aware of the system and have the ability to pick up and transport water.
- Staffing: During an emergency, trained volunteers or emergency response staff would be required to operate the system.

Similar to bulk water delivery (discussed below), portable surface water treatment systems may be appropriate to maintain for use during an emergency that impacts only a small portion of the water system, or to supplement supply after normal service is partially restored. However, due to their small capacity and inability to distribute (only treat) water, they should not be relied upon as a mitigation strategy for a system-wide disaster, when restoring the normal supply should be the first priority.

Community Points of Distribution (CPODs)

CPODs (or simply PODs) are temporary sites prepared to distribute commodities such as food, water, sanitation items and other essentials following a disaster. CPODs would typically be managed by the incident commander from the City's EOC or another agency, and not the Utilities Department, as described in Chapter 5. However, many CPODs are identified as critical water supply customers (see Chapter 4). In addition, multiple alternative water supplies described on the following pages could support or be co-located with CPODs, so coordinated CPOD site planning is relevant to Utilities.

Standard layouts for CPODs have been designed that can accommodate 5,000, 10,000 or 20,000 people per day at each site[43]. CPODs can be configured for either vehicular or pedestrian traffic, though not both due to safety concerns [44].

[43] *Emergency Support Function (ESF) #3 Field Guide*. US Army Corps of Engineers, 2012.
[44] *Disaster Logistics: Point of Distribution Manual*. Bay Area Regional Logistics Program, February 2014.

The City has developed a CPOD Annex[45] to guide CPOD staffing, setup, roles and responsibilities. Specific sites identified include the following, as shown on Figure 20:

- Surrey Downs
- Bellevue Downtown Park
- First Presbyterian Church
- Bannerwood Sports Park
- Crossroads Community Center
- Lewis Creek Park
- Newport High School

The City may consider further coordination with BSD to facilitate planning for potential CPOD sites in addition to Newport High School.

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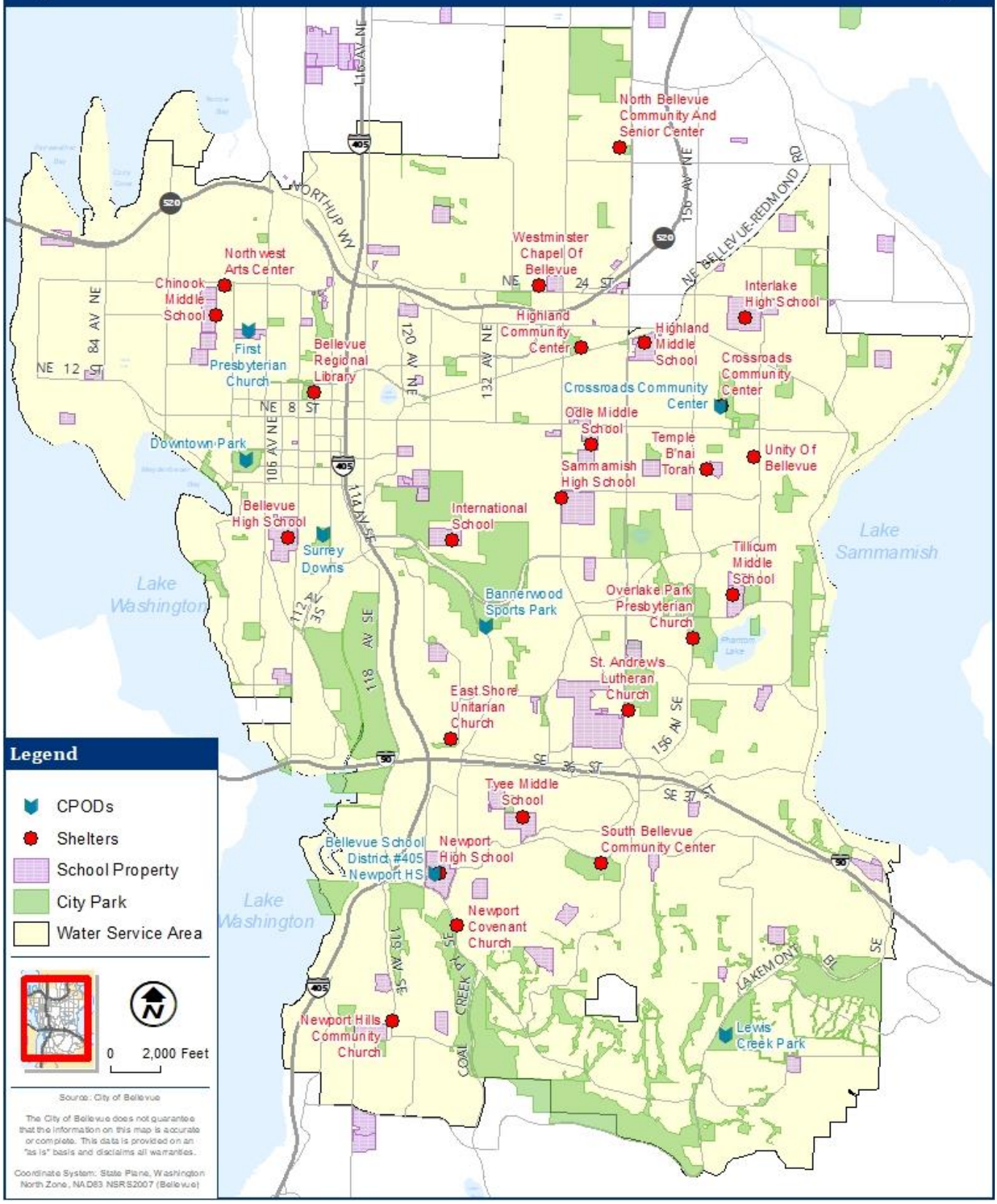
[45] City of Bellevue CPOD Plan – December 2011.

Potential Community Points of Distribution

Figure 20



Alternative Water Sources for Fire Fighting

The Bellevue Fire Department can use "drafting" to obtain water for fire fighting. Drafting is a tactic commonly used by rural fire departments where no water distribution network is available. Trucks are equipped to draw from either a pressurized supply (e.g. private hydrant or a well pump), or to pump surface water from a pool, pond, or other water body, provided that the suction lift (vertical distance from water to pump) is relatively small. Water can be pumped directly to fight a fire within a limited radius from the source, or pumped into a tank for hauling to the fire location.

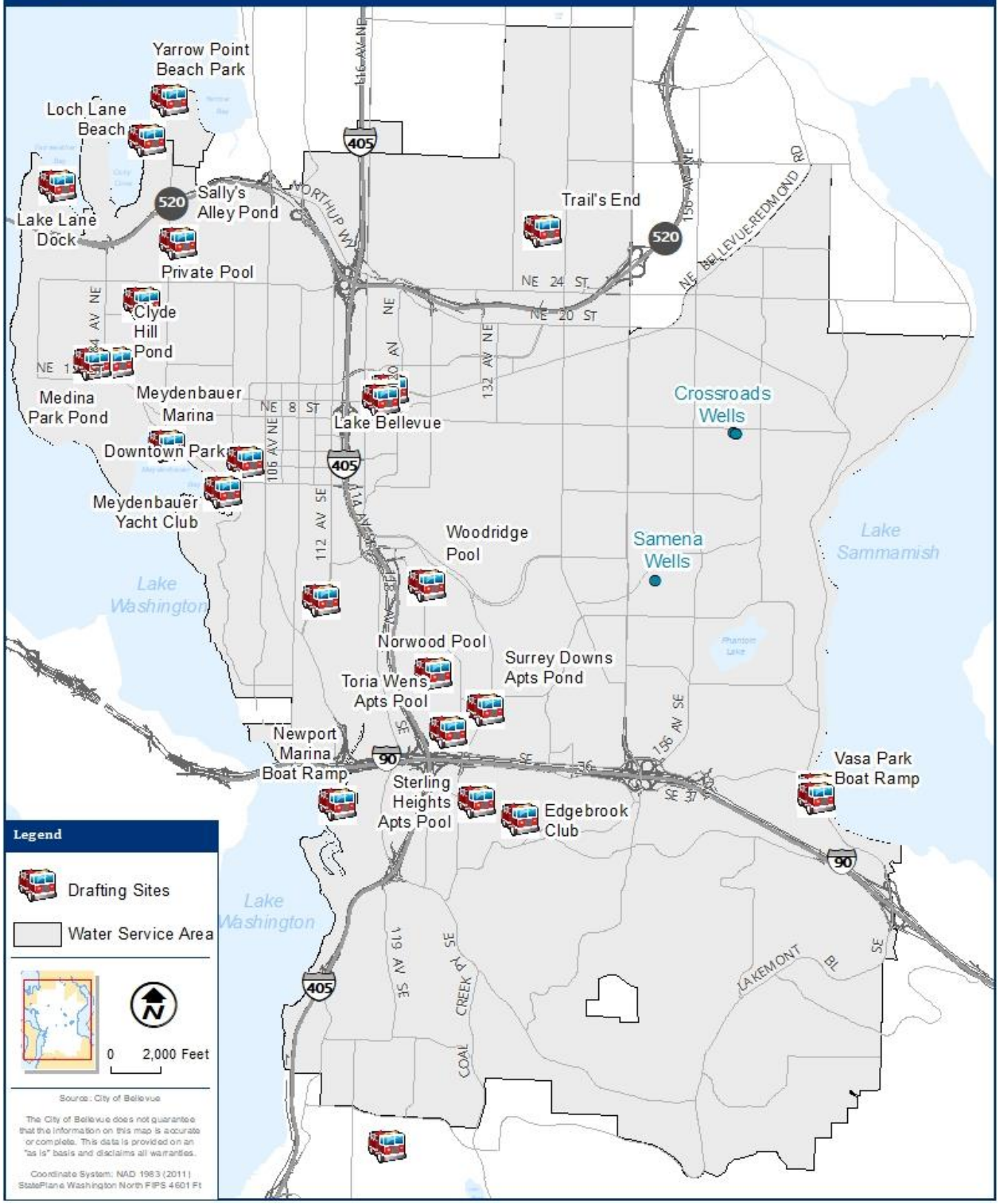
Fire Truck Drafting Operation with Suction (Black) and Discharge (Brown) Hoses

There are significant limitations to drafting, primarily related to access and water volumes. Drafting cannot replace the superior protection provided by automatic fire suppression systems (sprinklers) that would be lost with a water supply disruption. Drafting is most effective for fires near large, accessible surface water bodies, or for very small fires where a tanker truck provides enough volume to control the fire. Drafting alone cannot provide enough water for large fires except when located near boat ramps or other access points where crews can directly reach the fire with hoses (without hauling). Most of Bellevue's water customers are too far from surface water access points to benefit substantially from drafting.

Locations that have already been identified as potential drafting sites are shown in Figure 21. Crossroads wells are also proposed as a potential future alternative source of fire-fighting water, as discussed below. Additional, emergency-only wells placed in key, distributed locations could also improve fire protection coverage at higher ground (away from surface water), filling in gaps evident in Figure # and providing better emergency service to more of the service area during a water supply disruption.

Pre-Determined Surface Water Drafting Sites

Figure 21



Existing Groundwater Wells

Groundwater served as the original water supply to Bellevue in the 1950s and 1960s, and remains a viable source of water, despite some challenges. Existing wells are shown in Figure 12.

Groundwater Quality

Compared to the current supply of water from Seattle Public Utilities' Tolt and Cedar watersheds, existing wells in Bellevue produce water high in iron, manganese, and other minerals common to groundwater. This can make groundwater aesthetically unappealing due to taste, discoloration or odor, and can lead to water chemistry problems if blended with surface water (such as SPU's supplies). Confluence Engineering Group LLC evaluated samples of water from Bellevue's existing wells, and recommended treatment prior to supplying groundwater as a potable supply, not only for aesthetic reasons but to avoid public health risks such as metals release into water, and to protect infrastructure[46].

If an emergency well is intended to provide potable water, Washington State Department of Health (DOH) requires physical separation from the distribution system under normal circumstances, and periodic sampling, inspection and operation of the well to verify readiness and suitable water quality[47].

Non-potable water provided via drive-up points of distribution (PODs) may be combined with personal point-of-use treatment such as boiling (if gas or electricity service is available), chemical treatment (hypochlorite tablets, iodine, etc) or personal filtration devices such as Lifestraw® or backpacking filters[48].

Groundwater Capacity

Local groundwater hydrology in Bellevue includes confined aquifers made of outwash, sand and gravel, underneath an "aquitard" (low-conductivity layer) of glacial till. Based on observed pumping rates, the confined aquifer overall has adequate capacity and hydraulic conductivity to meet Bellevue's emergency water supply needs, but only if there are several wells or well fields dispersed throughout the service area. Aquifer conductivity is not high enough to meet the entire need through one localized wellfield. [49]

Confined aquifers are not recharged directly by vertical surface water infiltration, but recharge laterally through the soil. The aquifer used by Bellevue's Crossroads and Samena wells are recharged by connections to Lake Sammamish, Kelsey Creek, and other tributary streams. Groundwater modeling suggests that prolonged high-volume pumping from this aquifer could impact stream flows and fish populations[50].

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[46] *Water Quality Analysis Technical Memorandum*. Confluence Engineering Group LLC, 2018.
[47] *Emergency Drinking Water Sources*. WA DOH (331-317), January 2017.
[48] *Planning for an Emergency Drinking Water Supply*. USEPA (600/R-11/054), 2011. p. 15.
[49] *City of Bellevue Emergency Water Supply Plan – Aquifer Characterization and Well Yield Assessment*. Golder Associates, 9/18/2019.
[50] *City of Bellevue Emergency Water Supply Plan – Aquifer-Stream Delineation and Assessment*. Golder Associates, 4/9/2019

Existing Well Configuration Alternatives

Three emergency supply configuration alternatives have been identified[51] for the City's existing wells, and further evaluated[52]. Table 4 lists some advantages and disadvantages of each:

1. Stand-Alone CPOD: Emergency walk-up/drive-up community point of distribution (CPOD), plus regular non-potable uses with raw groundwater (treatment at point of use)
2. Quick-Connect Emergency Backup: Full capacity pumps and treatment, normally disconnected from the potable system by an air gap, plus regular non-potable uses
3. Normal Potable Supply: Full-time potable supply for all municipal water uses.

Regular non-potable uses indicated above may include local irrigation, a tanker truck fill station (for remote/off-site use), consumer fill station, or other non-potable municipal purpose.

Table 4: Comparison of Existing Well Site Configuration Alternatives

Alternative	Advantages	Disadvantages
1. Stand-Alone CPOD	• Drive-up/walk-up access to water • Inexpensive	• No restoration of piped water service in emergency • Limited use of groundwater resource • May be inequitable (car needed)
2. Quick-Connect Backup	• Drive-up/walk-up CPOD access • More regularly use resource • Staff training and readiness • Rapidly available to local piped system in emergency • Allows for Alt #3 in future with minimal modification	• More expensive • Requires more staffing, with additional qualifications (Water Treatment Plant Operator, WTPO)
3. Normal Potable Supply	• Maximize water resource • Potential to delay regional water supply development	• Former fuel tank; on-site soil contamination concerns • Stream flow & fish impacts • Water chemistry/quality, blending, aesthetics problems • Staffing, additional qualifications

At the Crossroads wells site, Alternative #2 is recommended for numerous reasons:

- Alternative #2 has the optimum balance of most advantages and fewest disadvantages shown in Table 4.
- Crossroads Park is across the street, and could be supplied with irrigation water, which would allow for more regular exercise of the equipment and staff training.

[51] City of Bellevue Groundwater Resource Development Analysis. Robinson-Noble, 1/6/2015.
[52] Attachment 2-G: Bellevue Emergency Water Alternatives Analysis. HDR, 12/20/2019.

- A designated CPOD (Crossroads Community Center) is across the street and could be used for drive-up/walk-up water distribution.
- Crossroads wells are near numerous critical customers that would benefit from the ability to quick-connect to the piped distribution system.
- The site is located on an arterial, which may allow for a tanker fill station.
- A fill station at Crossroads would help to fill a large gap in coverage for known Fire Department emergency "drafting" sites (see Figure #).
- Compared to Bellevue's service area, the local neighborhood has the highest USEPA Demographic Index[53], a measure of demographic indicators including low income and people of color. Emergency water supply access in this area may improve equity of services.

At the Samena Well site, Alternative #2 is also recommended. However, it would not be suitable for as many uses as Crossroads due to its location on a residential street and lower available capacity. Therefore improvements at the Samena site should be a lower priority than Crossroads.

Backbone piping is proposed to connect both the Crossroads and Samena wells sites to critical customers, as described in Section 6.2

Future Emergency-Only Wells

Two well alternatives listed above have also been identified for future, emergency-only wells:

- Stand-Alone CPOD:
- Quick-Connect Backup Emergency Backup: (with or without treatment, etc)

It is recommended that the City:

- Develop total well capacity (existing plus emergency-only) of 10 million gallons per day (MGD). This assumes demands are curtailed through public messaging, and some portion of the population leaves the area (Bellevue's average day demand is approximately 16 MGD).
- Initially plan to distribute a minimum 5-gal/day/person, or approximately 0.75 MGD total spread over 6 or more PODs, of non-potable water with home treatment provisions to meet basic drinking, food preparation, and hygiene needs. This assumes that local distribution piping is damaged and that it may take weeks or months to restore service for home delivery.

Although 10-MGD of water cannot be feasibly distributed to Bellevue's population via PODs, installing this higher well capacity at relatively low additional upfront cost would allow for the option to provide larger pumps, treatment and storage in the future to connect the emergency supply to the distribution system. If more resilient piping is installed, customers may then receive water from the emergency supply in their homes for bathing, dishwashing, and other normal uses.

Interties

Interties are connections with adjacent water utilities, separate from the regional supply. Bellevue's existing interties are shown on Figure 12.

[53] USEPA. EJScreen Version 2.0. Retrieved: March 14, 2022. www.epa.gov/ejscreen

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Interties with adjacent water utilities can be used to add supply redundancy in some situations. For Bellevue, interties provide only limited benefits for a widespread emergency, because neighboring utilities are dependent on the same regional water supplies and have their own needs to meet. However, interties could provide some redundancy during localized outages when the regional supply system is still operational, as described below.

Redmond

Redmond and Bellevue have an interwoven water distribution system in the Overlake and Lake Hills vicinity, with many connection points rather than discrete interties. Customers in Redmond's Overlake-Viewpoint Service Area (see Figure 12) are supplied via jointly-owned pipelines and facilities in Bellevue's distribution system. Redmond is dependent on Bellevue to convey water to these areas, and there is no alternative source in Redmond that could supply water to Bellevue with existing infrastructure.

Kirkland

Bellevue has one regular intertie and three emergency interties with the City of Kirkland. A portion of Bellevue's Bridle Trails neighborhood adjacent to Bellevue Golf Course is served through a one-way intertie from Kirkland. An emergency intertie on 13^{2n}d Ave NE will automatically (via pressure-reducing valve) serve Pikes Peak at reduced capacity in the case of a local loss of supply. A manual emergency intertie on Points Drive can be used to supply Yarrow Point from Kirkland at reduced pressure, if the normal supply (SR-520 crossing from Clyde Hill) is interrupted. Another manual intertie on Northup Way provides an emergency supply to the vicinity of 10^{8t}h Ave NE and Northup Way.

Coal Creek Utility District

Bellevue has 8 interties with CCUD. The Newport Hills and Newport Shores neighborhoods of Bellevue are dependent on water supply from CCUD. Bellevue does have some limited ability to supply water south into CCUD, but only at low elevations along Lake Washington.

Issaquah

Bellevue has 3 interties with the City of Issaquah. The Montreux and Lakemont Triangle interties operate in one direction, serving Issaquah neighborhoods that are dependent on Bellevue (not connected to the rest of Issaquah's water system), so Bellevue has ongoing responsibility for reliable service to these areas. The third intertie (serving South Cove) is currently dependent on Bellevue, but Issaquah is planning an alternative source, so that it could be converted to a 2-way emergency intertie. The cities are currently negotiating the potential for the South Cove intertie to provide backup supply to a limited number of Bellevue customers along Lake Sammamish.

Bulk and Bottled Water

Bulk water supply entails transport (via truck) of potable or non-potable water from an off-site source, or from a functional area of the distribution system to an impacted area. This method of water delivery depends on passable roads and highways, an accessible source, and may not be available immediately following an event. Typically bulk water is supplied at a POD with a piped manifold allowing for multiple fill stations (unless water is pre-bottled). Water can be packaged multiple ways:

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- Bottles loaded on pallets
- Large bladders, blivets or portable tanks
- Tanker trucks

Tanker trucks used solely for potable water or milk are preferred, but other food grade tanks may be acceptable[54]. Trucks that may have transported contaminated water in the past should not be used. For this reason tanker trucks maintained by fire departments, construction contractors, etc, might not be acceptable for emergency water delivery.

Piped Manifold Connected to Portable Blivet

Bottled water is a commodity with a supply chain and distribution network outside the expertise and capability of the Utilities Department to manage during an emergency:

> "In a large-scale emergency, local resources would likely be overwhelmed and outside assistance for the procurement and distribution of emergency drinking water would be required. In that case, utilities would have to focus their own resources on restoring service."[55]

Likewise, other bulk water delivery equipment such as portable blivets and temporary distribution manifolds require substantial labor to clean, transport, fill, set up, supervise, and refill, while only benefitting a small number of customers. Involving water maintenance crews with bulk water delivery during a widespread emergency would detract from the higher-priority, specialized work of restoring normal, piped water service. Therefore bulk water delivery is not recommended as a mitigation strategy for large-scale disasters.

Bulk water delivery systems may be practical if staffed by other agencies or by volunteers, or during a smaller water emergency that affects only a small portion of the system, where there are fewer high-priority demands on crews. It may be a useful tactic during recovery, after part of the normal system has been restored, but some areas lack service. Therefore some inventory of bulk water and distribution manifold equipment may be appropriate for the City to maintain for use in smaller emergencies.

The City should also encourage other agencies to develop pre-authorized contracts with the following to have vendors ready to assist the EOC during an emergency:

- Large retailers and beverage bottling plants: These companies warehouse large inventories of bottled water, and have a distribution network that can deliver supplies.
- Water, beverage and food delivery services: Tanker trucks approved to handle potable water or beverages (e.g. milk) could be useful for bulk water transfer.

[54] *Planning for an Emergency Drinking Water Supply*. USEPA (600/R-11/054), 2011. p. 11.
[55] *Planning for an Emergency Drinking Water Supply*. USEPA (600/R-11/054), 2011. p. 5.

The City should also identify additional POD sites (e.g. Parks, large parking lots, etc), develop any necessary agreements, and train on the setup and deployment of existing POD sites such as schools.

Personal Preparedness

Washington State Emergency Management Division and King County Emergency Management recommend that residents store 2-weeks of supplies, including water. As shown in Chapter 3, disruption of water supplies would be much longer than 2-weeks with existing infrastructure, but having this much water at home would allow residents to shelter in place for some time while temporary supplies are not yet available.

It is recommended that the City and its partners (e.g. Cascade Water Alliance) communicate the known risks to the system and encourage customers to store at least 2-weeks of water, consistent with emergency management agencies.

Some residents, particularly those with lower incomes, may be unable to store 14-days of water due to lack of storage space at small apartments and other housing arrangements. This equity concern is another reason to potentially prioritize emergency well and/or CPOD sites close to lower-income customers, in addition to the concerns described in Chapter 4.

6.2 Seismic Backbones

Seismic "backbones" are corridors of more resilient infrastructure that can be expected to out-perform the surrounding distribution system. Following an event, damaged portions of the distribution system would be isolated for repair, while the backbones would be relied on to stay in service, conveying water to key locations and less-damaged areas, while improving restoration time to heavily impacted areas as repairs are made.

Potential backbone routes were proposed and evaluated as part of the SVA, as shown in Figure 22. Modeling was performed to estimate the improved system restoration time and resulting economic benefit, and the backbones were prioritized based on optimal benefits per cost. The following routes are recommended for prioritization based on this evaluation:

- A Crossroads to Samena Well
- B Samena Well to Parksite/SBCC
- G LH520 to BV400
- L 13^{6t}h Ave Inlet to Hospitals
- M Bel-Red/Downtown/Clyde Hill

The other backbone routes do provide some benefit for reducing recovery time, and can be constructed opportunistically (e.g. in combination with other drivers such as existing pipe age or failure, overlapping projects, etc), but the seismic mitigation benefits alone do not warrant proactive replacement. The City's renewal & replacement program should factor in the value of the other backbone routes along with other benefits when prioritizing pipe replacement.

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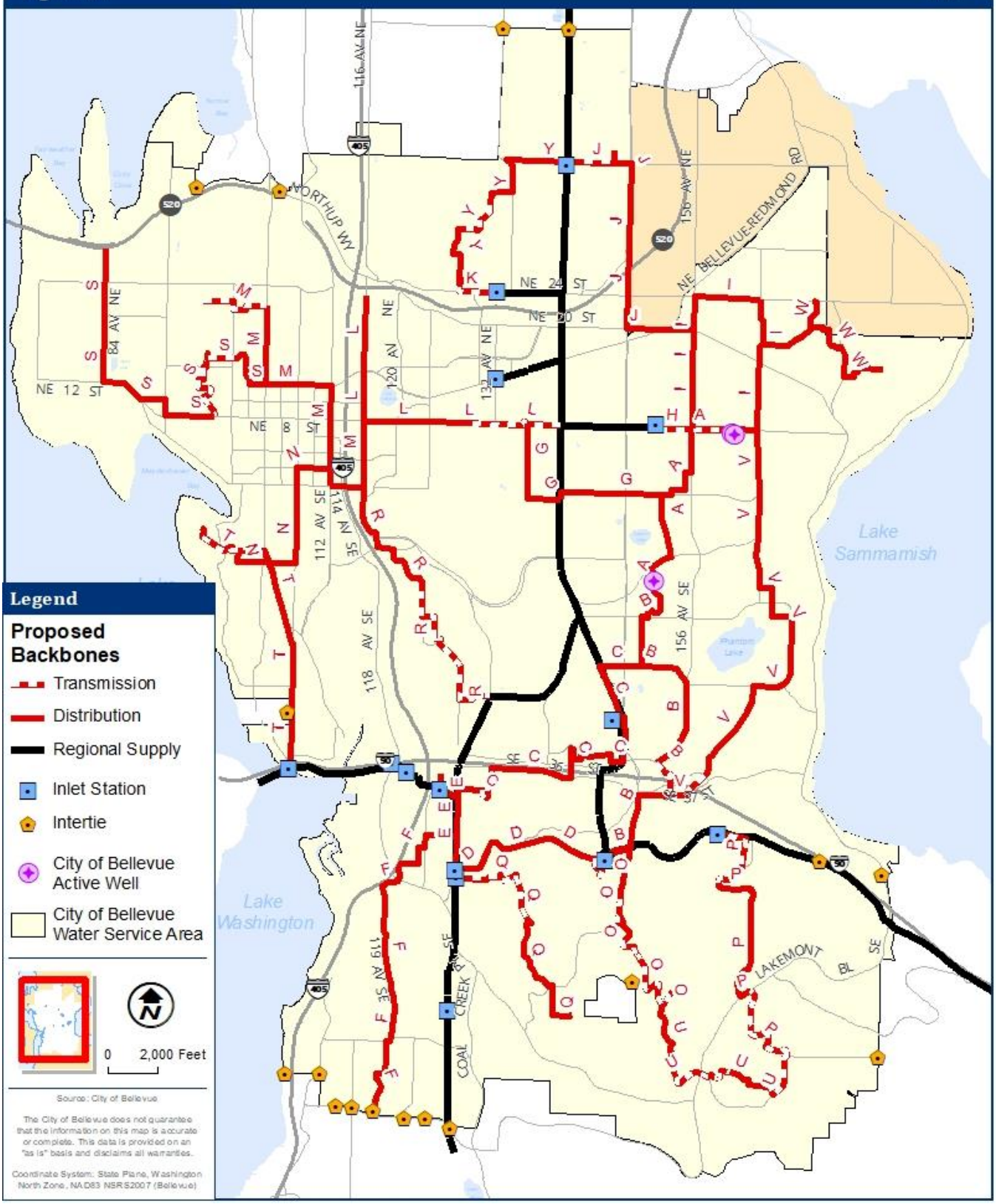
Proposed Backbone Routes

Figure 22



6.3 Distribution System Resilience

Although restoring water supply is a higher priority following a severe earthquake, far more time and labor will be required to repair distribution system infrastructure. Therefore, most of the opportunities to reduce restoration time come from improved distribution system resilience.

Water Main Replacement

The SVA found that predicted post-earthquake performance can be improved by replacing water mains with more resilient pipe.

Most of Bellevue's water mains were installed before local seismic risks were understood, so earthquake resilience was not considered during design or construction. Furthermore, earthquake-resistant pipe was not commercially available in the United States until the late 2010s.

Bellevue manages over 600 miles of water mains, with a total replacement cost of more than $2 billion. A main replacement program (CIP W-16) has been in place since the 1990s, however there are significant constraints on the feasible rate of pipe replacement, such as:

- Community impacts of pipeline construction
- Contractor availability
- City staff availability (project management, inspection, operations and maintenance, etc)
- Affordability

Due to these limitations, a risk-based strategy is applied to prioritize mains for replacement at an attainable rate. The current rate of replacement is 5 miles/year, which is viewed as a stable, sustainable rate of replacement assuming an average life of 100-125 years for the Cit''s 600+ miles of pipe.

Figures 23 and 24 show the current and future projected composition of pipe materials in Bellevue's system. All pipe materials are vulnerable to seismic hazards, but asbestos cement (AC) pipe is predicted to have the highest break rate. By continuing the City's existing program and installing newer ductile iron (DI) pipe throughout the system, predicted pipe failures during the SFZ earthquake are reduced by roughly 50%, from 460 to 220 failures in the median simulations (of 10,000), along with substantial reduction in the time it takes to restore service.

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Figure 23: Existing System (% of Pipe by Length)

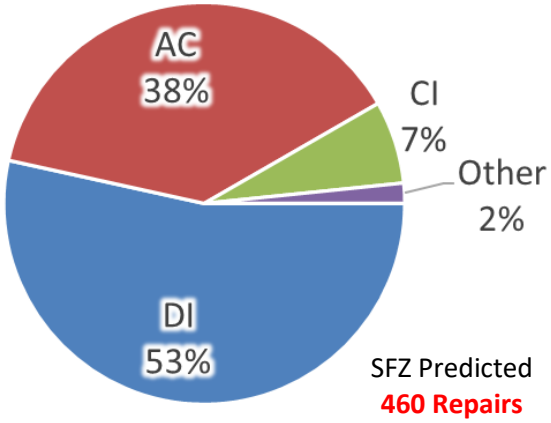
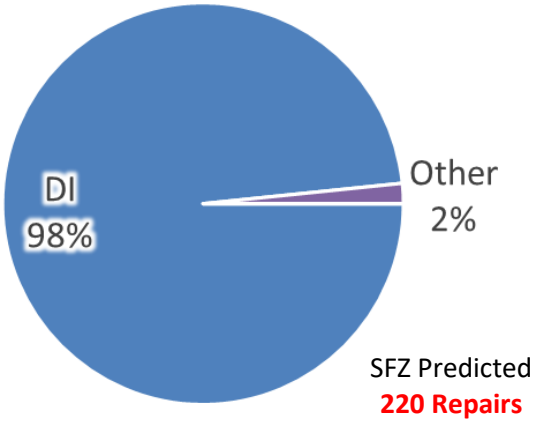


Figure 24: Future System (% of Pipe by Length)



The SVA also evaluated the benefits of different DI pipe joints, including standard non-restrained, restrained (RJ), and earthquake-resistant (ERDIP). Simulated performance improves substantially in liquefiable soils (4% of Bellevue's system by length) with ERDIP, demonstrating a clear benefit. However, in non-liquefiable soils only a nominal difference is predicted between non-restrained, RJ and ERDIP joints. There are numerous additional, non-seismic benefits of RJ and ERDIP pipe that make them appropriate, such as limiting service shutdowns during future construction, eliminating some thrust blocks, reducing break risk where access is limited, resisting pull-out on steep slopes, etc. However, seismic performance alone may not justify the added cost to install RJ or ERDIP in non-liquefiable soils.

Pump Station Rehabilitation

The majority of Bellevue's water service area is supplied by gravity, such that pumping is not necessary. In most cases, pressure needs to be reduced from the regional transmission pipelines.

However, certain higher-elevation areas do require pumping for service. This includes:

- All customers south of Newport Way and east of Coal Creek Parkway (South Operating Area)
- Some portions of Eastgate south of I-90 (Eastgate 590 and Horizon View 590 zones)
- A portion of the Clyde Hill vicinity (Clyde Hill 500 zone)
- Customers in the Pikes Peak and Bridle Trails neighborhoods, seasonally due to high summer demands (served by gravity most of the year)

For these areas, the SVA found that impacts and service restoration times following a severe earthquake can be significantly reduced by improving the resilience, survivability and redundancy of pump stations.

In the South Operating Area, some redundancy has already been designed into the system, as shown in Figure 25. The largest pressure zone, Somerset 850 (SS850) is supplied via 3 separate corridors, proposed as backbones O, P and Q (See Figure #). The Horizon View 1175 (HV1175) zone can be fed independently by Horizon View 2 or Forest Hills pump station. However, Forest Hills Pump Station may be vulnerable to seismically-induced landslide (discussed in Chapter 4), and the Cougar Mountain 1150

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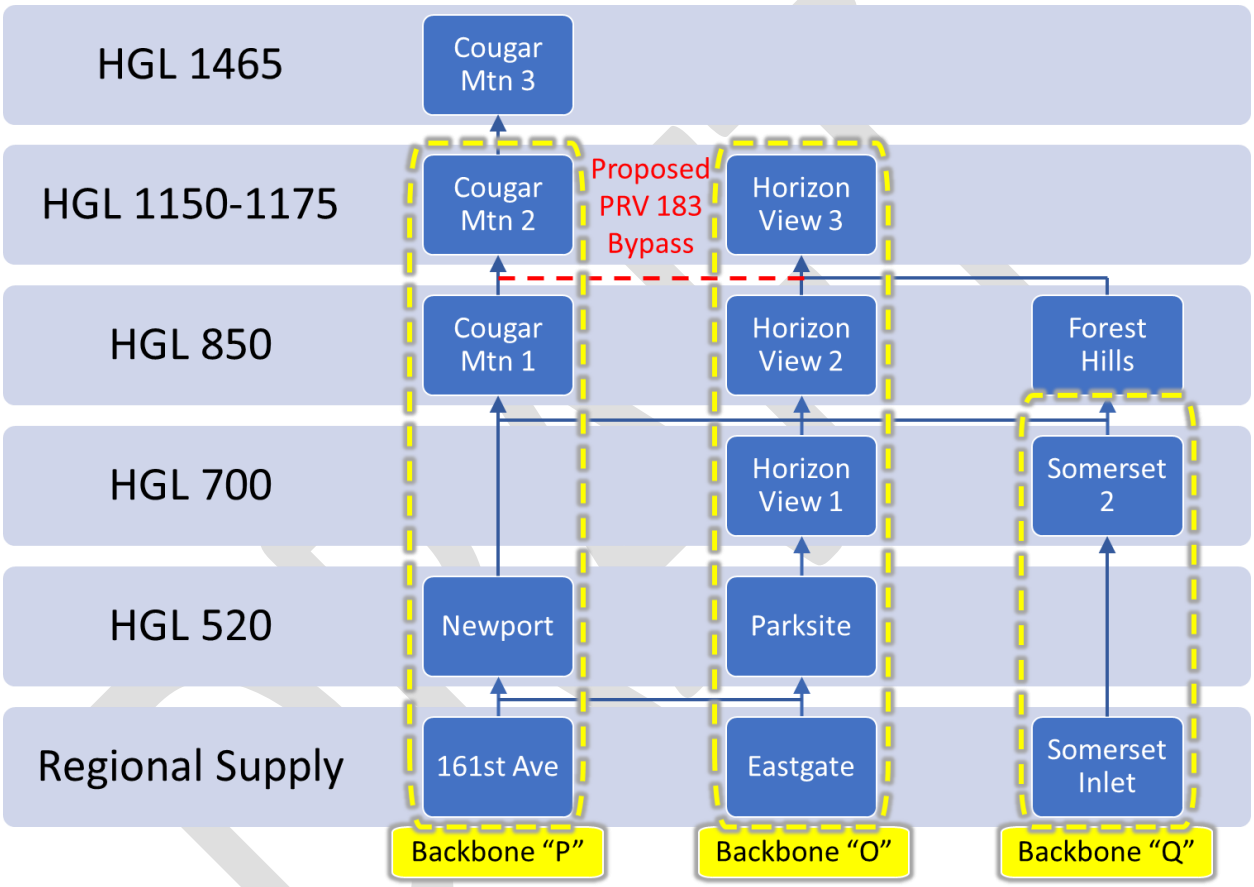
(CM1150) zone lacks a redundant supply. To address these concerns, the following mitigation actions are proposed:

- Assume Forest Hills may not be reliable following a SFZ or CSZ event, so prioritize resilience through Horizon View 2 (Backbone "O").
- For emergency redundancy between CM1150 and HV1175, install bypass piping around PRV station #183, and size Cougar Mountain #1 pumps (pending rehabilitation) to allow emergency pumping to HV1175.

Figure 25: South Operating Area Pump Stations



Customers in the Eastgate 590 (EG590) and Horizon View 590 (HV590) zones are normally supplied via pressure reducing valves from the Horizon View 700 zone (HV700), as part of the South Operating Area (not shown in Figure #). They will benefit from Parksite Pump Station replacement as part of Backbone O. In addition, check valves from the Lake Hills 520 (LH520) provide redundancy to meet basic domestic supply at reduced pressure in case HV700 is impacted. No additional facilities are recommended for EG590 or HV700.

The Clyde Hill 500 Zone (CL500) is supplied by Clyde Hill Pump Station, with only about one day of water stored in the 465 standpipe. Due to the lack of redundant supply and existing seismic vulnerabilities, Clyde Hill Pump Station should be replaced.

The Pikes Peak and Bridle Trails neighborhoods are supplied by two redundant pump stations, Cherry Crest and 670 Pump Station. Pumping is required during warmer seasons, when demands are high and pressure drops in the regional Tolt Eastside Supply Line (TESSL). However, during winter when TESSL pressure is higher, these neighborhoods are supplied by gravity. Cherry Crest Pump Station was replaced in 2021 with a more resilient facility. The 670 Pump Station is very vulnerable to the SFZ or CSZ event, and should be replaced at the next rehabilitation (current scheduled after 2030), however this does not need to be a top priority given that pumping may not be necessary after an event (TESSL conditions similar to winter due to water use curtailment), and redundancy with Cherry Crest.

Reservoir Rehabilitation

Reservoirs are required to operate any water distribution system, and serve an important role during normal operations, brief emergencies and planned shutdowns. They are critical infrastructure facilities that require ongoing maintenance and occasional rehabilitation, and should be designed to stay in service following an earthquake.

However, the SVA found that following a major regional disaster with extended loss of water supply, reservoirs will be fully depleted within days. During the recovery period, the performance of empty reservoirs is less critical to basic service restoration than supply and transmission infrastructure. Therefore, while reservoir performance is important, from the standpoint of disaster mitigation and post-earthquake service restoration they should not prioritized as highly as the pipelines, inlet stations, and (where applicable) pump stations that deliver the water.

Reservoir seismic resilience is important to eventually restore normal service, and the City has had a reservoir seismic and structural rehabilitation program (CIP W-85) in place since the 1990s. As a result of this program, reservoir seismic resilience in Bellevue has improved.

Jumper Hoses

Jumper hoses do not provide any supply, but during a localized outage due to main break or other interruption can be used to temporarily connect nearby piping to maintain some level of service. Jumper hoses could also be used to restore service sooner to some customers during recovery following a widespread major event such as an earthquake.

A major disadvantage of jumper hoses is that they take substantial time and effort to transport, deploy, disinfect, connect, and then drain and store. In most main break situations, the break itself could be repaired in less time that it would take to put a jumper hose into service. Jumper hoses also have a limited shelf life, require storage space, and entail ongoing staff training to maintain readiness.

Another limitation of jumper hoses is that they only act to convey water between customers within a particular pressure zone. They cannot provide service to customers at higher elevations without a portable pump, or service to customers at lower elevations without a pressure reducing valve.

The City has a limited supply of jumper hose available. It was procured via a Urban Area Security Initiative (UASI) grant, and is jointly-owned with other regional utilities. This hose was successfully used along with other measures to maintain service during a water main replacement project in 2017, reducing a shutdown from over 300 customers to less than 20. The pictures below are from that event.

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Unspooling jumper hose

Jumper hose in service

As demonstrated by successful deployment in 2017, jumper hoses can be useful to temporarily maintain service in certain situations. This could include similar, planned shutdowns where a large number of customers could be impacted due to a lack of isolation valves or redundant piping, and there is adequate time to plan for the event. Jumper hoses may also be useful following a main break that cannot be quickly repaired (e.g. creek crossings or other sensitive areas). However, for most main breaks in accessible locations, the time required to repair the main and restore normal service can be less than that required to install a jumper hose.

It is recommended that the City maintain some stock of jumper hoses as an available tool to assist in providing temporary service where appropriate, depending . However, it is not apparent that procuring jumper hose on a larger scale would have a significant benefit.

6.4 Improvement Timetable

Regardless of which capital, maintenance, or other technical mitigation actions are taken, there are numerous alternatives for how quickly to make these improvements.

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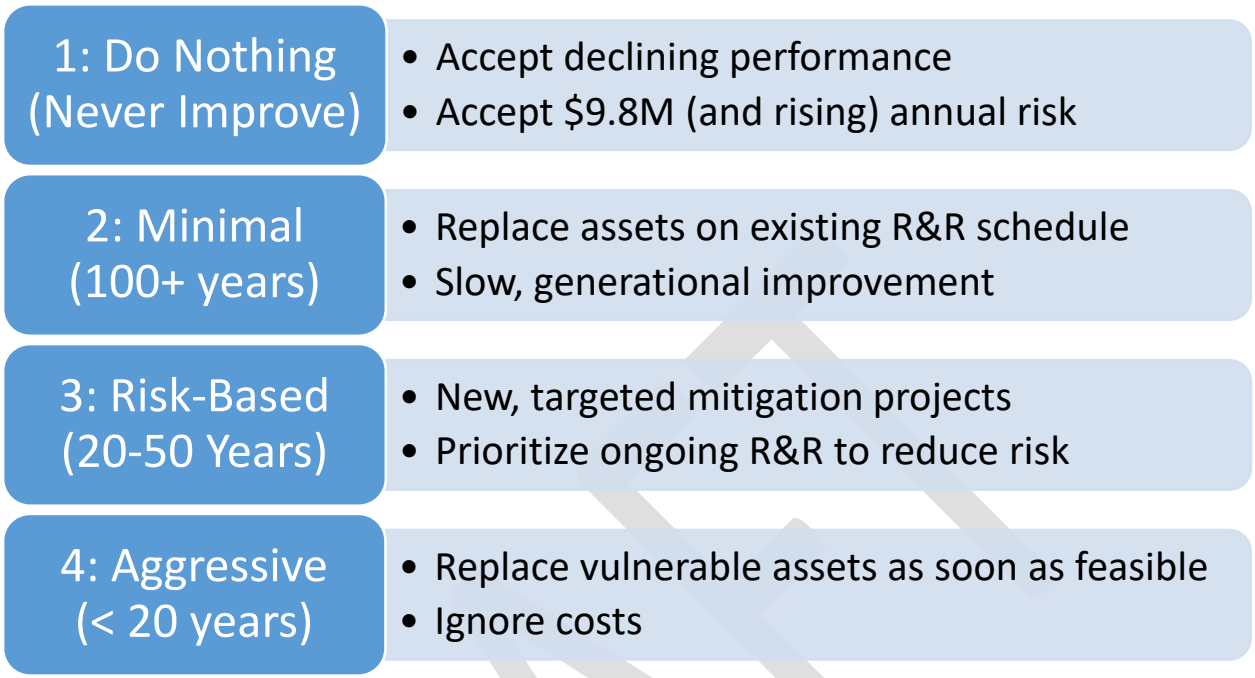
Figure 26: Improvement Timetable Alternatives



Alternative 1: Do nothing

This alternative conflicts with both City policy and the U.S. America's Water Infrastructure Act, and is not recommended.

Alternative 2: Minimal

This alternative does not add any new projects or mitigation actions, but continues the existing R&R program at its current schedule, replacing water mains, pump stations and reservoir with more resilient infrastructure at the end of useful life (often 100 years). Projects are scheduled and prioritized based on non-emergency criteria such as age, obsolescence, and operational deficiencies. This strategy is viable, but accepts an annual economic risk currently estimated to be +/- $9.8 Million per year with existing infrastructure, and lags behind similar utilities' approach to seismic resiliency. Substantial improvement in PE-LOS may not occur within our lifetimes.

Alternative 3: Risk-Based

This alternative seeks to balance measurable improvements in PE-LOS with affordability, by making the most efficient, beneficial, and critical resiliency improvements over a reasonable timeframe. This strategy is the most consistent with other local and regional utilities.

Alternative 4: Aggressive

This alternative takes a "moon shot" approach to rapidly improving seismic resilience. It is disproportionate with industry practices, is likely not feasible or affordable, and may not be defensible based on the estimated risk and event return periods.

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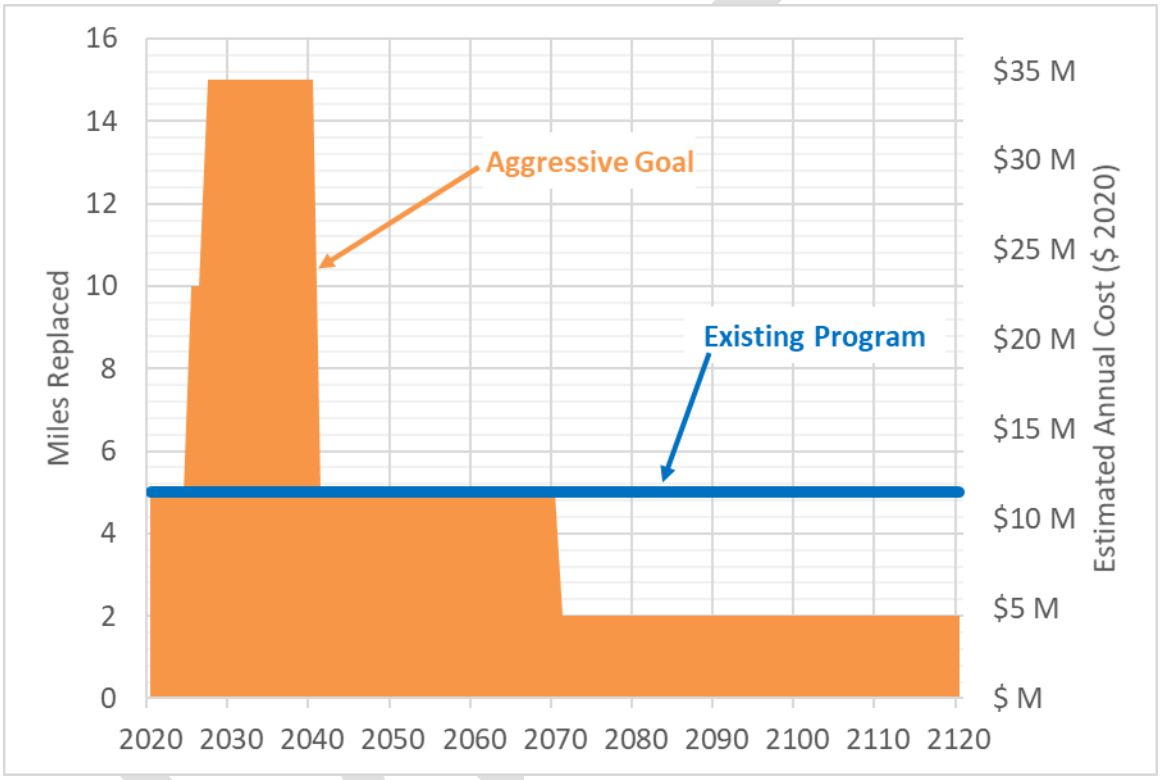
As mentioned in Section 6.3, there are many practical limits on the amount of water main that can be replaced on an annual basis. In order to achieve the aggressive timetable, the City would have to substantially increase water rates, substantially increase the Utilities Department's Engineering Division staffing, triple the amount of pipe replaced each year, and accelerate pump station replacement and reservoir projects.

Figure 27 illustrates the logistical and feasibility challenges that the aggressive timetable would entail for water main replacement. The aggressive and existing schedules would replace the same length of pipe over 100 years, but the aggressive schedule would triple the rate from 5 to 15 miles/year through 2041.

Figure 27: Aggressive Pipe Replacement Schedule vs. Existing Schedule



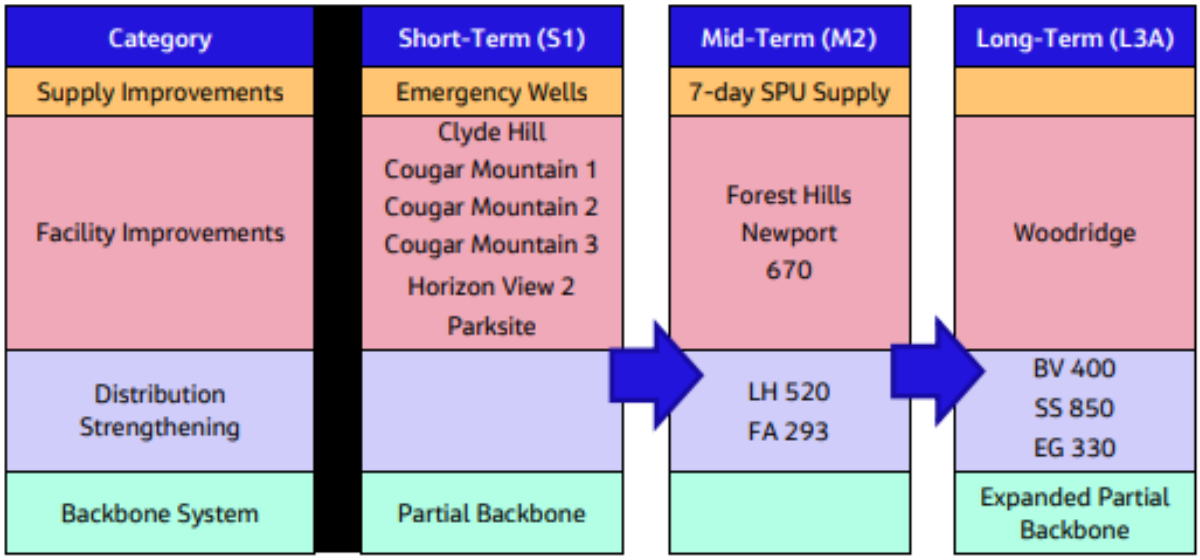
7. Recommendations

This chapter summarizes the recommendations presented throughout the Master Plan, the anticipated system performance following those improvements, and anticipated costs.

7.1 Summary of Recommendations

Figure 28 summarizes infrastructure (capital) improvements that are recommended to meet the proposed PE-LOS goals within the 50-year timeframe. More detail is provided in the following pages.

Figure 28: Summary of Recommended Infrastructure Improvements



General mitigation actions:

- Implement a 50-year, risk-based improvement timetable, consistent with other Pacific Northwest water utilities.
- Develop a roster of Washington State certified Water Treatment Plant Operators (WTPO), as needed to maintain and operate proposed groundwater well treatment systems.
- When prioritizing and siting locations for improvements, consider equitable, inclusive, and culturally competent access for vulnerable or under-represented residents. For instance consider residents who lack a vehicle to pick up water, language barriers, and other factors.
- When evaluating resilience and redundancy improvements, consider the risks (likelihood and consequence) of all hazards and threats cumulatively, including intentional acts, natural hazards, and failures due to age or deterioration.
- The Utilities Department should not rely on any of the following as mitigation for widespread regional disasters or any complete disruption of water supply:
  - Portable surface water treatment
  - Bulk water storage and delivery (e.g. blivets, distribution trailers, etc)
  - Jumper hoses

  These measures should be considered as tools to address small, localized, planned or unplanned shutdowns or emergencies, so a small inventory may be appropriate. However, they require substantial storage space, maintenance, exercise and training, they lack substantial capacity,

and following a major disaster they would divert water utility staff from higher-priority service restoration tasks (see Chapter 6).

- Evaluate Federal grant programs for mitigation funding opportunities, if and where the value provided exceeds the application and compliance requirements, and when Bellevue's application would likely be competitive.
- Encourage emergency response agencies to execute pre-authorized contracts with water delivery services, to have vendors potentially available to truck bulk water (tankers) or bottled water (large retailers) when the need arises. (See Chapter 5)
- Develop Standard Operating Procedures (SOPs), perform initial & refresher training, and conduct periodic exercises to establish and maintain readiness for alternative supply and delivery methods.
- Inform and encourage residents to store 14 days of water, if possible.
- Provide translation of public messaging, signage and other media related to emergency preparation and response, to improve cultural competency and access to emergency services.

Water Supply:

- Encourage SPU to prioritize improvements to the TESSL and CESSL, in coordination with Cascade Water Alliance.
- Improve the Crossroads and Samena well sites to allow for:
  - Rapid conversion of the local distribution system to groundwater supplies in an emergency
  - Well head protection meeting current standards
  - Staff readiness and more effective use of resources for non-emergency demands
- Further evaluate local hydrogeology to understand and mitigate potential risks to stream flow from pumping groundwater.
- Perform a siting study to identify potential new (emergency-only) well sites.
- Implement best practices for well head protection at the Crossroads site, including site improvements, further remediation of contaminated soils, land use changes, and a sensitive area designation, if appropriate and applicable.

Water Distribution:

- Continue the existing pump station rehabilitation program (CIP W-91), and prioritize renewal or replacement of the pump stations listed in Figure 28.
- Enhance the required seismic design criteria for pump stations and reservoirs (see Attachment 1-H, Table 4).
- Require earthquake-resistant pipe in liquefiable soils (see Attachment 1-H, Section 5.3).
- Continue the existing water main replacement program (currently 5 miles per year), using earthquake risk reduction as part of the prioritization criteria. This should add higher priority to pipeline replacement in the Lake Hills 520 (LH520) and Factoria 293 (FA293) zones in the mid-term period (by 2050), due to large numbers of critical customers, population density, equity benefits, and relative vulnerability. The Bellevue 400 (BV400), Somerset 850 (SS850) and Eastgate 330 (EG330) zones should be prioritized in the longer-term (by 2070). See Attachment 1-I, Section 6.2.

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- Incorporate post-earthquake recovery into the risk model for prioritizing water main replacements. In particular, increase priority for the most critical zones (e.g. BV400, FA293 and LH520) and for the most vulnerable pipeline (e.g. in liquefiable soils).

Backbone:

- Install seismically-resilient backbone piping, as described in Section 6.2. Prioritize the following backbone routes (see Figure 22 for locations), which have positive benefit/cost ratio based on seismic risk reduction alone:
    - A Crossroads to Samena Well
    - B Samena Well to Parksite/SBCC
    - G LH520 to BV400
    - L 136th Ave Inlet to Hospitals
    - M Bel-Red/Downtown/Clyde Hill

  Other backbone routes provide value, but do not provide enough seismic risk reduction benefit to justify early replacement. They can be installed opportunistically in combination with other benefits (e.g. renewal and replacement) or as cost efficiencies arise (e.g. overlapping projects).

7.2 Anticipated Level of Service Improvements

As described in Section 3.3, iterative, Monte-Carlo models were developed to simulate service restoration times throughout the service area after the SFZ and CSZ events with existing infrastructure. The same simulations were performed to develop the above recommendations and meet the PE-LOS goals in Chapter 2. Figures 29 and 30 show the results with existing infrastructure (2020), and with recommended short-term (2035), mid-term (2050) and long-term (2070) improvements.

Figure 29 - Simulated SFZ Restoration Time with Proposed Improvements

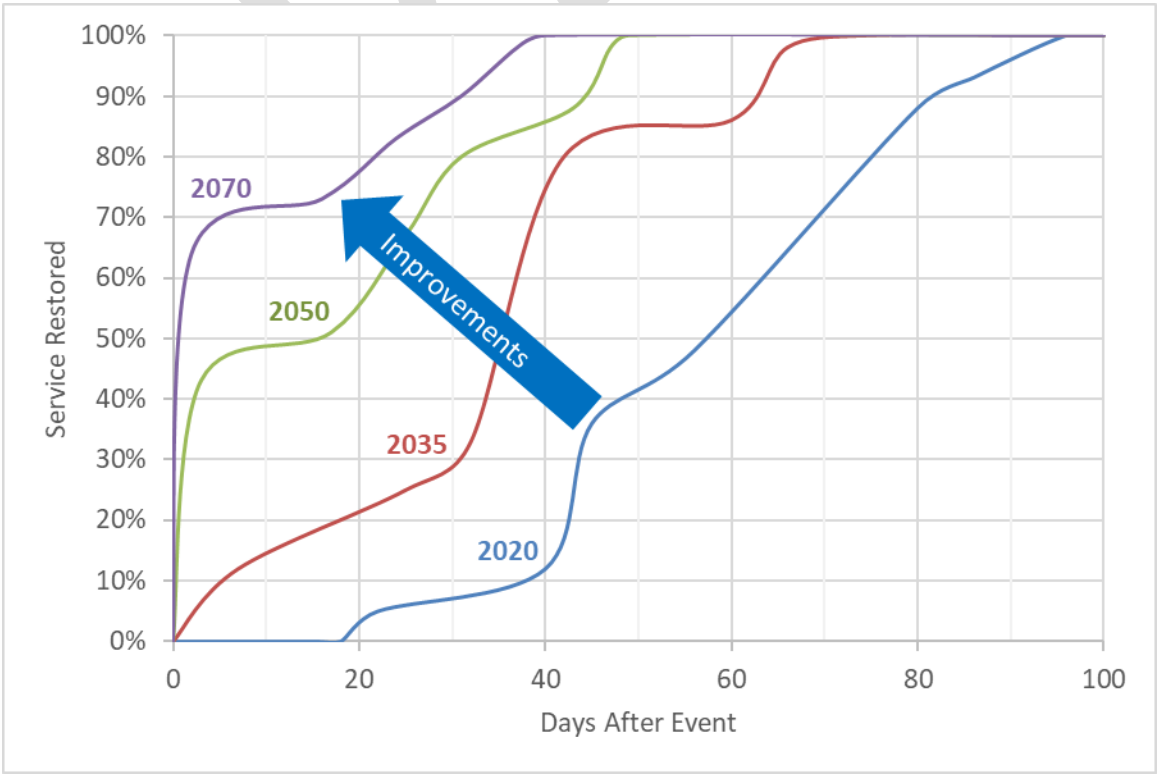

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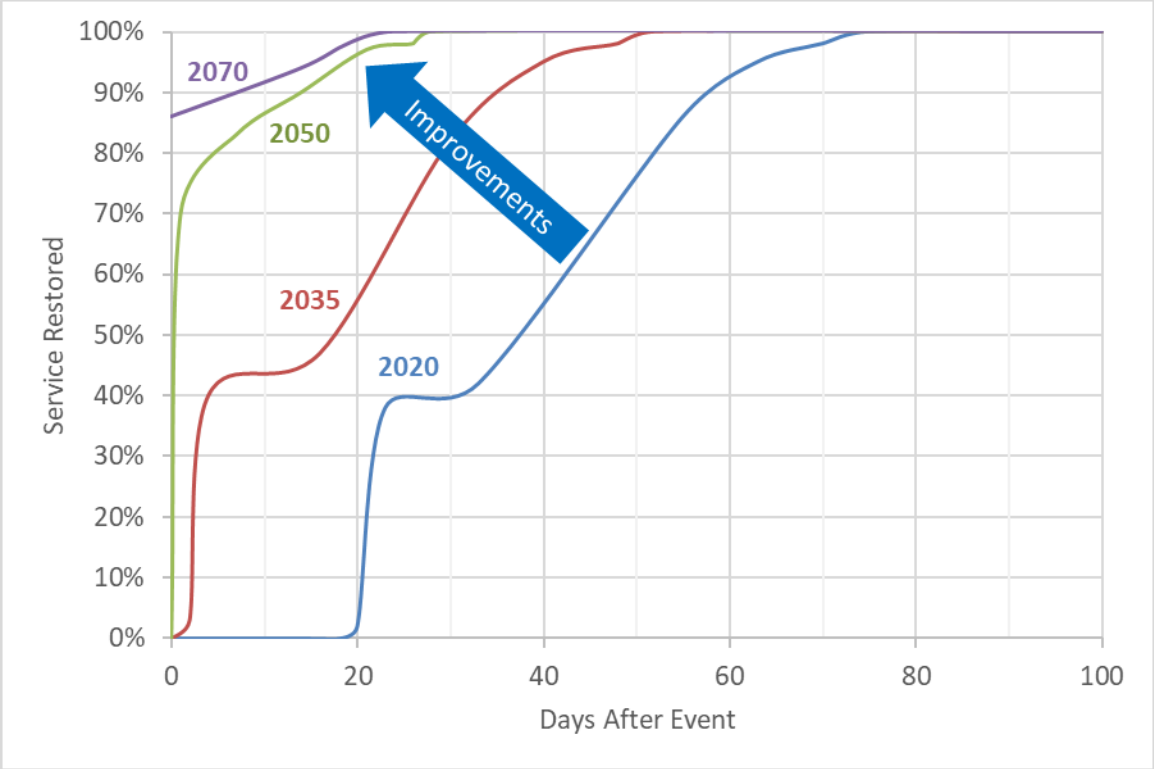
Figure 30 - Simulated CSZ Restoration Time with Proposed Improvements



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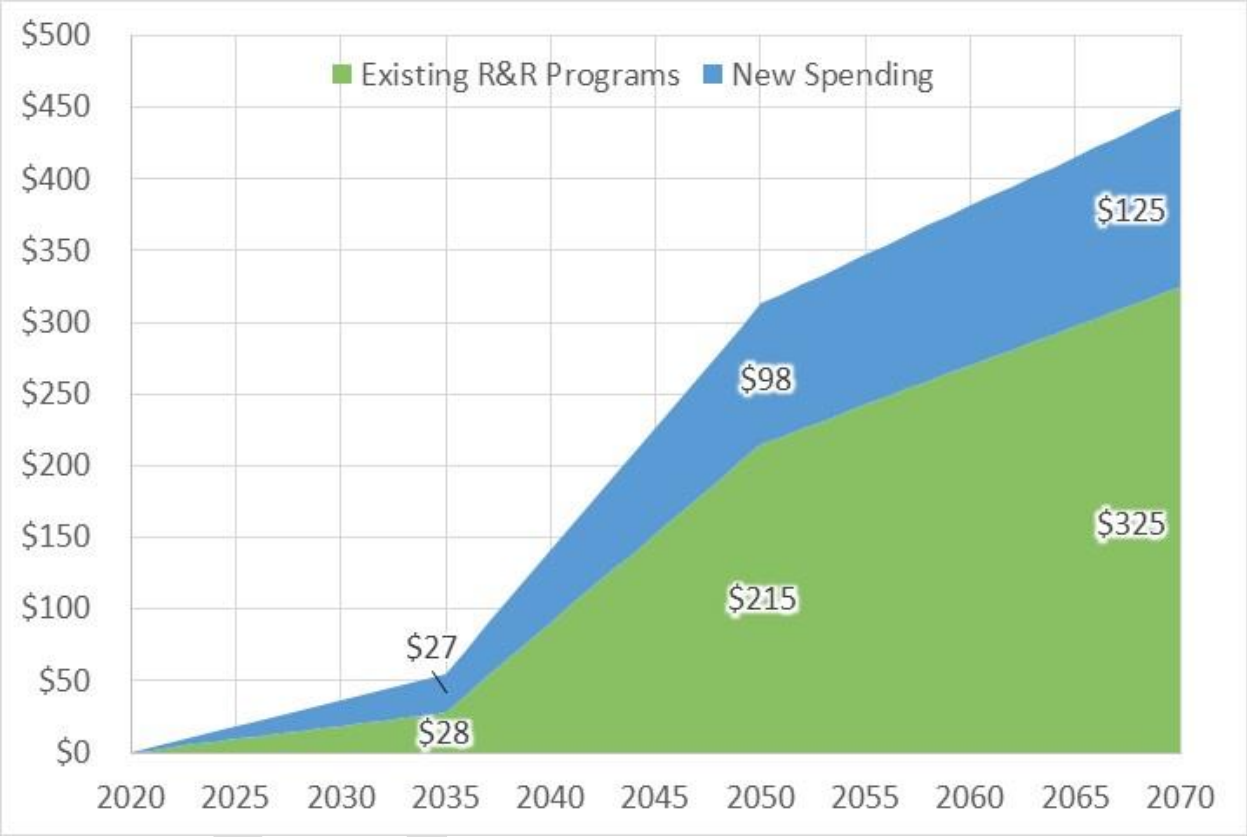
7.3 Anticipated Benefits vs. Cost of Improvements

As noted in Chapter 6, most of the recommended mitigation actions involve continuing existing annual CIP programs (W-16 water main replacement and W-91 pump station rehabilitation or replacement), with some changes to project criteria and prioritization. As a result, most of the recommended improvements do not represent new spending, but provide additional justification for already planned renewal and replacement work. Some new spending is proposed, including the addition of new emergency wells, and backbone piping above and beyond planned pipeline replacement. Figure 31 shows the estimated cumulative costs for the recommended improvements.

Figure 31 - Proposed Cumulative Spending on Improvements ($ 2019, uninflated)



Costs shown in Figure 31 are based on 2019 costs, prior to COVID-related inflation and supply chain challenges. Due

To quantify the basis for recommended projects, benefit/cost ratios specific to earthquake mitigation were estimated, as shown in Table 5. Benefit is estimated as reduced risk, using 100-year net present value assuming 2% inflation and 5% discount rate. Benefit/cost ratios only account for seismic-related benefits, so total benefit/cost (including existing programs) is higher considering other benefits for programs that are already budgeted.

Table 5: Seismic Benefit / Cost Ratio for Recommended Projects

Timeframe	Seismic Benefit / New Spending	*Added* Seismic Benefit / New + Existing Spending**
Short-Term (15-year)	5.2	2.6
Mid-Term (30-year)	2.4	0.7
Long-Term (50-year)	2.5	0.7

**Only considers seismic benefits. Ongoing benefits for existing R&R programs (increased reliability, streamlined operations, reduced life-cycle costs, etc) are not included and would be cumulative. Total benefits/cost ratios are higher.

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Bellevue Water System Seismic Vulnerability Assessment

Draft Final Project Report

December 29th, 2021

City of Bellevue, Washington

Bellevue Water System Seismic Vulnerability Assessment

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Appendices

Appendix A. Geotechnical Data Refinement and Seismic Vulnerability Assessment Scenario Selection

Appendix B. Seismic Analysis Methodology

Appendix C. System Modeling Methodology

Appendix D. Existing System Performance

Appendix E. Economic Impacts Characterization

Appendix F. Existing System Seismic Vulnerability and Potential Service Outage Severity

Appendix G. Post-Earthquake Level of Service Goals

Appendix H. Improvements Alternatives

Appendix I. Recommended Seismic Resilience Improvements

Executive Summary

Evolving understanding of seismic threats across western Washington and the Pacific Northwest is raising awareness of previously unrecognized risks relative to water supply system resiliency. In response, the City of Bellevue has completed a seismic vulnerability assessment (SVA) of the City's water system. The primary objectives of the SVA are to better understand these seismic risks, better understand potential impacts and develop a plan to increase seismic resiliency. Loss of water service, as is likely to occur after a major seismic event, can have an overwhelmingly negative impact on communities as well as local and regional economies. Figure 1 illustrates the process used to achieve the primary objectives of the Bellevue SVA.

Figure 1: Seismic Vulnerability Assessment process and objectives

Assessment Process

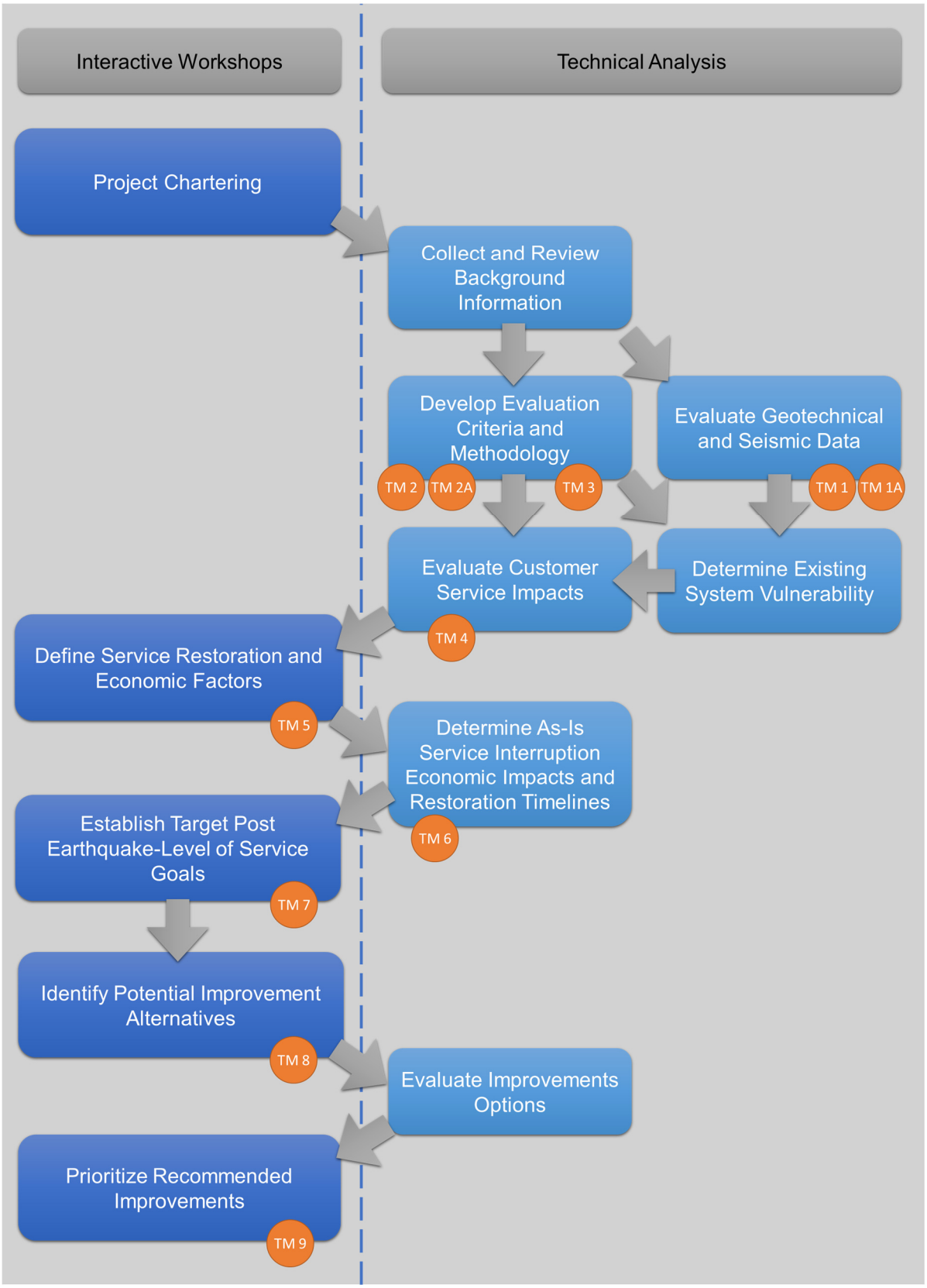
The SVA employed an innovative assessment process incorporating probabilistic system modeling and economic risk and cost-benefit analysis to predict the seismic resilience of existing water system infrastructure and proposed system improvements. This process provides an in-depth understanding of the current seismic risk and highlights the economic and social benefits of system resilience improvements. An overview of the assessment processes employed as part of the SVA effort is described Table 1. For additional information and detail, refer to technical memoranda (TMs) included in this report.

The seismic vulnerability analysis was advanced through a series of site visits and workshops with City staff, with technical analysis approaches, progression, and results documented via workshop summary presentations and detailed technical memoranda (TMs) as summarized in Table 1 and further illustrated Figure 2.

Table 1: SVA approach and Technical Memorandum summary

Assessment Process	Corresponding Technical Memo
Evaluated the seismic threats to Bellevue water system to define seismic event scenarios to be evaluated.	▪ TM1: Geotechnical Data Refinement ▪ TM1A: Seismic Vulnerability Assessment Scenario Selection
Evaluated potential impacts of seismic events on existing Bellevue water supply system to determine likely: ▪ Water system infrastructure damage and failure states (likely impacts to pipes and facilities) ▪ Resulting water service outages, durations, and water service restoration timelines ▪ Potential economic impacts of water service outages	▪ TM2: Seismic Analysis Methodology for Pipeline and Facilities Assessment ▪ TM2A: Comparison of ALA Equations to Christchurch Earthquake Repair Data ▪ TM3: Modeling Methodology ▪ TM4: Existing System Vulnerability and Customer Outage Probability ▪ TM5: Economic Impact Parameters ▪ TM6: As-Is Service Outage, Restoration Times, and Economic Impacts
Assessed Post-Earthquake Level of Service (PE-LOS): ▪ Reviewed likely water system PE-LOS performance relative to water service outage and restoration times ▪ Established target PE-LOS improvement goals	▪ TM7: Post Earthquake-Level of Service Goals
Assessed and evaluated potential water system seismic resilience improvement alternatives and associated costs relative to: ▪ Improved system resilience and reduced likelihood of seismic infrastructure damage ▪ Ability to reduce likely water service outages and durations, improve water service restoration times, and reduce economic impacts of water service outages ▪ Ability to improve system performance to meet target PE-LOS goals	▪ TM8: Improvement Alternatives
Identified optimized water system seismic resilience improvements providing maximum benefits in terms of reduced economic risk relative to improvement costs while meeting PE-LOS goals	▪ TM9: Improvement Prioritization

Figure 2: SVA project approach and progression



Seismic Scenarios and Projections

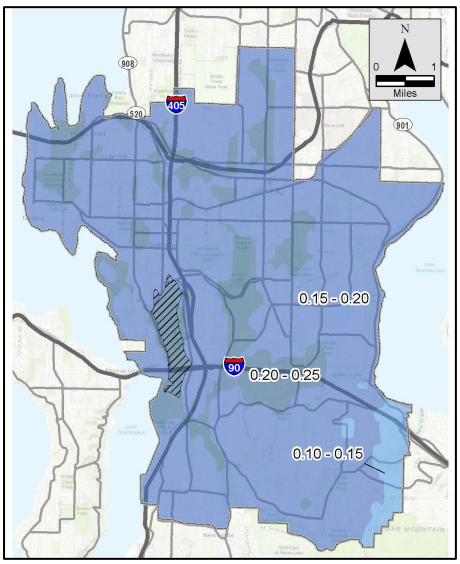
Earthquake risks associated with the Cascadia Subduction Zone (CSZ) and Seattle Fault Zone East (SFZE) were determined to pose the most significant seismic threats to the Bellevue water supply system based on both anticipated event severity and likely frequency of occurrence. Large earthquakes associated with the CSZ are expected to occur once every 500 years, and major event frequencies are likely to be every 800 years for portions of the Seattle Fault Zone. There is great uncertainty around the specific portions of the Seattle Fault Zone that are likely to rupture on this relatively frequent basis, especially along the eastern extent of the fault zone that runs through Bellevue. Figure 3 shows the proximity of local and regional fault zones to the City of Bellevue. Figure 4 illustrates the expected earthquake shaking intensity across the water service area for major CSZ and SFZE seismic events, and demonstrates the greater shaking intensity expected from a major SFZE event.

Figure 3: Washington seismic faults and threats (adapted from Washington Department of Natural Resources)

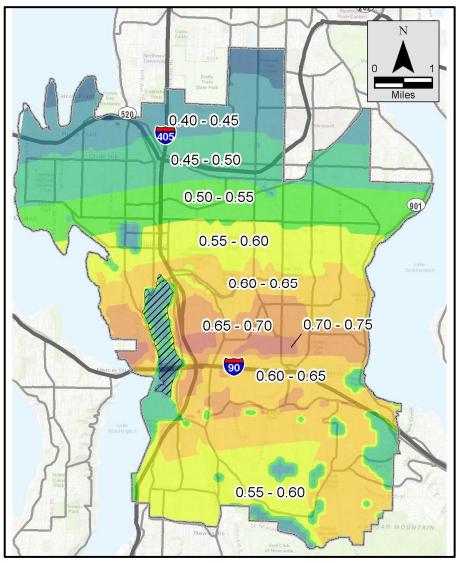
(Shaking hazard shown is for Cascadia Subduction Zone Only)

Figure 4: Projected seismic peak ground acceleration (PGA) shaking intensity

Cascadia Subduction Zone Mw 9.0



Seattle Fault Zone East Mw 6.6



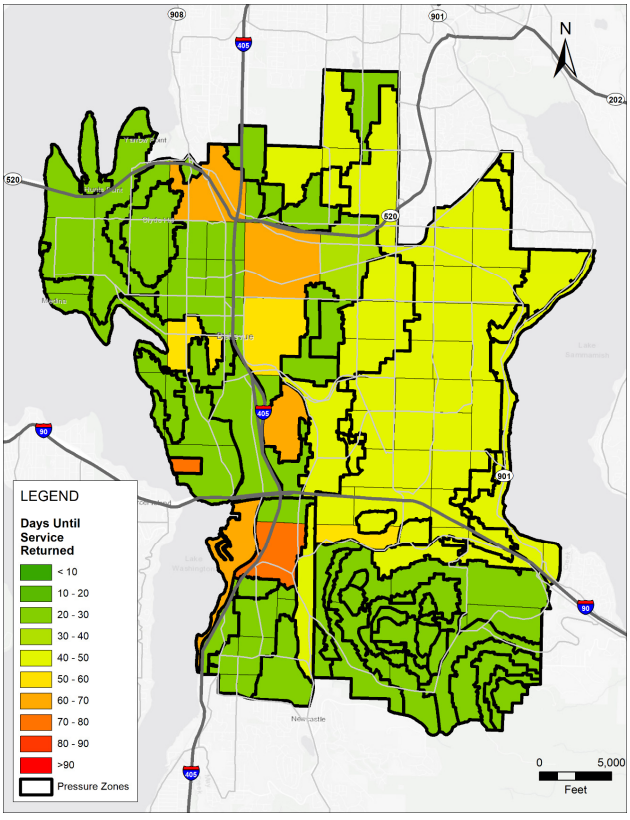
Existing System Seismic Vulnerability and Impacts

Estimated CSZ and SFZE seismic event severity, local geologic conditions, and water supply infrastructure condition, configuration, age, and materials were used to evaluate and estimate the seismic resilience of the existing system, and project likely system levels of service following major seismic events. Based on this information, it was determined that:

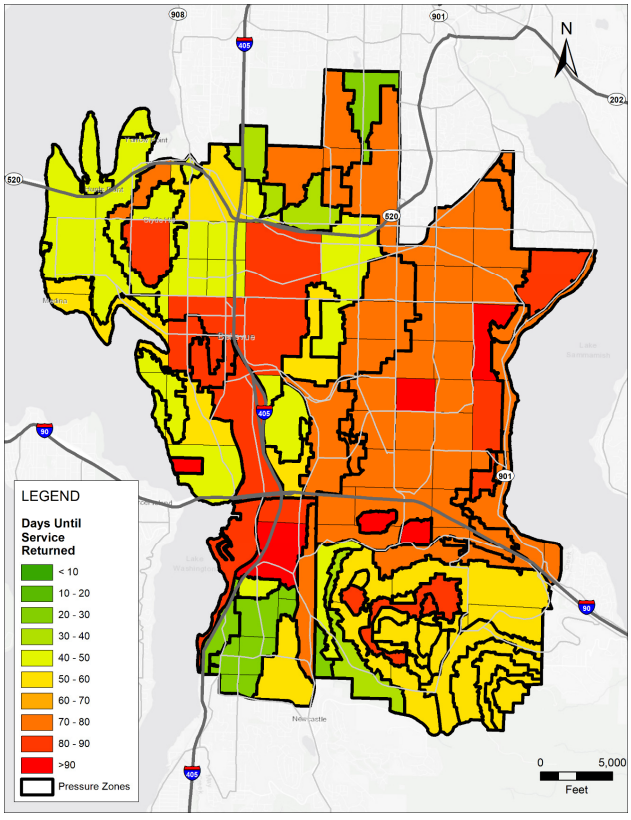
- Significant and widespread damage and failures in existing water supply pipes and facilities are likely under both CSZ and SFZE seismic scenarios including at least 200 to 400 pipe breaks, respectively, within the Bellevue water system and potential major damage to the regional Seattle Public Utilities (SPU) water infrastructure that supplies water to Bellevue.
- Resulting water service outage and restoration times following a significant CSZ or SFZE seismic event could be on the order of months. As illustrated in Figure 5, the greater shaking intensity predicted for the SFZE compared to the CSZ is likely to result in longer and more widespread water supply service outages, resulting in significant impacts on existing water system infrastructure and supply availability for months after a seismic event.
- The economic impacts of resulting Bellevue water service outages could accrue to totals on the order of $2.4 to $8.3 billion for the CSZ and SFZE earthquake scenarios, respectively.

Figure 5: Water service outage durations projected to result from major seismic events

Cascadia Subduction Zone Mw 9.0



Seattle Fault Zone East Mw 6.6

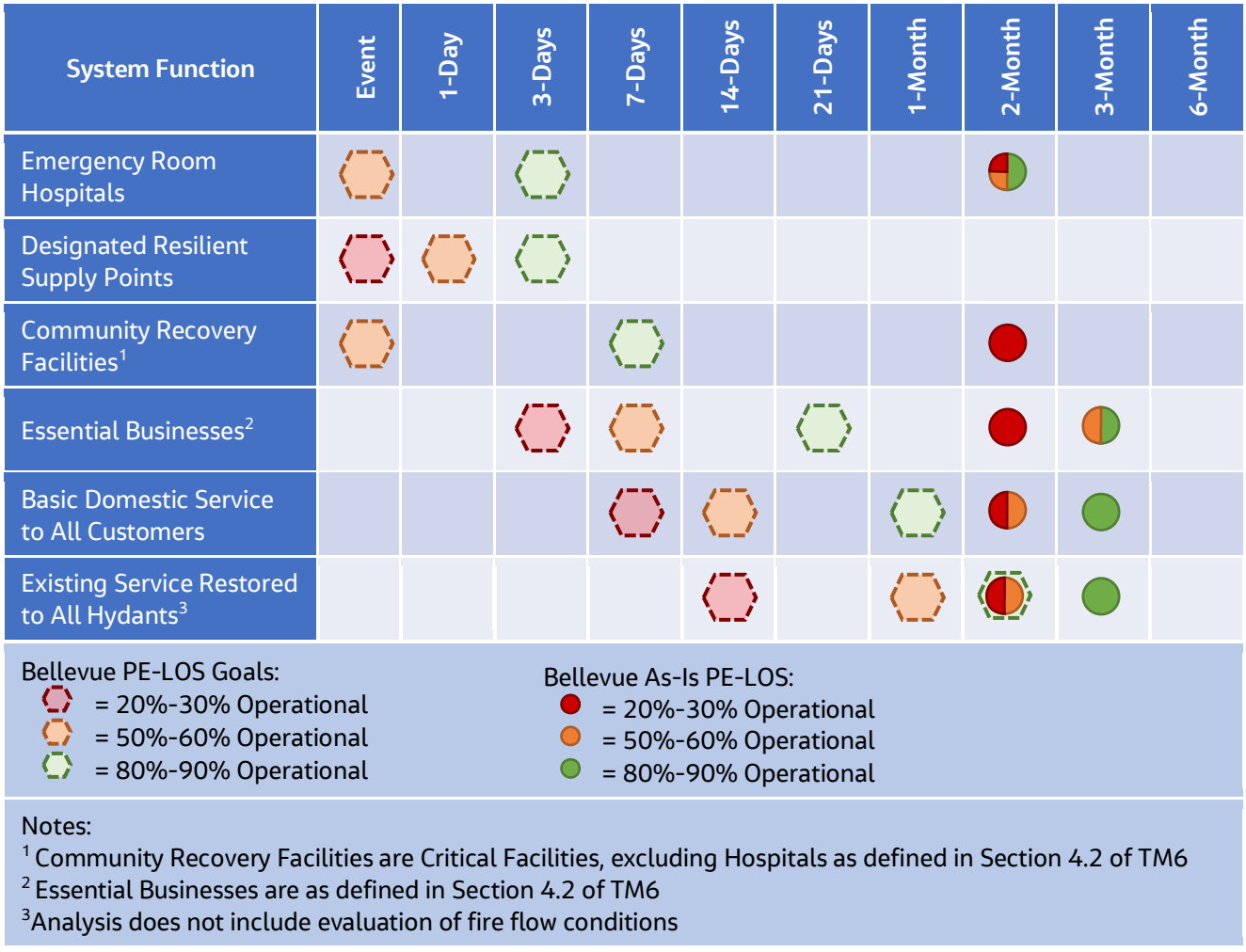


Post-Earthquake Level of Service Goals

Post-Earthquake Level of Service (PE-LOS) goals are used by water systems to define target levels of system seismic resilience and post event performance that should be expected following an earthquake. As-Is PE-LOS shows the amount of time that water supply service may be unavailable based on the state of the existing system infrastructure if no improvements are made. PE-LOS goals illustrate the outage durations that should be expected from a more resilient system after it has been seismically strengthened. SVA evaluations of the existing Bellevue water system indicate that water supply outage durations following a major seismic event are likely to extend well beyond acceptable timeframes. Based on an understanding of the existing system and a peer review of other municipal water system PE-LOS goals, incremental short-, mid-, and long-term PE-LOS goal targets were developed relative to various water user classifications. These goal targets can then be used to support development of appropriate and optimized system seismic resilience improvement priorities.

PE-LOS goals are structured to establish appropriate water service restoration time targets for different services and customer types. Figure 6 shows the target Long-Term PE-LOS goals developed for the Bellevue Water System as well as the expected outage durations in the as-is state of the system for the SFZE scenario as an example. The SFZE results in the longest restorations expected from the earthquake scenarios considered. For the CSZ and SFZE mid- and short-term goals, refer to TM 7: Post Earthquake-Level of Service Goals.

Figure 6: SFZE Long-Term Target PE-LOS Goals



Improvements Identified for Evaluation

Five categories of improvements were identified and specific alternatives in each category were developed to support improvements in water system seismic resilience, reduce potential water service outage durations, and accelerate likely water supply restoration times. The improvement categories included:

- Water Supply Resilience Improvements
- Resilient System Piping Backbone Corridors
- Seismic Improvements to Pump Stations
- Distribution Pipe Resilience Improvements
- Operational Adjustments and Improvements

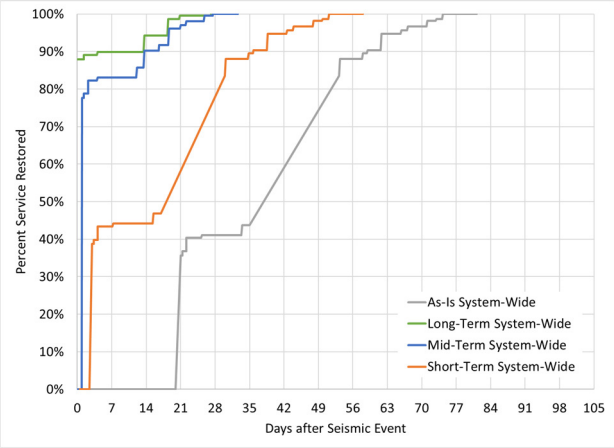
Improvement Selection and Prioritization

An optimized suite of seismic resilience improvements, structured to reduce water supply outage durations following earthquake events, were developed to improve water system resilience and improve system performance consistent with the target PE-LOS goals for each timeframe. The selection of the specific combinations of improvements is based on those that most efficiently and effectively meet the PE-LOS goal targets for more critical water supply customers (as summarized in Figure 6), and the overall system as whole, and provide favorable risk reduction benefits relative to the projected improvement costs involved.

The water supply outage duration and economic impact reductions that can be expected to result from recommended seismic resilience improvements at each implementation milestone are illustrated in Figure 7 through Figure 9**Error! Reference source not found.** (additional detail and comparative assessments of the various improvement combinations considered are detailed in TM9, included in the appendices). The selected improvement combinations provide improved system resilience and service recovery timelines to reduce predicted water system seismic economic impacts from as much as $8.3 billion for the existing system, down to $0.7 billion or less.

Figure 7: System-Wide Service Improvement with Selected Combinations

Cascadia Subduction Zone Mw 9.0



Seattle Fault Zone East Mw 6.6

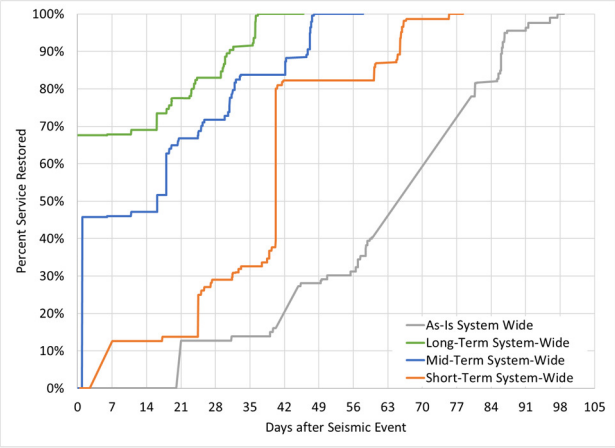
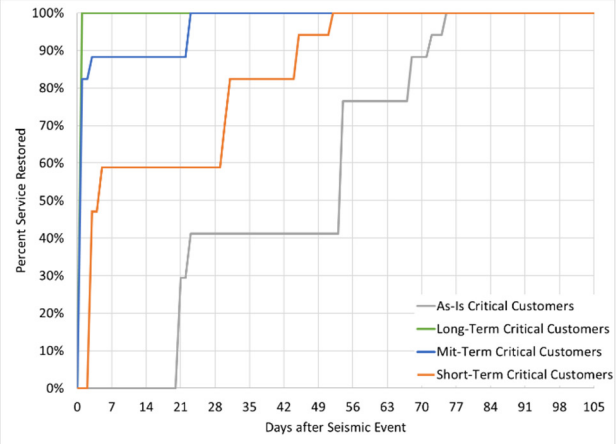


Figure 8: Critical Customer Service Improvement with Selected Combinations

Cascadia Subduction Zone Mw 9.0



Seattle Fault Zone East Mw 6.6

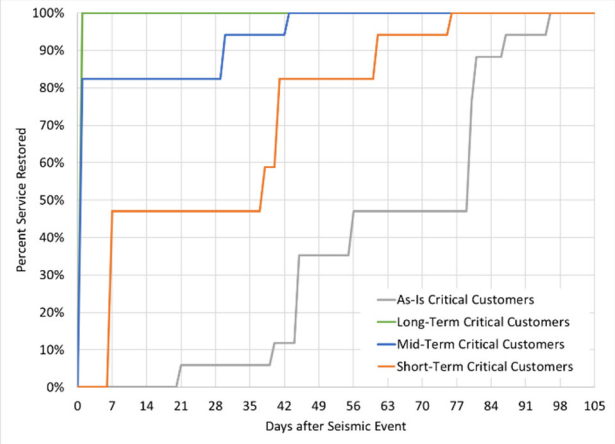
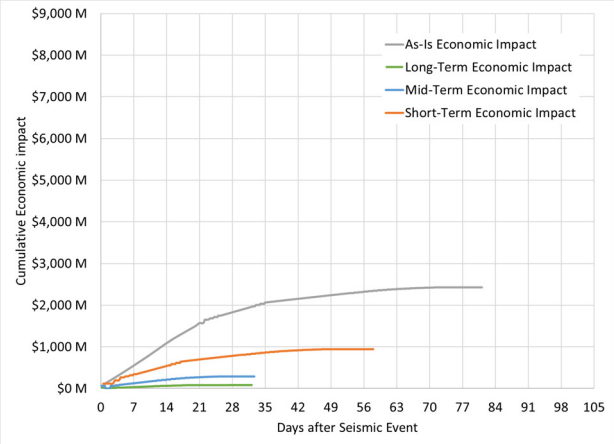


Figure 9: Economic Impact Improvement with Selected Combinations

Cascadia Subduction Zone Mw 9.0



Seattle Fault Zone East Mw 6.6

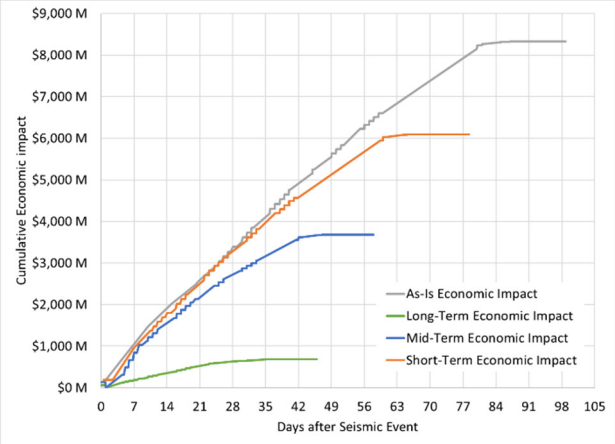


Figure 10 shows an overview of the improvements selected to achieve each of the short-, mid- and long-term PE-LOS goals.

Figure 10: Summary of recommended water system seismic resilience improvements

Water System Improvement Category	Short-Term (10-15 years)	Mid-Term (20-30 years)	Long-Term (40-50 years)
Water Supply	9 MGD of Emergency Wells	7-day SPU Supply Restoration	
Pump Station Facility Seismic Upgrades or Replacement	Clyde Hill Cougar Mountain 1 Cougar Mountain 2 Cougar Mountain 3 Horizon View 2 Parksite	Forest Hills Newport 670	Woodridge
Pressure Zone Distribution Pipe Strengthening		LH 520 FA 293	BV 400 SS 850 EG 330
Backbone System Piping Strengthening	Partial Backbone		Expanded Partial Backbone

The following summarizes the improvements for each of the three timeframes in more detail.

Short-term improvements

- Includes $55M of investment over the next 10 to 15 years, $28M of which is for previously planned pipe replacement of asbestos cement (AC) and cast iron (CI) pipe and facility upgrades
- Develops Bellevue emergency water supply wells to provide 9 million gallons per day (mgd) of emergency supply capacity
- Implements initial strengthened system piping and pump stations along key backbone corridors, using ductile iron (DI) pipe at a minimum, and earthquake resistant ductile iron pipe (ERDIP) in more vulnerable areas

Mid-term improvements

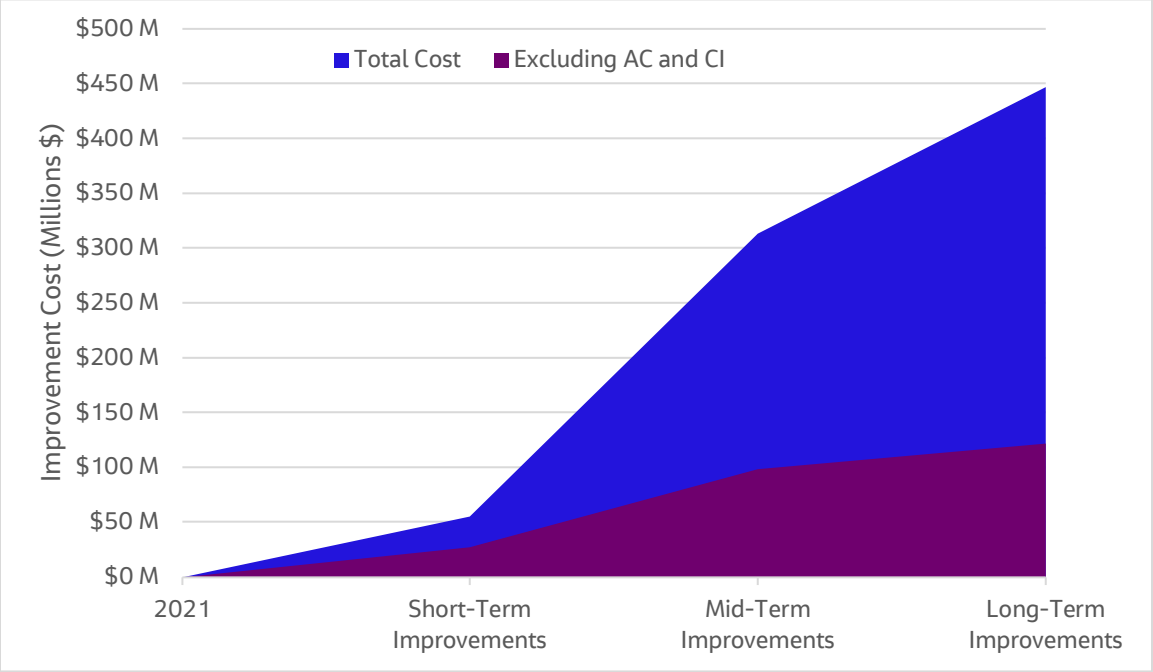
- Includes $258M of additional investment by year 2050, $187M of which is for replacement of asbestos cement (AC) and cast iron (CI) pipe already part of an ongoing replacement program
- Requires collaboration with Cascade Water Alliance and SPU to reduce regional water supply restoration times to 7-days or less for Bellevue and other eastside communities (It is recognized that this type of interagency coordination to improve water supply resilience will be challenging and require time to negotiate and implement. However, the analysis from the Bellevue SVA shows that this is a critical component to achieve a resilient water supply for Bellevue's customers. As such a target of 20 years has been assigned to accomplish this goal, with the assumption that coordination and negotiation to reach this goal will begin immediately.)
- Includes strengthening of all pipe in the Lake Hills 520 and Factoria 293 pressure zones by replacing seismically vulnerable water mains with DI pipe at a minimum, and with ERDIP in more seismically vulnerable areas.
- Includes upgrades to additional pump station facilities

Long-term improvements

- Includes $134M of additional investment by year 2070, $110M of which is for pipe replacement of asbestos cement (AC) and cast iron (CI) pipe already part of an ongoing replacement program
- Incorporates strengthening of pipes in the Bellevue 400, Somerset 850 and Eastgate 330 pressure zones, similar to other zones completed in the mid-term improvements
- Expands the initial backbone corridor system strengthened in the short-term improvements to several additional critical corridors and upgrades one additional pump station

Figure 11 shows the cumulative spending by improvement timeframe for total improvement cost and improvement costs without inclusion of asbestos cement and cast iron pipe.

Figure 11: Cumulative Spending by Improvement Timeframe



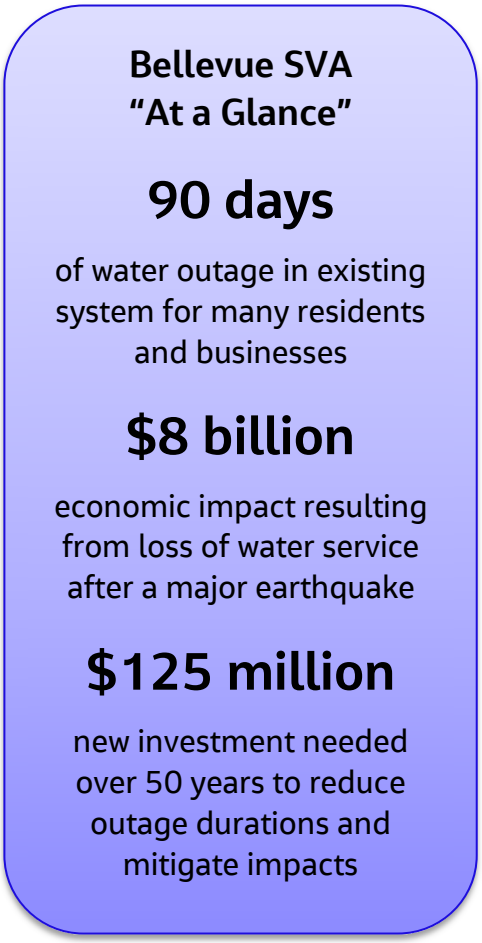
Summary and Recommendations

Based on SVA analysis, many of Bellevue's water customers are likely to experience service interruptions for up to 90 days following a major seismic event. These water supply interruptions can be expected to result in as much as $8.3 billion dollars of regional economic impact. Target Post-Earthquake Level of Service goals were defined, and improvements to achieve those goals identified, to reduce and mitigate these expected water supply outage durations and resulting economic impacts. Based on the results of the analysis, a suite of improvements are recommended to improve the seismic resiliency of water system infrastructure in a way that provides optimized reduction in seismic risks at the lowest overall cost, effectively meeting the proposed target PE-LOS goals.

The water system seismic resilience improvements identified include developing a 9 MGD emergency groundwater supply in Bellevue, navigating and working through collective regional water supply resilience issues with Cascade Water Alliance and Seattle Public Utilities to strengthen the regional eastside supply system, developing seismically resilient critical water supply backbone pipe routes, upgrading key system pump stations, and strengthening distribution system piping in 5 strategic pressure zones to reduce the total number of repairs required after an earthquake to allow system water supply service to be restored more quickly.

The proposed improvements are recommended to be completed in three phases over the course of the next 50 years, with a total cost of $450 million, of which $325 million is for replacing seismically vulnerable and end of useful life AC and CI pipe already part of an ongoing replacement program and implementing resilience improvements at water system infrastructure facilities already planned for replacement or upgrade. This results in a need for $125 million added investment over the next 50 years to achieve the recommended PE-LOS goals.

Figure 12: Bellevue SVA "at a Glance"



The proposed improvements provide economic risk reduction benefits 2.5 times greater than the cost of the associated system improvements, based on a 100-year life-cycle analysis. Adverse economic impacts stemming from seismically induced water service disruption can be expected to be reduced from $8.3 billion for the existing system condition down to just $700 million once the improvements are fully implemented.

SVA Project Technical Documentation (Appendices)

The following SVA Technical Memoranda provide additional detail to support the information provided in this executive summary.

TM1: Geotechnical Data Refinement
TM1A: Seismic Vulnerability Assessment Scenario Selection

Background and foundational information supporting the SVA effort, including details of the local/regional Bellevue seismic setting and relevant geotechnical conditions, are documented and summarized in the two initial project TMs. *TM1: Geotechnical Data Refinement*, characterizes the local/regional seismic settings and conditions, and the primary seismic risks facing Bellevue. *TM1A: Seismic Vulnerability Assessment Scenario Selection*, evaluates the spectrum of seismic scenarios and risks considered in TM1, and selects the key seismic scenarios to be explored in subsequent SVA evaluations. The result of the analysis documented in TM1 and TM1A include the geotechnical parameters used to support subsequent SVA analyses and the selection of the Cascadia Subduction Zone (CSZ) and Seattle Fault Zone East (SFZE) earthquake scenarios as the appropriate seismic events to consider throughout the SVA evaluations.

TM2: Seismic Analysis Methodology
TM2A: Comparison of ALA Equations to Christchurch Earthquake Repair Data

Approaches, methodologies, and parameters used throughout the SVA to characterize and assess potential Bellevue water system seismic risks, impacts, and resilience for the City of Bellevue water system are captured and documented in TM 2 and TM 2A. *TM2: Seismic Analysis Methodology* details the data and approaches used to characterize seismic risks to Bellevue water system assets and supply systems. *TM2A: Comparison of ALA Equations to Christchurch Earthquake Repair Data*, evaluates and leverages relevant supporting water system resilience data and studies from representative earthquake events to help inform pipeline and infrastructure seismic performance parameters for the Bellevue SVA effort.

TM3: Modeling Methodology

Approaches, system modeling, and evaluation methodologies and parameters used as part of the SVA to characterize, estimate, and assess potential Bellevue water system performance and service levels for the City of Bellevue water system are captured and documented in *TM3: Modeling Methodology*. This TM details computer modeling approaches used in the SVA to evaluate likely seismic impacts to the Bellevue water system and resulting system performance and service outage restoration times. These approaches provide a means to project potential seismic system, community, and economic impacts, and plan appropriate system resilience improvements that can cost effectively mitigate potential impacts and reduce risks.

TM4: Existing System Vulnerability and Customer Outage Probability

SVA modeling and evaluation results estimating the performance and service levels that can likely be expected from existing Bellevue water system pipe and facility infrastructure following a major CSZ or SFZE seismic event are described in *TM4: Existing System Vulnerability and Customer Outage Probability*. This TM describes the application of the modeling approaches described previously in TM3 and details projections of likely seismic damage to the existing water system under CSZ and SFZE scenarios in terms of the likelihood that different areas within the system may experience water supply interruptions after a major event, as well as how long it may take to restore water service to those areas.

TM5: Economic Impact Parameters

TM5: Economic Impact Parameters documents the methodologies used and economic impact parameters employed to estimate economic impacts that would occur following a major seismic event. The economic impact parameters considered evaluate four components that are combined to represent potential overall impacts to the local and regional economy resulting from potential loss of water service: impacts to residential customers and service, decreased economic activity, loss of life if hospitals and medical facilities are unable to operate effectively due to prolonged water service interruptions, and inability to deliver water to effectively support fire suppression activities.

TM6: As-Is Service Outage, Restoration Times, and Economic Impacts

The results of modeling the expected as-is performance of the existing water system and infrastructure, looking at the likely time to restore water supply to the system given specific repair and facility damage scenarios for each earthquake, and the corresponding economic impact to the community are described in *TM6: As-Is Service Outage, Restoration Times, and Economic Impacts*. This information forms the basis for estimating expected performance of the water system in its current state for comparison to customer expectations and seismic event recovery needs and sets expectations for future water system seismic resilience improvements.

TM7: Post-Earthquake Level of Service Goals

Post-Earthquake Level of Service (PE-LOS) goals are developed and compared against as-is performance and service levels that can be expected from the existing water system to identify and aid in the development of performance measure targets for water system seismic resilience improvements. The PE-LOS goals consider likely water supply quality, quantities, expected water supply outage durations, and critical locations where water service restoration needs to be prioritized following a major seismic event. The development of target PE-LOS goals and comparison against expected as-is performance from the existing water system is summarized in *TM7: Post-Earthquake Level of Service Goals.*

TM8: Improvement Alternatives

Improvement alternatives for the Bellevue water system to improve water system seismic resilience in order to achieve target PE-LOS goals are identified, categorized, and developed in *TM8: Improvement Alternatives.* The TM describes development of associated improvement costs, potential resulting benefits, and rationale for assessment of water system resilience improvements are detailed to support subsequent identification of optimized groups of improvements that can effectively mitigate likely seismic event economic impacts and cost effectively deliver on related PE-LOS goals.

TM9: Improvement Prioritization

Evaluation and prioritization of various potential combinations of improvements are defined in *TM9: Improvement Prioritization*. This evaluation incorporates a stepwise process that looked at effective combinations of short-, mid-, and long-term resilience improvements that support phased implementation and prioritize addressing the most critical system performance deficiencies. The analysis includes evaluating combinations of improvements that meet the target PE-LOS goals established for short-, mid-, and long-term timeframes. The selected improvements incrementally improve system resilience by sequencing a progression of improvements to achieve target PE-LOS goals and provide the highest benefit/cost ratios by providing the greatest reduction in economic seismic impacts at the lowest overall cost.

Appendix A. Geotechnical Data Refinement and Seismic Vulnerability Assessment Scenario Selection

A.1 TM1: Geotechnical Data Refinement

A.2 TM1A: Seismic Vulnerability Assessment Scenario Selection

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Technical Memorandum

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Subject	**FINAL DRAFT - TM 1: Geotechnical Data Refinement**
Project Name	Bellevue Water System Seismic Vulnerability Assessment
Attention	Doug Lane, City of Bellevue
From	Jacobs Shannon & Wilson
Date	June 3rd, 2019

1. Introduction

The City of Bellevue Water System Seismic Vulnerability Assessment (SVA) will incorporate vulnerabilities of Bellevue water system pipelines and facilities into a comprehensive modeling analysis to predict the performance of the water system in seismic events and develop restoration expectations and mitigation alternatives. This Technical Memorandum summarizes the earthquake scenarios considered for the vulnerability assessment, the associated ground shaking level (ground motion) within the service area, permanent ground displacements related to potential fault rupture, and liquefaction and landslides induced by the scenario ground motions that will be used in this analysis.

TM 1A: Seismic Scenario Selection describes the selection of the scenarios developed under the work described in this TM that will be used for the remainder of the analysis.

TM 2: Seismic Vulnerability Assessment Methodology describes how this geotechnical information will be applied to determine the vulnerability of the Bellevue water system.

2. Scenario Earthquake Ground Motions

Scenario earthquakes were used to assess the seismic vulnerability of the Bellevue water system resulting from earthquake-induced transient and permanent ground displacements. The scenarios represent earthquake sources that could realistically affect the Bellevue water system. Each scenario has a different likelihood of occurrence and therefore presents a different level of risk to the Bellevue water system. For each scenario earthquake estimates of peak ground acceleration (PGA), peak ground velocity (PGV), and permanent ground displacement (PGD) were made for use in evaluating the seismic vulnerability of the Bellevue water system. This section briefly describes the regional earthquake sources and seismicity, the selected earthquake scenarios, and development of ground motion maps for the corresponding scenario PGA, PGV, PGD estimates.

2.1 Regional Seismological Setting

The Bellevue water system is located in the Puget Sound Lowland, an active tectonic region subjected to occasional strong earthquakes during the brief 170-year historical record. The regional tectonics and seismicity are the result of northeastward subduction of the Juan de Fuca Plate beneath the North American Plate along the Cascadia Subduction Zone (CSZ). The subduction results in east-west compression, dextral shear, clockwise rotation, and north-south compression of the leading edge of the North American Plate (Wells and others, 1998; Wells and Simpson, 2001). Within this regional tectonic framework, three seismogenic sources are identified.

- CSZ deep subcrustal zone (intraslab) in the subducted Juan de Fuca Plate.
- CSZ mega-thrust zone at the interface between the North American and Juan de Fuca plates.
- Shallow crustal zone within the North American Plate.

2.2 Intraslab Earthquakes

CSZ intraslab earthquakes occur in the subducted Juan de Fuca Plate at depths of about 40 to 60 kilometers (km). The Bellevue water system is situated above this zone. These earthquakes are associated with down-dip tension forces in the subducted plate due to density changes in the plate at depth.

The largest recorded intraslab earthquakes to affect the site include the surface-wave magnitude (M_S) 7.1 Olympia earthquake of April 13, 1949; the body-wave magnitude (M_b) 6.5 Seattle-Tacoma earthquake of April 29, 1965; and the February 28, 2001, moment magnitude (M_W) 6.8 Nisqually earthquake. The United States Geologic Survey (USGS) estimates the maximum moment magnitude from CSZ intraslab earthquake to be about M_W 7.5.

While these magnitudes are relatively large, the depth of the event results in only moderate ground motions. Levels of ground shaking from these intraslab events in Bellevue can range from less than 0.1 g (standard gravitational acceleration) to more than 0.5 g, depending on the location of the seismic event and the types of soils at the site For reference, accelerations of 0.1 to 0.3 g were measured in the 2001 Nisqually Earthquake, while accelerations of 0.5 to 0.8 g were common in the 2004 Northridge and 2005 Kobe earthquakes. The duration of shaking would likely be less than a minute. This category of earthquake controlled the regional building code until the 1980s.

2.3 Interface Earthquakes

CSZ mega-thrust earthquakes (greater than M_W 8.0) occur at the interface between the subducting Juan de Fuca and North American Plates. The most recent rupture occurred in roughly anno domini (AD) 1700 (Satake and others, 1996; Atwater and Hemphill-Haley, 1997; Clague, 1997; Yamaguchi and others, 1997; Goldfinger and others, 2003 and 2012). Paleo-seismic evidence indicates that ruptures have occurred at irregular time intervals ranging from about 100 to more than 1,200 years with an average recurrence interval of about 500 years (Atwater and Hemphill-Haley, 1997; Clague, 1997; Goldfinger and others, 2003 and 2012). Because of the significant uncertainty pertaining to the easterly extent of a potential rupture surface, estimates of the closest distance between the Bellevue water system and a potential rupture surface range from about 50 to 100 km horizontally at depths on the order of 20 to 35 km.

The moment magnitude (M_W) of the interface event can range from less than 8 to greater than 9, depending on the length and width of rupture. The rupture length of a M_W 9 event may extend from mid-Vancouver Island in British Columbia to Eureka, California. Typical ground accelerations in Bellevue might range from less than 0.1 to 0.3 g; the duration of shaking could be several minutes. These ground motions could occur even during smaller M_W events (e.g., 8 to 8.5) if the northern half of the CSZ were to rupture.

2.4 Crustal Earthquakes

Shallow crustal earthquakes within the North American Plate beneath western Washington have historically occurred within 20 km of the earth's surface, and with the exception of those associated with active volcanoes, typically occur in a diffuse pattern. However, crustal faults with evidence of pre-historic Holocene rupture (within 10,000 years) (e.g., Seattle Fault) have been identified beneath the Puget Sound Lowland to be capable of producing earthquakes with magnitudes on the order of M_W 7 to 7.5. The largest historic event is the 1872 North Cascades earthquake (estimated magnitude about 6.8 in the vicinity of Lake Chelan). Levels of ground shaking from the crustal events in Bellevue can be very high –

with levels of ground shaking ranging from less than 0.1 g to 0.7 g or higher. Durations of strong ground shaking could exceed a minute.

The most relevant active fault for the Bellevue water system seismic vulnerability study is the Seattle Fault Zone (SFZ). The SFZ is an east-west trending, south-dipping, largely concealed thrust fault that crosses the central Puget Sound near the latitude of Seattle and forms the northern structural boundary of the Seattle Uplift (Brocher and others, 2001 and 2004). The SFZ is a 4 to 7 km wide zone of active deformation that separates uplifted bedrock to the south from thick sequences of sediment that fill the Seattle Basin to the north (Blakely and others, 2002). The SFZ cuts east-west through the Bellevue water system with the northern edge along Interstate 90 (I-90); the hills on the south of I-90 are bedrock uplifts on the south side of the fault zone's leading edge.

At the ground surface, the SFZ deformation zone is defined by fault scarps and warped shorelines (e.g., Nelson and others, 2003; Haugerud, 2003; Kelsey and others, 2008). These shorelines were uplifted as much as 8 meters (m) during a single large event about 1,000 years ago (AD 900 to 930) (Bucknam and others, 1992; Atwater, 1999; Kelsey and others, 2008). On the western end of the fault zone (west of Puget Sound) Light Detection and Ranging (LiDAR)-identified fault scarps mark where several short north-dipping reverse faults have ruptured to the ground surface in the hanging wall of the south-dipping master fault (Nelson and others, 2003; Kelsey and others, 2008; Nelson and others, 2014).

Trench excavations and shoreline studies across these north-dipping faults indicate that: (a) they ruptured at least three times during the past 2,500 years (including during the AD 900 to 930 event) producing moderate-sized earthquakes (Nelson and others, 2003; Kelsey and others, 2008; Nelson and others, 2014), and (b) their rupture areas were small compared to the master fault rupture area during the AD 900 to 930 earthquake (Kelsey and others, 2008). Kelsey and others (2008) concluded that these shallower north-dipping faults may slip during large events along the master thrust or during moderate earthquakes (about M_W 6.5) independent of slip on the deeper master thrust.

In contrast, land-level-change studies of the uplifted shorelines suggest the master thrust likely ruptured only twice during the past 10,000 years: most recently during the AD 900 to 930 earthquake and previously, about 6,000 years before that (Bucknam and others, 1992; Sherrod, 2001).

3. Earthquake Scenarios

Within the framework of the regional seismological setting, four (4) potential earthquake scenarios were considered for use in the vulnerability assessment, one CSZ interface event and three SFZ events of various size and locations. The scenarios are listed in the Table 1. The CSZ intraslab source was not considered in the four scenarios because: (a) the ground shaking intensity is about the same or lower than the other potential scenarios, and (b) the large uncertainty in assigning a recurrence interval and specific location in the source zone (i.e., the source zone covers thousands of square km, and the location of faults within the source zone have not been mapped as it is 50 to 100 km below the ground surface).

Table 1: Considered Earthquake Scenarios

Scenario	*Magnitude*	*Distance from the Bellevue water system (km)*	*Ground Motion Data Source*	*Holocene Paleo-Seismicity*	*Earthquake Recurrence Interval (years)*
CSZ *(Cascadia Subduction Zone Interface)*	9	~120	Modified from USGS M9 project	Yes	~500
SFZ Full *(Seattle Fault Zone Full Rupture)*	7.2	0	USGS	Yes	~6,000
SFZ West *(Seattle Fault West Side Partial Rupture)*	6.6	18	This Project	Yes	~800
SFZ East *(Seattle Fault East Side Partial Rupture)*	6.6	0	This Project	?	~800

For each scenario Table 1 shows the magnitude, distance from the Bellevue water system, the data source for the mapped ground motions (ground motion data), whether-or-not there is geologic evidence this scenario has actually occurred in the last 10,000 years (Holocene paleo-seismicity), and an estimate of the typical time between events (earthquake recurrence interval). Additional descriptions of these scenarios, including the data source used for each event, are discussed below.

3.1 CSZ Interface

The CSZ scenario is a M_W 9 interface event that ruptures the entire subduction zone, from northern California to southern British Columbia. Because the best estimate of the rupture area extent is approximately 120 km from the Bellevue water system, the ground shaking levels are relatively moderate when compared to the nearer SFZ scenarios. However, the duration of shaking of a CSZ Interface event will be much longer (on the order of minutes) than the crustal SFZ scenarios.

3.2 SFZ

Three scenarios considered for the SFZ. An earthquake on a fault does not necessarily rupture the entire width and length of the fault, e.g., a fault may rupture in its entirety in one large earthquake or in smaller sections over time, resulting in a series of smaller earthquakes. Consequently, the three SFZ scenarios are based on the rupture surface size (length and width) and the location of the potential rupture surface along the fault: (a) full rupture of the entire fault, (b) west side partial rupture, (e) east side partial rupture

The SFZ Full rupture scenario represents complete rupture on the large master fault. Based on the paleo-seismic studies, such full rupture earthquakes have a recurrence interval of approximately 6,000 years. For reference, building codes are based on shorter, 2,500-year return period ground motions. This long recurrence interval makes the likelihood of ground motions from this scenario relatively low compared to the other scenarios.

The SFZ West side partial rupture scenario represents an earthquake with a smaller, partial rupture of the SFZ on the west side of the Puget Sound, where the paleo-seismic studies have found evidence of these partial ruptures. These paleo-seismic studies indicate that SFZ earthquakes with west side partial rupture

have a recurrence interval of approximately 800 years. The distance from the source will result in lower levels of ground shaking; however, the likelihood of occurrence is higher than the full rupture.

The SFZ East side partial rupture scenario also represents an earthquake with a smaller, partial rupture of the SFZ but centered where the SFZ crosses the Bellevue water system. Because this scenario ruptures through the Bellevue water system it poses a significant hazard to the system. The assumption recommended for this vulnerability study is that the SFZ East scenario has the same recurrence interval as the SFZ West scenario (i.e., approximately 800 years). However, at present there are no paleo-seismic studies that have identified a partial east side rupture of the SFZ (the limited paleo-seismic studies in the Bellevue area have only identified events that likely ruptured the entire fault). Therefore, considering the lack of the paleo-seismic evidence to confirm or refute occurrence of a partial east side rupture of the SFZ, a 50 percent chance of occurrence is assumed for the SFZ East scenario. This will result in a likelihood of 1/800 x 0.5 = 0.000625 to be used in the risk calculation for the partial SFZ East scenario consequences.

4. Scenario Ground Motions

The earthquake ground motion parameters required to evaluate performance of the Bellevue water system for each earthquake rupture scenario include:

- Peak Ground Acceleration (PGA) used for facility assessment (units of standard gravitational acceleration, g)
- Peak Ground Velocity (PGV) used to assess wave propagation effects on pipe (units of cm/second)
- Permanent Ground Displacement (PGD) used to assess fault rupture and liquefaction effects on pipe (units in inches and feet)

PGA and PGV values were available in the literature or could be derived from published sources for the CSZ and SFZ Full rupture scenarios. Published SFZ East and West scenarios were not available in the literature and were therefore calculated specifically for this study. The following discussions provides a description of published ground motions, modifications, and how ground motions were developed specifically for this project where no ground motions previously existed. Scenario PGA and PGV maps are provided in Attachment A.

4.1 SFZ East and West Side Partial Rupture Scenarios

Ground motions were developed for the Bellevue water system on an approximately 200 m grid spacing. For each grid location the parameters required to calculate the SFZ West and East scenarios include:

- Fault parameters (i.e., rupture type, area and magnitude)
- Distance between the fault and the grid point
- Ground motion prediction equations (GMPEs) that use the above parameters and Site Class to estimate the ground motion
- Site Class information that accounts for local soil or rock conditions

For both the SFZ East and West scenarios, a M_W 6.6 and a corresponding fault rupture area were assumed. The rupture area dimensions had a length and aspect ratio (rupture length to width) of approximately 26 km and 1.2, respectively. The partial ruptures used the same 71-km long northernmost-strand of the SFZ, as used in the USGS 2014 National Seismic Hazard Mapping Project (NSHMP) (Petersen and others, 2014) source model. For the SFZ West scenario, the fault rupture area was assumed to be located west of the Puget Sound. For the SFZ East scenario, the fault rupture area was assumed to be centered in the Bellevue water system between Lake Sammamish and Lake Washington. These scenario fault rupture areas were used as the basis for determining the distance between the fault and a given site.

The median (50th percentile) deterministic ground motions for SFZ West and East scenarios were calculated using the same GMPEs as used to calculate shallow crustal ground motion in the 2014 USGS NSHMP model:

- Abrahamson and others (2014) (ASK14);
- Boore and others (2014) (BSSA14);
- Campbell and Bozorgnia (2014) (CB14);
- Chiou and Youngs (2014) (CY14); and
- Idriss (2014) (I14).

The 50th percentile ground motions represent average earthquake ground motions for the defined event, that would produce average damage estimates. In any given location, larger or smaller ground motions could occur.

In accordance with the 2014 USGS NSHMP model, the first four GMPEs above were weighted equally, but the I14 relationship was given a half of the weight for each of the other crustal GMPEs (i.e., I14 weighted 0.12 and each of the other GMPEs weighted 0.22). I14 was given a lower weight because it has less details in predicting the spectral values than the four other crustal GMPEs.

The soil or rock conditions across the Bellevue water system were characterized using National Earthquake Hazards Reduction Program (NEHRP) Site Classes obtained from Washington State Department of Natural Resources (WDNR) (i.e., www.dnr.wa.gov) Geologic Information Portal. Site Class is determined primarily by the time-weighted average of the shear wave velocity of the soil and/or rock within 30 meters (approximately 100 feet) of the ground surface (V_{S30}). All of the NGA-West2 ground motion models incorporates V_{S30} as a shallow site-response parameter. The V_{S30} corresponding to each Site Class definition used in the GMPEs is given in Table 2.

TABLE 2: V_{S30} Used for NEHRP Site Classes

NEHRP Site Class	*V_{S30} (m/sec)*
B	1,150
BC	760
C	537
CD	360
D	259
DE	180
E	150

m/sec = meters per second

PGA and PGV values were calculated for a grid with longitude and latitude increment of 0.0025 and 0.0015 degrees, respectively (less than 200 m grid spacing). The ground motions were calculated using the GMPE's reference values of $Z_{1.0}$ and $Z_{2.5}$ (depth to shear wave velocity of 1.0 and 2.5 kilometers per second (km/s), respectively), and then the site-specific basin effects factor from CB14 were applied to the ground motion values.

4.2 SFZ Full Rupture Scenario

The SFZ Full rupture scenario PGA and PGV data were directly obtained from the USGS Shake Map with a M_W 7.2 earthquake on SFZ northern strand.

https://earthquake.usgs.gov/scenarios/eventpage/bssc2014570n_m7p23_se#shakemap

The northern strand runs through the southern part of Bellevue. Strands that are located farther to the south beyond the Bellevue city limits were not evaluated in this project.

4.3 CSZ Interface Scenario

The PGA and spectral value at period (T) of 1.0 second (S_1) data were obtained from the USGS M9 project (Frankel and others [2018] and Wirth and others [2018]). The USGS data are the result of 30 simulated ruptures on CSZ interface considering variations in several of the ground motion parameters and a 3-dimensional shear wave velocity model on 1 km spacing grid in Puget Lowland area. The USGS provided the average of these simulated values for only sites with V_{S30} of 600 m/sec.

The PGA and S_1 site factors for the Bellevue water system were calculated from Abrahamson and others (2018) GMPE, and the USGS provided data were adjusted to include the appropriate site amplification. The PGV values were estimated from S_1 adjusted for soil condition using the methodology provided by American Lifelines Alliance (2005) guidelines.

5. Scenario Fault Rupture Ground Displacements

Ground surface fault displacements in the Bellevue water system were estimated for the SFZ East and SFZ Full scenarios using the methods in Wells and Coppersmith (1994). Table 3 presents estimates of the rupture displacement (expected permanent ground displacement) on the SFZ fault plane. The ground displacements in Table 3 are for both combined horizontal and vertical components of the rupture.

Table 3: Ground Rupture Displacement

	Average Ground Displacement (inches)			
Scenario	16th Percentile	Median	84th Percentile	Expected Maximum Ground Displacement (inches)
SFZ East (M_W 6.6)	15	27	48	39
SFZ Full (M_W 7.2)	27	51	93	99

These ground surface rupture displacements could occur on any one or multiple mapped or as-of-yet unmapped fault locations along the SFZ where it passes through the Bellevue water system. For the purposes of analyzing ground surface rupture associated with these scenarios, the estimated ground surface rupture was assumed to occur anywhere within the zone highlighted in Figure 1.

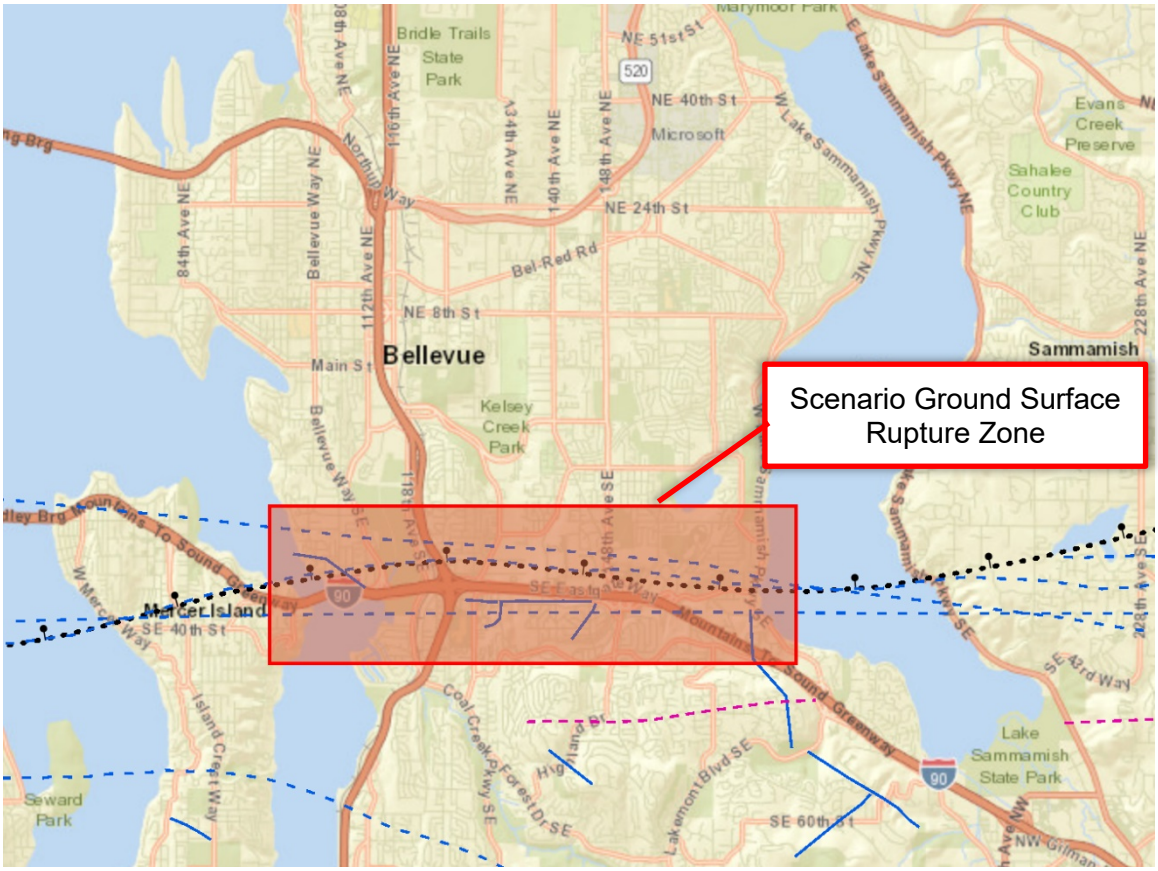

Figure 1: Surface fault rupture zone for SFZ full and east side scenarios

6. Liquefaction and Landslide Permanent Ground Displacements

This section summarizes the methodology followed to estimate permanent ground displacements within the boundaries of the Bellevue water system associated with liquefaction and slope instabilities. Based on a careful inspection among the four scenarios of the amplitude of predicted ground motions (e.g., SFZ West scenario ground motions are relatively low compared to the other scenarios) and associated recurrence intervals (e.g., SFZ Full recurrence interval is very long), the CSZ and the SFZ East scenarios were identified as the two main scenarios to be considered for the further seismic vulnerability analysis. Both the liquefaction- and seismic slope instability-induced permanent ground deformations were predicted for CSZ and the SFZ East scenarios.

6.1 Liquefaction Induced Permanent Ground Displacements

The liquefaction-induced permanent displacement throughout Bellevue's water system was estimated using the following information:

- PGA mapping for each scenario earthquake
- Magnitude associated with each scenario earthquake
- Local soil/rock conditions
- Sloping ground conditions and/or distance from a free face of a lake, stream, or river.

Approximate permanent ground deformations due to liquefaction-induced lateral spreading in areas designated as low-moderate, moderate, or moderate-high liquefaction susceptibility by WDNR were estimated in accordance with the predictions using simplified empirical methods developed by Youd and

others (2002) and Kramer and Baska (2007). Note that published liquefaction hazard potential maps for the City of Bellevue appear to be similar to the WDNR liquefaction maps used in this study.

The liquefaction-induced permanent ground deformation maps are provided in Attachment B. These maps were developed to indicate three main zones with predicted maximum permanent ground deformations: (1) less than 6 inches (in), (2) between 6 in and 12 in, and (3) over 12 in.

It should be noted these maps were developed from generalized information and are appropriate only for planning level vulnerability studies. If a critical location is identified within the Bellevue water system, site-specific liquefaction hazard analysis should be performed at the location to establish a more accurate estimate of expected liquefaction-induced permanent ground motion.

6.2 Seismic Slope Instability Induced Permanent Ground Displacements

The potential for permanent displacement throughout the Bellevue water system from seismic slope instabilities was estimated using the following information:

- PGA mapping for each scenario earthquake
- Magnitude and approximate epicentral distance associated with each scenario earthquake
- Local soil/rock conditions
- Sloping ground conditions

The available terrain and steep slope maps from the City of Bellevue and the WDNR were used in combination with simplified empirical predictive method of Bray and Travasarou (2007) to predict approximate permanent ground deformations within the Bellevue water system. Similar to liquefaction-induced permanent ground displacements, seismic slope instability-induced permanent ground displacements were predicted without any site-specific subsurface data. Attachment C provides seismic slope instability-induced permanent ground motions maps for both the CSZ and SFZ East scenarios. These maps were developed to indicate three main zones with the following predicted maximum permanent ground deformations: (1) less than 6 in, (2) between 6 in and 12 in, and (3) over 12 in.

These evaluations were appropriate for an area wide water system vulnerability study but should not be used to make site-specific assessments. Detailed information about geotechnical conditions at the site, including groundwater locations, will determine the potential for and magnitude of ground displacements. Geotechnical explorations and laboratory testing are required to make these assessments.

6.3 Use of Permanent Ground Deformation Data in Vulnerability Analysis

The liquefaction induced lateral spreading and seismic slope displacements along the Bellevue water system is provided in ranges. The associated ground displacements should be implemented into the vulnerability analysis using a normal distribution with parameters summarized in Table 4.

Table 4: Lateral spreading and slope displacement parameters to be used in vulnerability study

Displacement, d (in)	*Mean (in)*	*Standard Deviation (in)*
0 < d < 6	3	2
6 ≤ d < 12	9	3
d ≥ 12	18	6

7. Summary

This TM summarized the earthquake scenarios considered for the Bellevue water systems vulnerability assessment, the associated ground shaking level (ground motion) within the service area, permanent ground displacements related to potential fault rupture, and liquefaction and landslides induced permanent ground displacements due the scenario ground motions.

Ground motion maps were developed for four earthquake scenarios: CSZ, SFZ Full, SFZ West, and SFZ East. Fault rupture based permanent ground displacement estimates were developed for SFZ Full and SFZ East scenarios. Liquefaction and seismic landslide induced permanent ground displacement maps were developed for CSZ and SFZ East Scenarios.

This geotechnical information will be incorporated into the seismic vulnerability study performed to predict the performance of the water system in seismic scenario events and develop restoration expectations and mitigation alternatives.

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Attachment A

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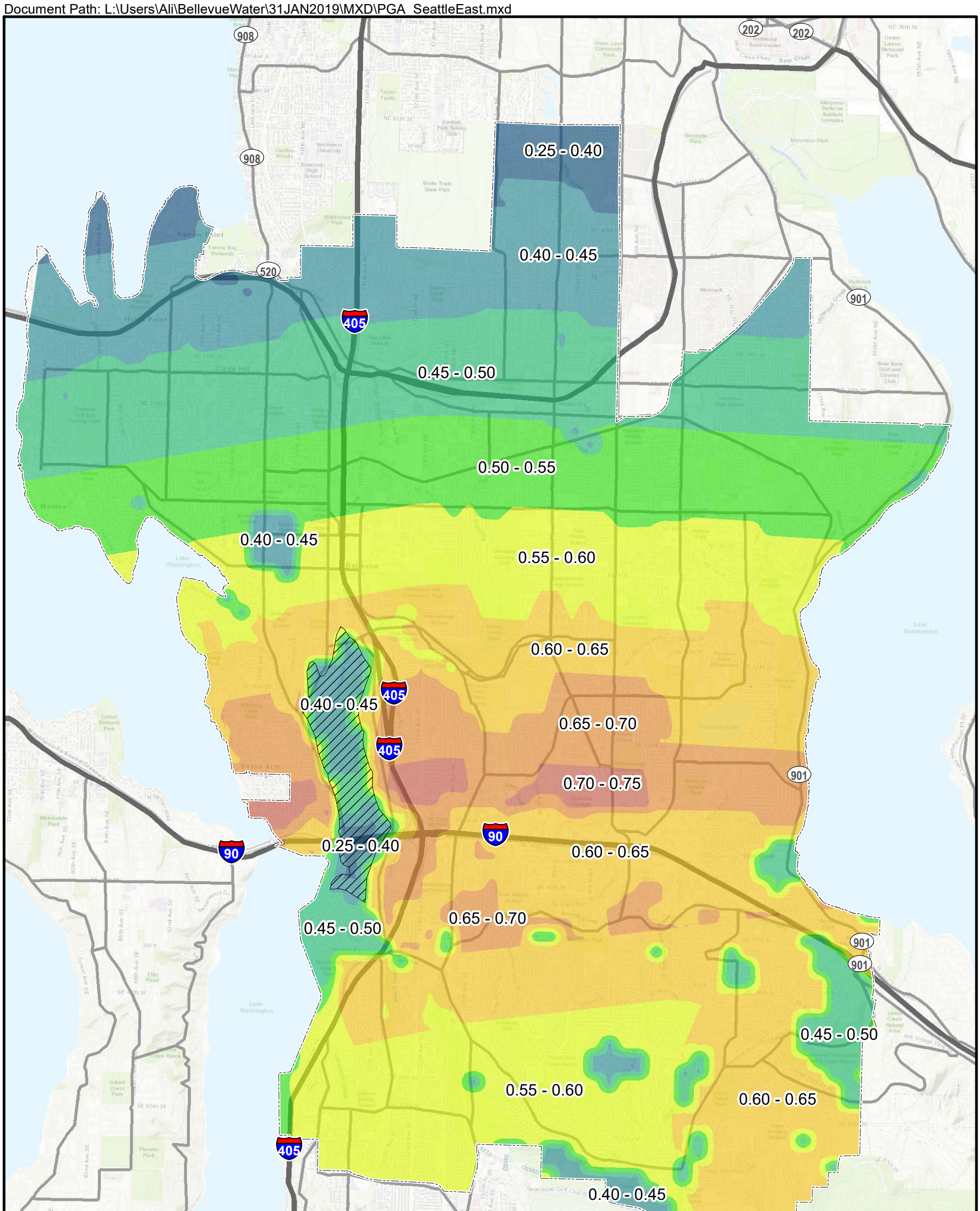

NOTES

1. Mw = Moment Magnitude
2. A site-specific response analysis is required for Site Class F conditions. The Site Class E values were provided as a rough estimate for Site Class F conditions.
3. PGA = Peak Ground Acceleration (g)

LEGEND

Service Area

Seismic Site Class Code 'F'

PGA = Peak Ground Acceleration (g)

0.08 - 0.10	0.10 - 0.15	0.15 - 0.20	0.20 - 0.25	0.25 - 0.40	0.40 - 0.45	0.45 - 0.50	0.50 - 0.55	0.55 - 0.60	0.60 - 0.65	0.65 - 0.70	0.70 - 0.75

Bellevue Water Distribution System
Seismic Vulnerability Assessment
Bellevue, Washington

SEATTLE FAULT (PGA)
Mw 6.6 SFZ EAST SCENARIO

January 2019 102185-001

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FIG. 1

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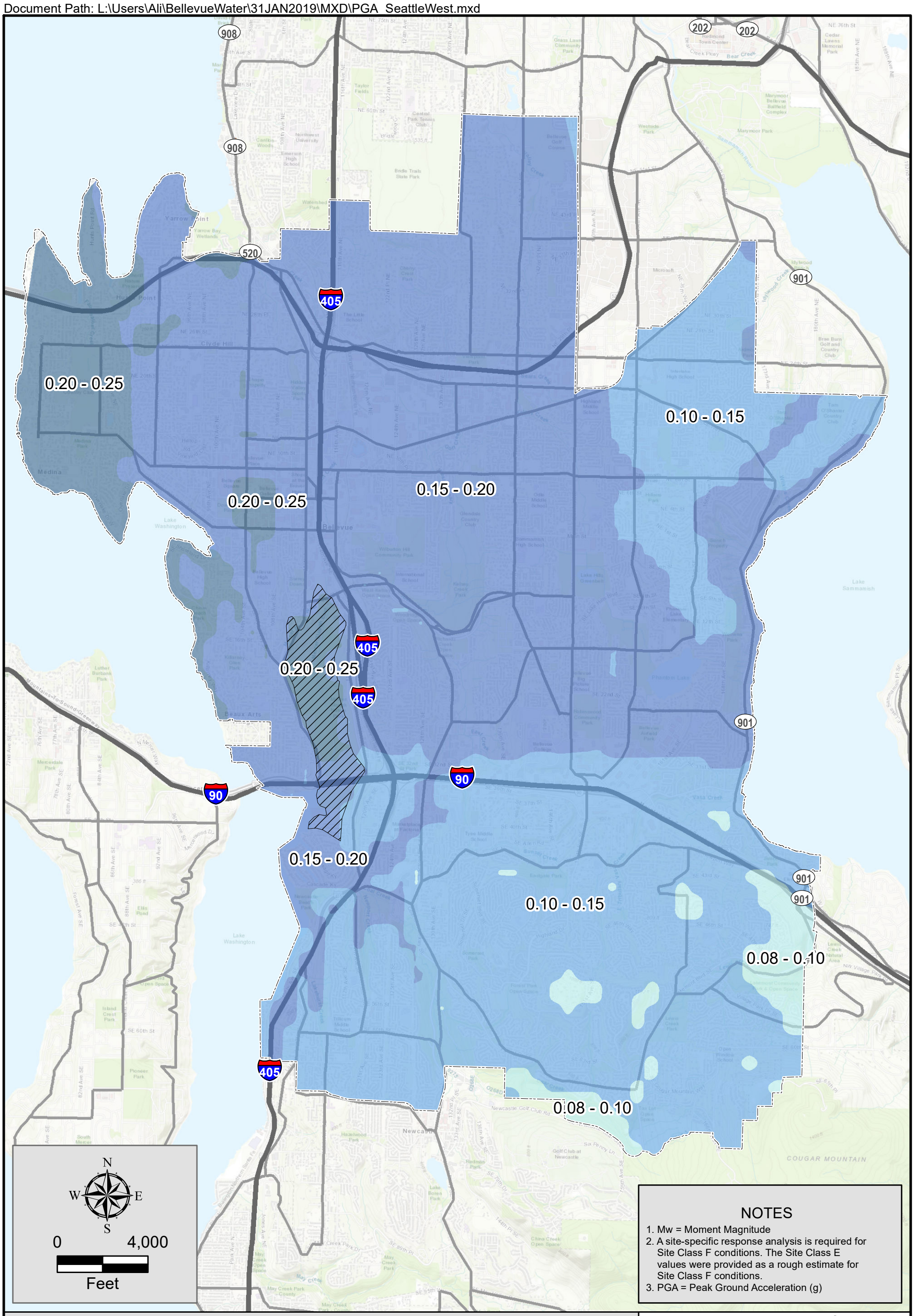

NOTES

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3. PGA = Peak Ground Acceleration (g)

LEGEND

Service Area

Seismic Site Class Code 'F'

PGA = Peak Ground Acceleration (g)

0.08 - 0.10	0.10 - 0.15	0.15 - 0.20	0.20 - 0.25	0.25 - 0.40	0.40 - 0.45	0.45 - 0.50	0.50 - 0.55	0.55 - 0.60	0.60 - 0.65	0.65 - 0.70	0.70 - 0.75

Bellevue Water Distribution System
Seismic Vulnerability Assessment
Bellevue, Washington

SEATTLE FAULT (PGA)
Mw 6.6 SFZ WEST SCENARIO

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FIG. 2

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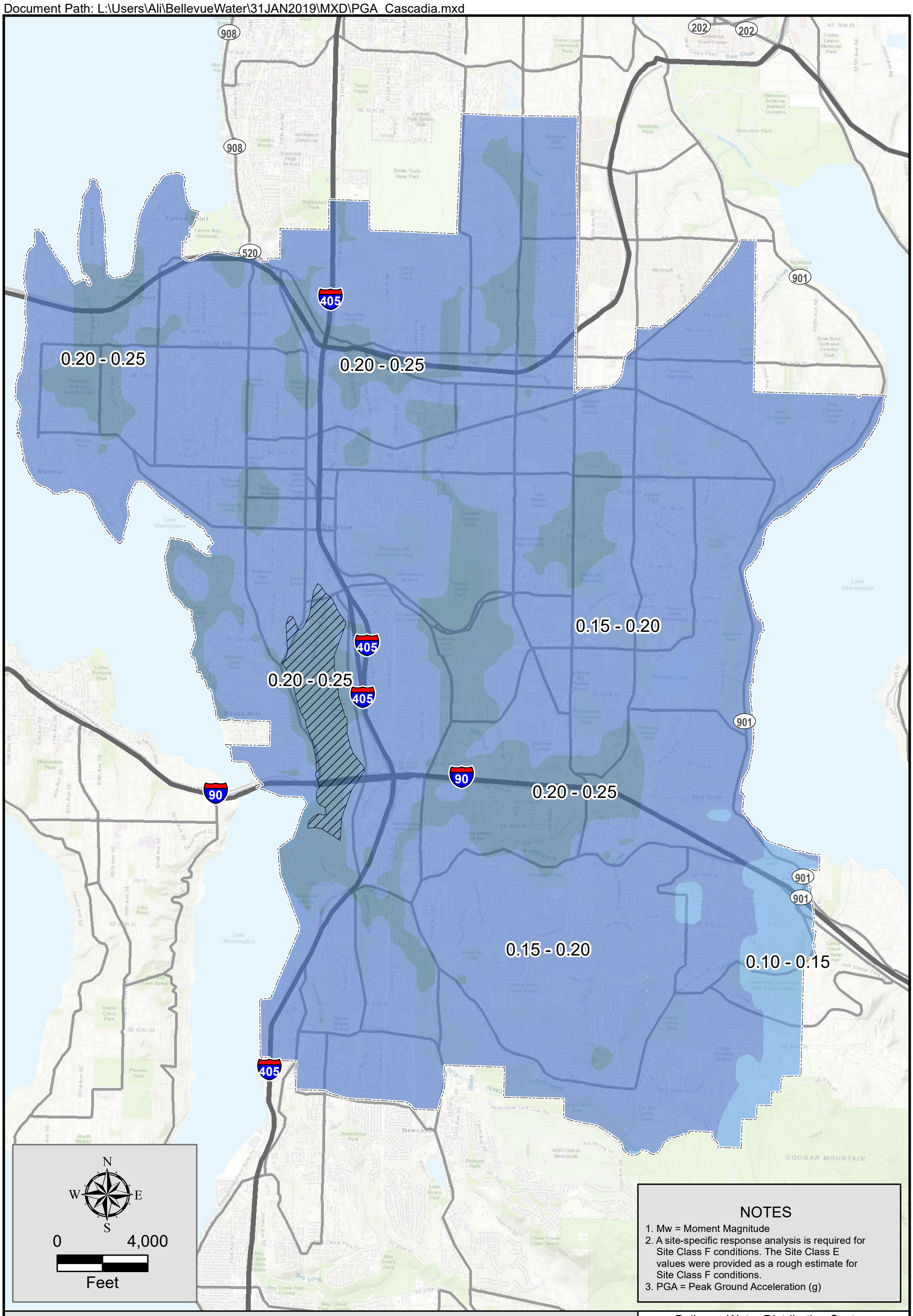

NOTES

1. Mw = Moment Magnitude
2. A site-specific response analysis is required for Site Class F conditions. The Site Class E values were provided as a rough estimate for Site Class F conditions.
3. PGA = Peak Ground Acceleration (g)

LEGEND

Service Area

Seismic Site Class Code 'F'

PGA = Peak Ground Acceleration (g)

0.08 - 0.10 | 0.10 - 0.15 | 0.15 - 0.20 | 0.20 - 0.25 | 0.25 - 0.40 | 0.40 - 0.45 | 0.45 - 0.50 | 0.50 - 0.55 | 0.55 - 0.60 | 0.60 - 0.65 | 0.65 - 0.70 | 0.70 - 0.75

Bellevue Water Distribution System
Seismic Vulnerability Assessment
Bellevue, Washington

CASCADIA SUBDUCTION ZONE (PGA)
Mw 9.0 CSZ SCENARIO

January 2019 102185-001

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FIG. 3

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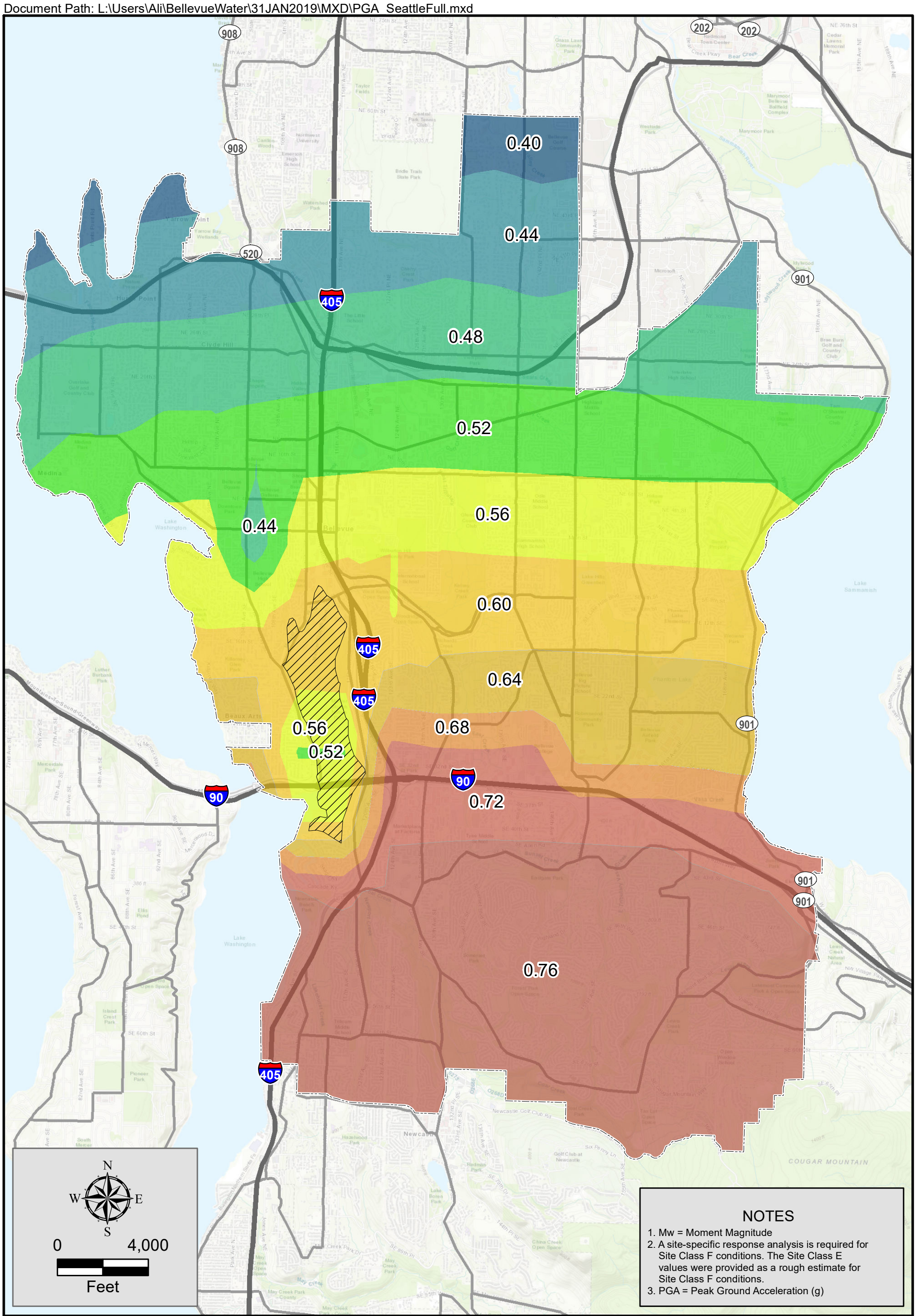

NOTES

1. Mw = Moment Magnitude
2. A site-specific response analysis is required for Site Class F conditions. The Site Class E values were provided as a rough estimate for Site Class F conditions.
3. PGA = Peak Ground Acceleration (g)

LEGEND

Service Area

Seismic Site Class Code 'F'

PGA = Peak Ground Acceleration (g)

0.08 - 0.10	0.10 - 0.15	0.15 - 0.20	0.20 - 0.25	0.25 - 0.40	0.40 - 0.45	0.45 - 0.50	0.50 - 0.55	0.55 - 0.60	0.60 - 0.65	0.65 - 0.70	0.70 - 0.75

Bellevue Water Distribution System
Seismic Vulnerability Assessment
Bellevue, Washington

SEATTLE FAULT (PGA)
Mw 7.2 SFZ FULL SCENARIO

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FIG. 4

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35.1 - 40.0
45.1 - 50.0
35.1 - 40.0
50.1 - 55.0
40.1 - 45.0
55.1 - 60.0
40.1 - 45.0
55.1 - 60.0
45.1 - 50.0
60.1 - 65.0
45.1 - 50.0
70.1 - 75.0
50.1 - 55.0
50.1 - 55.0
80.1 - 85.0
55.1 - 60.0
70.1 - 75.0
55.1 - 60.0
70.1 - 75.0
60.1 - 65.0
75.1 - 80.0
75.1 - 80.0
55.1 - 60.0
80.1 - 85.0
80.1 - 85.0
65.1 - 70.0
65.1 - 70.0
85.1 - 90.0
90.1 - 95.0
85.1 - 90.0
90.1 - 95.0
90.1 - 95.0
70.1 - 75.0
70.1 - 75.0
55.1 - 60.0
50.1 - 55.0
30.1 - 35.0
30.1 - 35.0
45.1 - 50.0
25.1 - 30.0

0 4,000
Feet

NOTES

1. Mw = Moment Magnitude
2. A site-specific response analysis is required for Site Class F conditions. The Site Class E values were provided as a rough estimate for Site Class F conditions.
3. PGA = Peak Ground Velocity (cm/sec)

LEGEND

Service Area

Seismic Site Class Code 'F'

PGA = Peak Ground Velocity (cm/sec)

5.0 - 10.0	10.1 - 15.0	15.1 - 20.0	20.1 - 25.0	25.1 - 30.0	30.1 - 35.0	35.1 - 40.0	40.1 - 45.0	45.1 - 50.0	50.1 - 55.0	55.1 - 60.0	60.1 - 65.0	65.1 - 70.0	70.1 - 75.0	75.1 - 80.0	80.1 - 85.0	85.1 - 90.0	90.1 - 95.0	95.1 - 100

Bellevue Water Distribution System
Seismic Vulnerability Assessment
Bellevue, Washington

SEATTLE FAULT (PGV)
Mw 6.6 SFZ EAST SCENARIO

January 2019 102185-001

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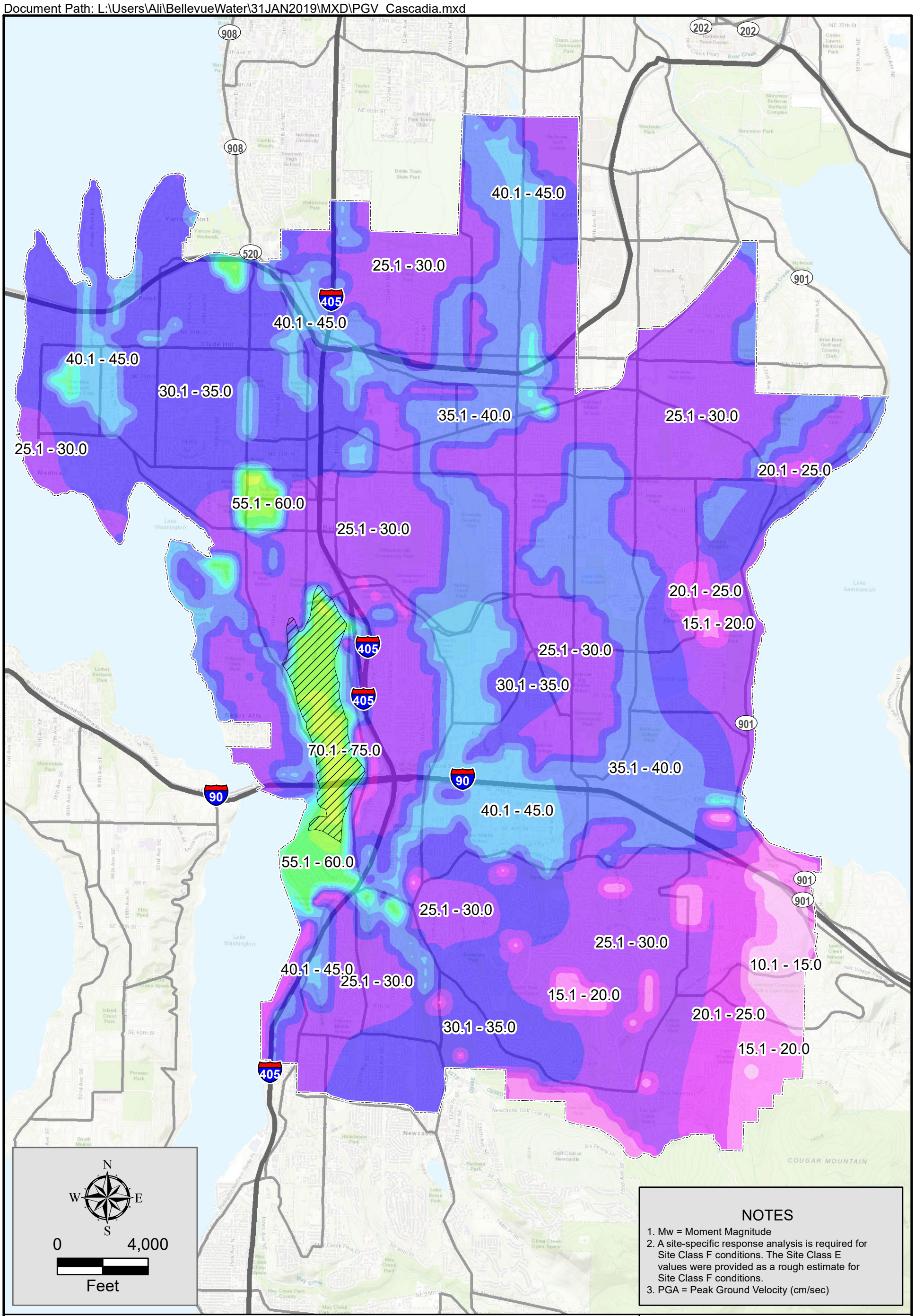
FIG. 5

Document Path: L:\Users\Ali\BellevueWater\31JAN2019\MXD\PGV_Cascadia.mxd



NOTES

1. Mw = Moment Magnitude
2. A site-specific response analysis is required for Site Class F conditions. The Site Class E values were provided as a rough estimate for Site Class F conditions.
3. PGA = Peak Ground Velocity (cm/sec)

LEGEND

Service Area

Seismic Site Class Code 'F'

PGA = Peak Ground Velocity (cm/sec)

5.0 - 10.0	10.1 - 15.0	15.1 - 20.0	20.1 - 25.0	25.1 - 30.0	30.1 - 35.0	35.1 - 40.0	40.1 - 45.0	45.1 - 50.0	50.1 - 55.0	55.1 - 60.0	60.1 - 65.0	65.1 - 70.0	70.1 - 75.0	75.1 - 80.0	80.1 - 85.0	85.1 - 90.0	90.1 - 95.0	95.1 - 100

Bellevue Water Distribution System
Seismic Vulnerability Assessment
Bellevue, Washington

CASCADIA SUBDUCTION ZONE (PGV)
Mw 9.0 CSZ SCENARIO

January 2019 102185-001

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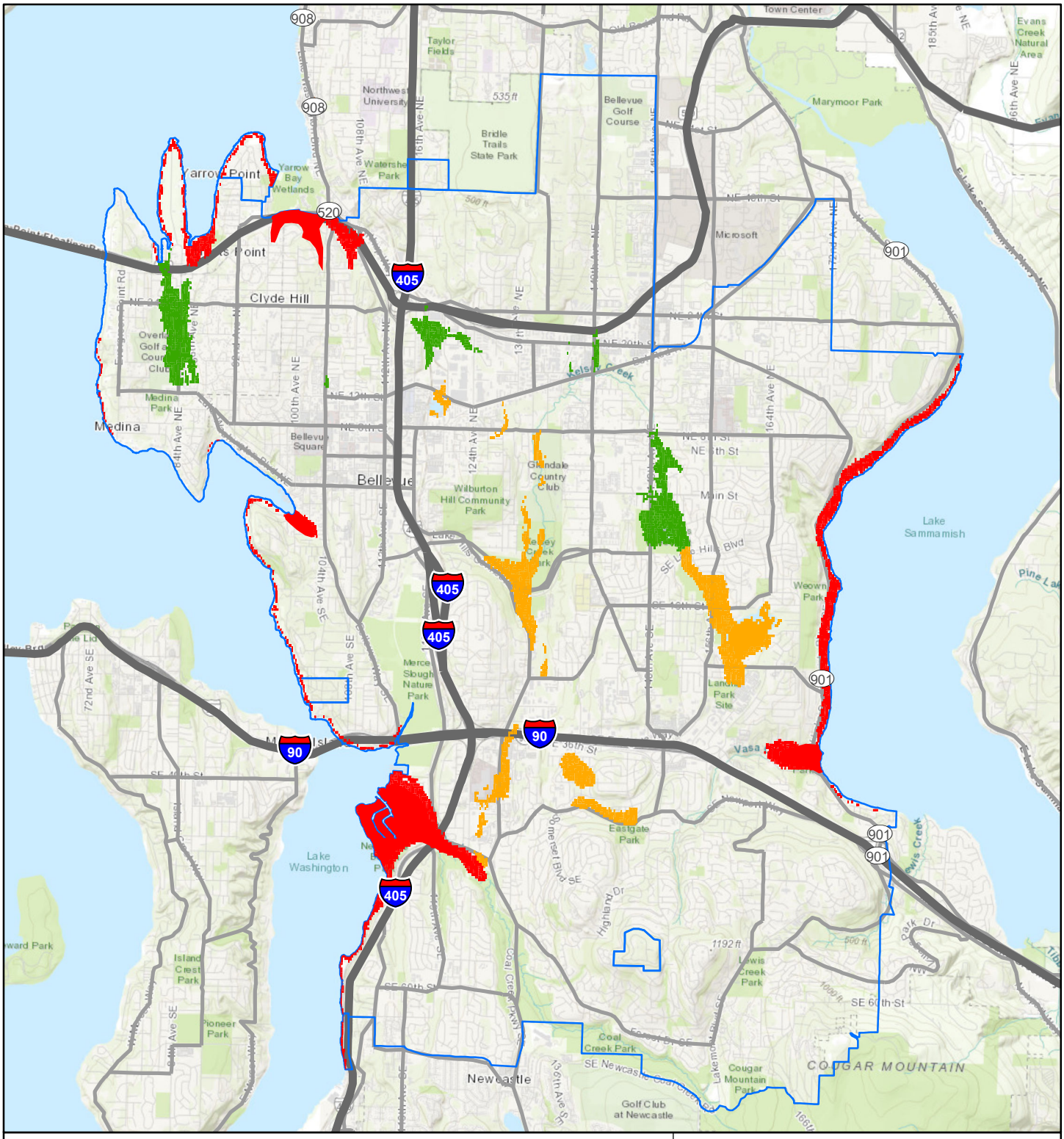
FIG. 6

Attachment B



LEGEND

Water Service Area

SFZEast

PGD (in)

0

1 - 6

6 - 12

> 12

0 5,000

Feet

N

Note: The displacement reported in this map are appropriate only for planning level vulnerability studies and should not be used for site-specific hazard evaluations. See TM-1: Geotechnical Data Refinement for the assumptions and limitations of the study.

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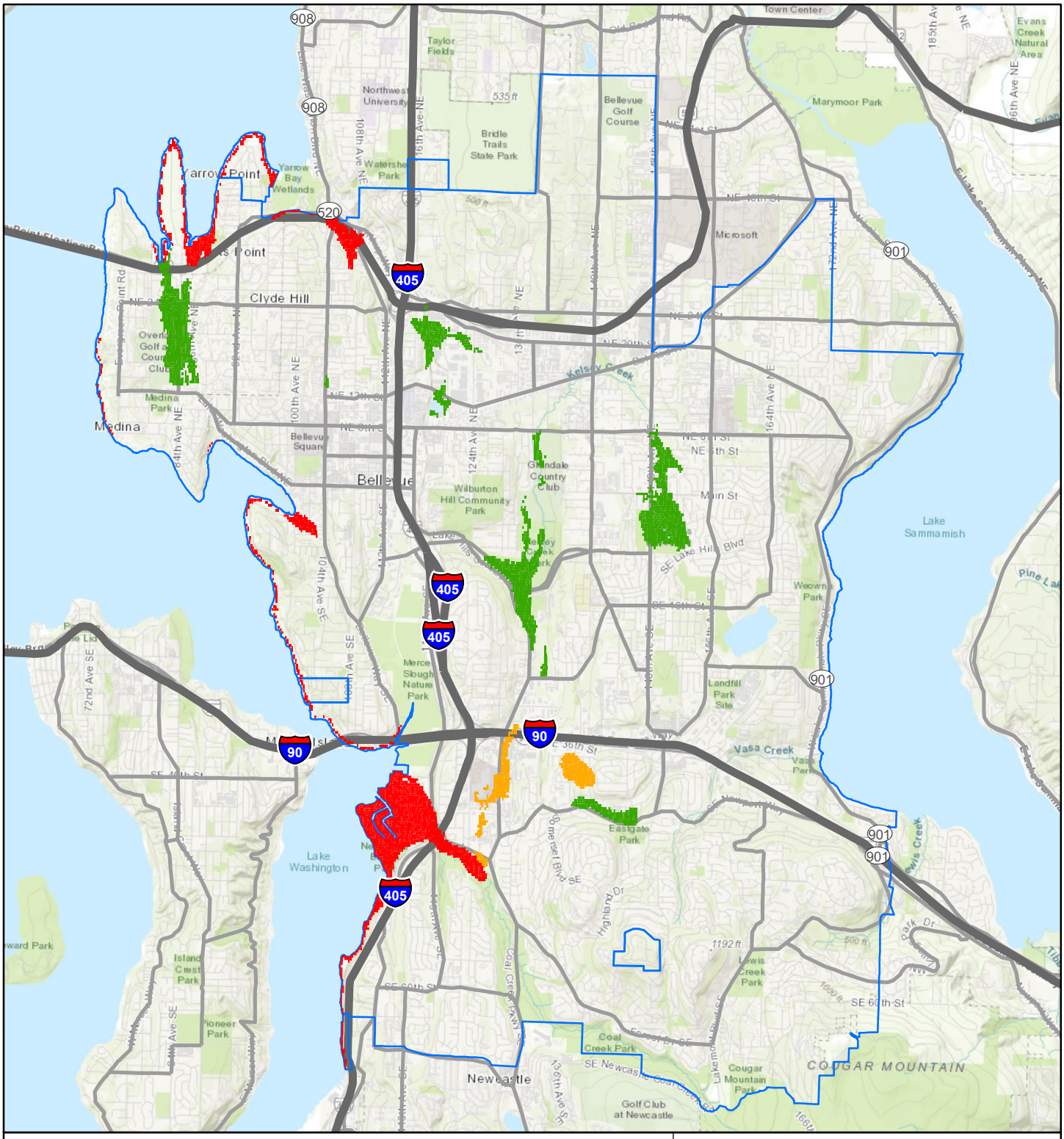
SFZ East Liquefaction Hazards

Bellevue Water System
Seismic Vulnerability Assessment

UNK C:\USERS\KL056713\DOCUMENTS\PROJECTS\BELLEVUE SVA\BELLEVUE WATER SYSTEM PLAN\GIS\MAP FILES\BELLEVUE_SEISMIC_KS_LIQUEFACTIONHAZARDS_KL.MXD KL056713 5/15/2019 8:40:42 AM



LEGEND

Water Service Area

SFZEast

PGD (in)

0

1 - 6

6 - 12

> 12

0 5,000

Feet

N

Note: The displacement reported in this map are appropriate only for planning level vulnerability studies and should not be used for site-specific hazard evaluations. See TM-1: Geotechnical Data Refinement for the assumptions and limitations of the study.

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CSZ Liquefaction Hazards

Bellevue Water System
Seismic Vulnerability Assessment

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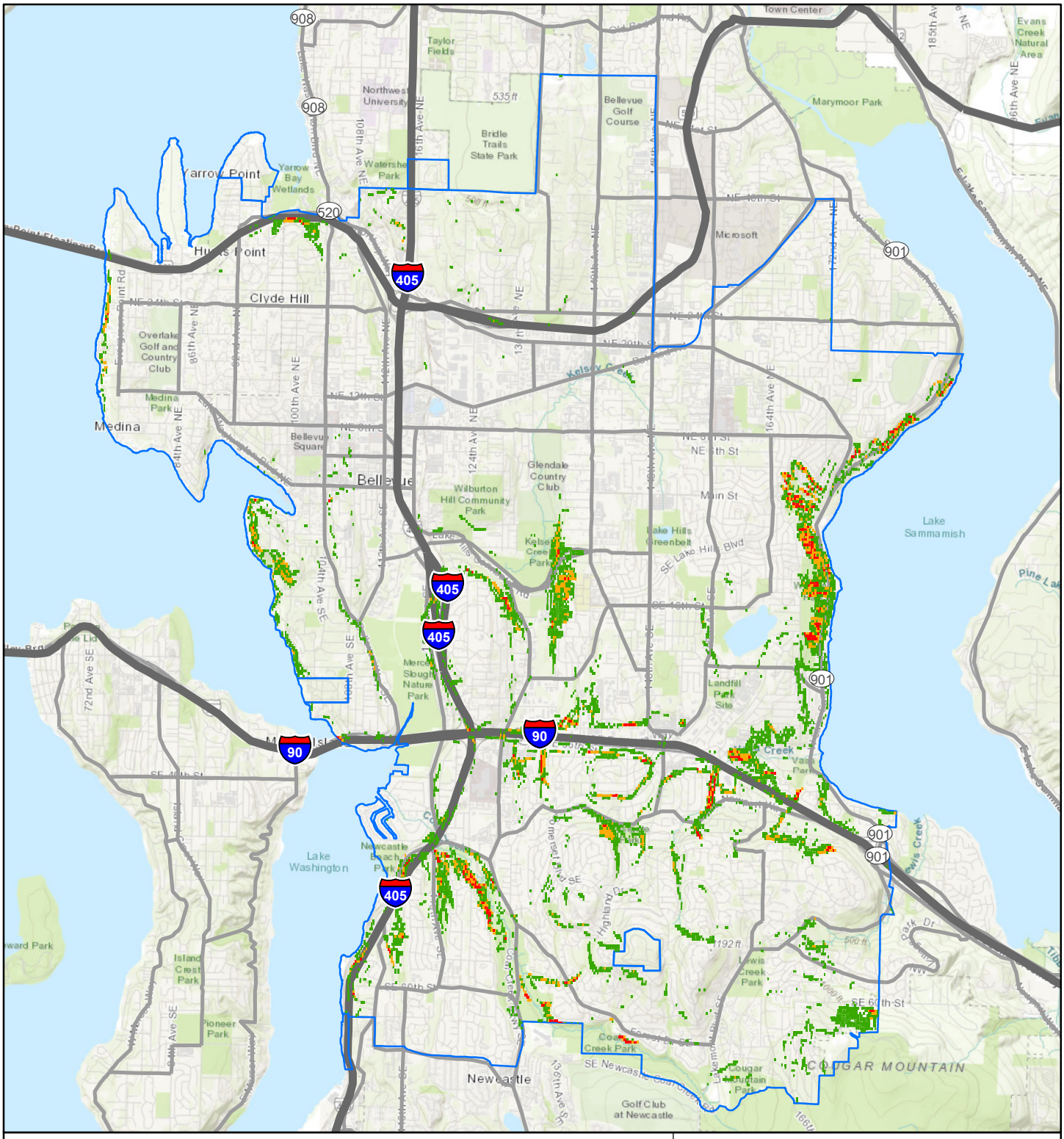
Attachment C



LEGEND

Water Service Area

SFZEast

PGD (in)

0

1 - 6

6 - 12

> 12

0 5,000

Feet

N

Note: The displacement reported in this map are appropriate only for planning level vulnerability studies and should not be used for site-specific hazard evaluations. See TM-1: Geotechnical Data Refinement for the assumptions and limitations of the study.

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SFZ East Landslide Hazards

Bellevue Water System
Seismic Vulnerability Assessment

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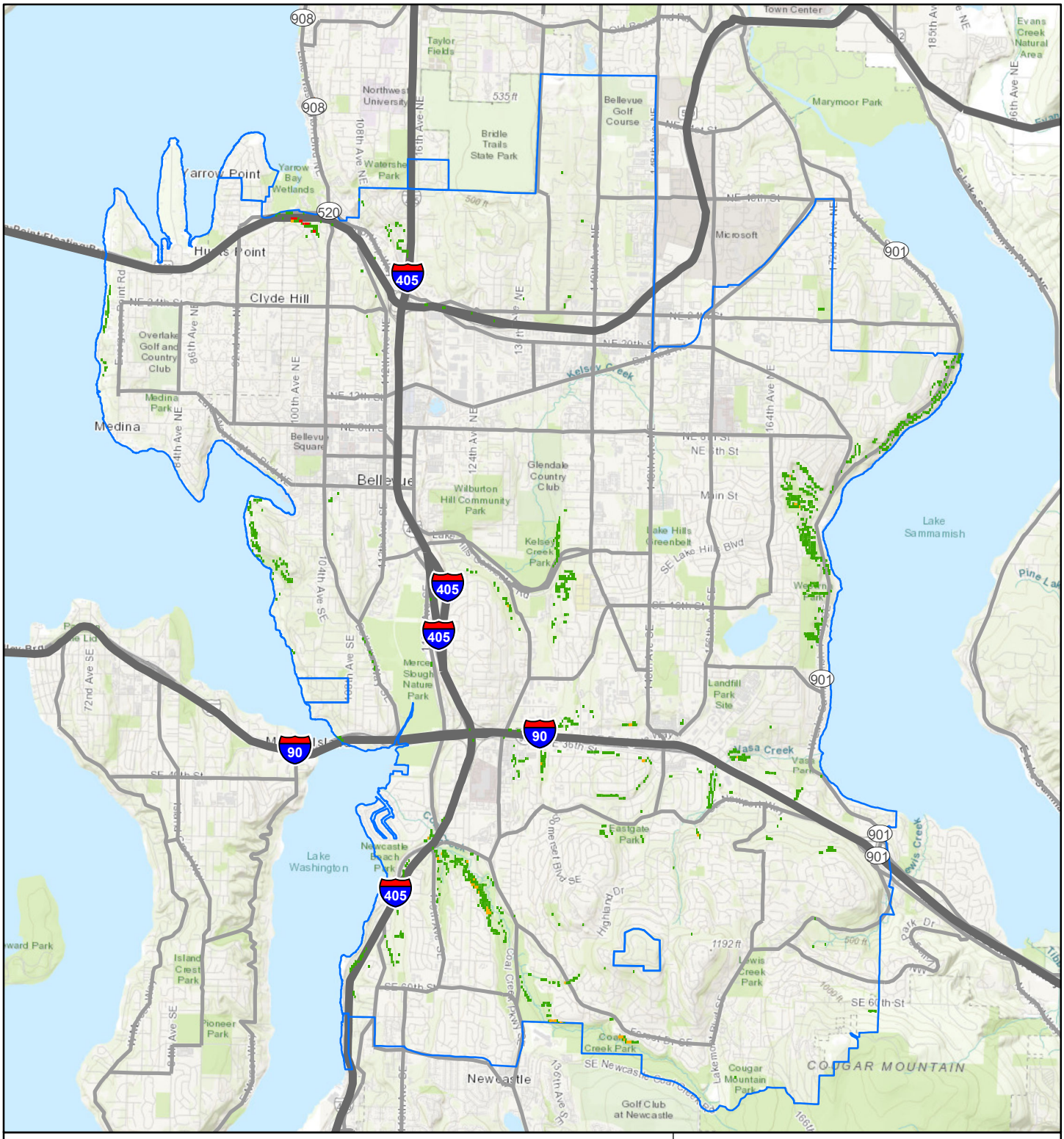

LEGEND

Water Service Area

SFZEast

PGD (in)

0

1 - 6

6 - 12

> 12

0 5,000

Feet

N

Note: The displacement reported in this map are appropriate only for planning level vulnerability studies and should not be used for site-specific hazard evaluations. See TM-1: Geotechnical Data Refinement for the assumptions and limitations of the study.

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CSZ Landslide Hazards

Bellevue Water System
Seismic Vulnerability Assessment

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Technical Memorandum

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Subject	**FINAL DRAFT - TM 1A: Bellevue Seismic Vulnerability Assessment Scenario Selection**
Project Name	Bellevue Seismic Vulnerability Assessment
Attention	Doug Lane, City of Bellevue
From	Jacobs Shannon & Wilson
Date	June 3rd, 2019

1. Executive Summary

For use in the City of Bellevue Water System Seismic Vulnerability Analysis, four earthquake scenarios were considered. The Cascadia Subduction Zone (CSZ) event was included to provide consistency among peer utilities conducting similar studies. The second even to be considered will be the Seattle Fault Zone East (SFZE) event developed specifically for this project. This event was selected because it has a similar level of ground shaking to the full Seattle Fault event, incorporates a higher likelihood of surface fault rupture in Bellevue, and has a lower return period than the full Seattle Fault Zone event.

2. Background

As part of the City of Bellevue water system seismic vulnerability analysis, four initial earthquake scenarios were identified, and potential ground motion estimates were developed for each. Two of these scenarios will be selected to be carried forward for further analysis in subsequent evaluations. This document describes the approach and rationale used to select earthquake scenarios.

The four initial earthquake scenarios are as follows and are described in more detail in TM 1: Geotechnical Data Refinement.

1. CSZ - Cascadia Subduction Zone (CSZ) interface, M_W 9.0, ~500-year recurrence interval.

2. SFZ West - Seattle Fault Zone (SFZ) partial rupture west of Puget Sound, M_W 6.6, ~800-year recurrence interval, assumed 100% probability of occurrence.

3. SFZ East - SFZ partial rupture through Bellevue, M_W 6.6, ~800-year recurrence interval, assumed 50% probability of occurrence in the eastern reaches of the fault, relative to probability of a SFZ West event.

4. SFZ Full – Full rupture of the SFZ, M_W 7.2, ~6,000-year recurrence interval.

Another earthquake scenario used by nearby utilities but not included in this analysis is a Deep Benioff Zone (DBZ) earthquake on the Nisqually Fault. This event would be similar to the 2001 Nisqually event (Mw 6.8) but with a higher magnitude. USGS published ground motions show similar PGAs in the Bellevue water system as are predicted by the Mw 9.0 CSZ scenario included in this evaluation. While including a DBZ scenario would potentially result in calculation of higher risk than the CSZ due to shorter return periods (~100 years) in the DBZ, the similar ground motions make it somewhat redundant with the more prominent and frequently evaluated CSZ event. Additionally, the 2001 Nisqually earthquake

produced no known impacts on the Bellevue water system according to Bellevue staff working in the water department at the time.

The selection of scenarios to be used for further analysis in this study was based on the following input variables:

- Earthquake scenario ground motion
- Probability of scenario occurrence (return period x probability of occurrence based on paleo-seismic evidence)
- Potential impact on Bellevue water system facilities (based on Hazus fragility curves)

3. Scenario Ground Motions

Peak ground acceleration (PGA) and peak ground velocity (PGV) maps for the CSZ, SFZ East, and SFZ West scenarios were developed by Shannon & Wilson and are further defined in TM 1: Geotechnical Data Refinement. The PGA map for the SFZ Full scenario was obtained from the USGS online database. Figures 2 through 5 show the PGA maps for each scenario. Figure 1 provides the legend for Figures 2 through 5.

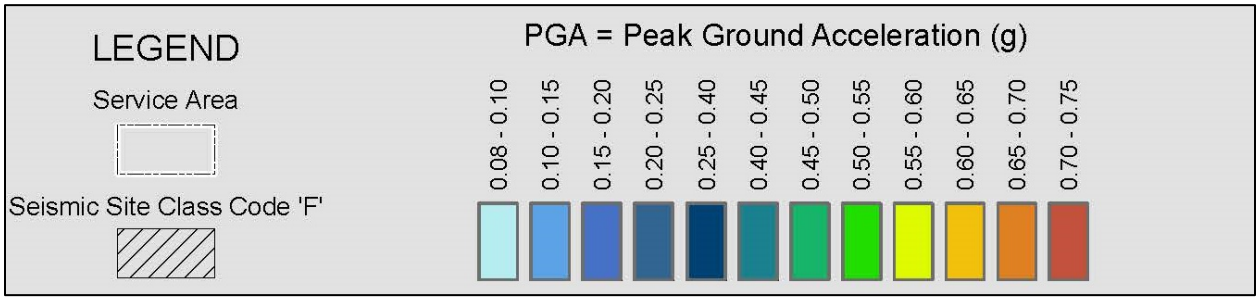

Figure 1. Enlarged PGA Legend for Figures 2 through 5

As shown in Figures 2 and 3, the CSZ and SFZ West scenarios result in similar ground motions, though slightly higher for the CSZ Scenario. Additionally, the CSZ is predicted to occur more frequently (recurrence interval of ~500 years) and has a longer duration of shaking than the SFZ West (~800-year recurrence interval) scenario.

Similarly, as shown in Figures 4 and 5, the SFZ East and the SFZ Full scenarios result in similar ground motions north of I-90 with slightly lower intensity south of I-90. While the ground motions are similar, the SFZ East is predicted to occur more frequently (~800 years) than the latter (~6,000 years). With similar ground motion that is higher across the Bellevue Water System, and with more frequent return periods, the SFZ East scenario is expected to result in higher risk (Consequence x Likelihood) to the Bellevue water system.

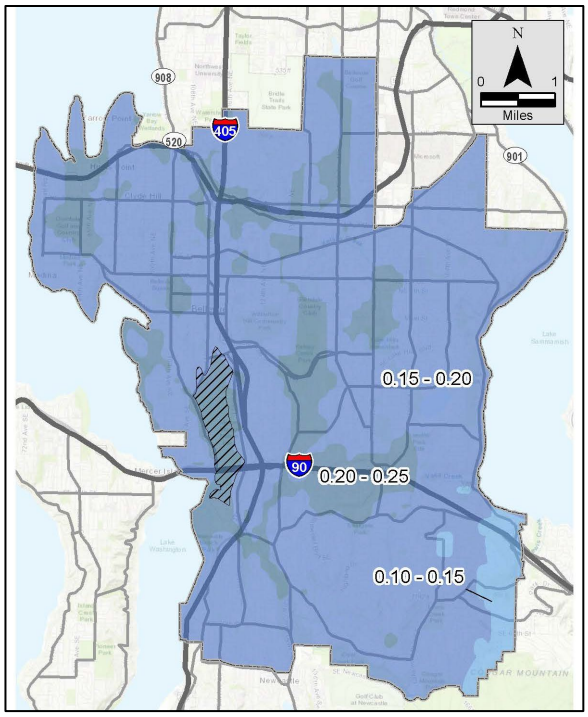

Figure 2. CSZ Scenario PGA (M_W 9.0 Cascadia Subduction Zone)

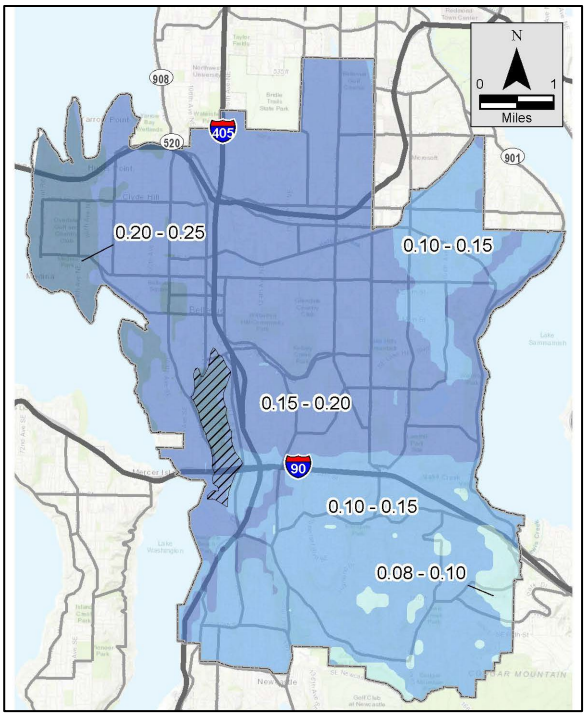

Figure 3. SFZ West Scenario PGA (M_W 6.6 SFZ partial rupture west of Puget Sound)

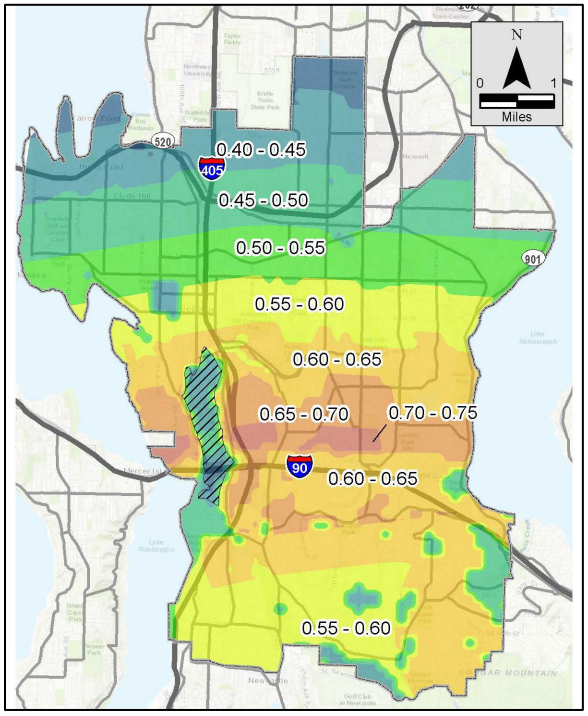

Figure 4. SFZ East Scenario PGA (M_W 6.6 partial rupture through Bellevue)

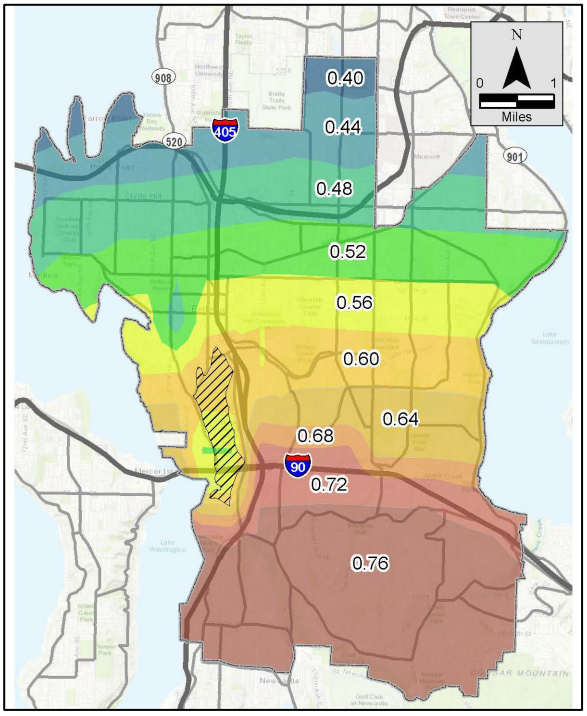

Figure 5. SFZ Full Scenario PGA (M_W 7.2 full rupture of the SFZ)

4. Facility Assessment and Fragility Curves

TM 2: Seismic Analysis Methodology for Pipeline and Facilities Assessment describes the proposed approach for assessing the potential seismic fragility of water system facilities and pipelines, including the methodology for analysis of facilities using the Hazus fragility curve methodology. In order to aid in the selection of earthquake scenarios, the estimated ground motions from each of the four initial earthquake scenarios were applied to fragility curves developed for Bellevue water system facilities to assess the likelihood that each facility would be offline following an earthquake.

Figure 6 shows a color-coded table that indicates the probability that a given facility would be offline for each of the four initial earthquake scenarios considered. This can be used as a means to compare the expected relative consequence for each of the four initial scenarios. Based on this analysis, the implication is that the CSZ and SFZ West scenarios could be expected to have similar overall consequences, as would the SFZ East and SFZ Full scenarios.

Reservoirs	CSZ M9	SFZ East	SFZ West	Full SFZ
Cherry Crest	0.34%	12.37%	0.19%	12.81%
Clyde Hill 465	0.19%	6.40%	0.20%	7.04%
Clyde Hill 390	0.38%	11.87%	0.38%	12.81%
Clyde Hill 335 Rd	4.46%	33.40%	4.52%	32.11%
Clyde Hill 335 Sq	0.38%	8.12%	0.15%	7.47%
Cougar Mt. 1	0.19%	22.84%	0.02%	35.58%
Cougar Mt. 2	0.13%	23.17%	0.02%	35.58%
Cougar Mt. 3	2.08%	44.67%	0.81%	55.89%
Cougar Mt. 3A	2.08%	44.15%	0.76%	55.89%
Factoria	5.51%	45.69%	2.10%	53.03%
Forest Hills	0.37%	21.10%	0.04%	35.58%
Horizon View 1 - NEW	0.18%	13.25%	0.02%	22.18%
Horizon View 2	4.26%	42.58%	1.16%	55.89%
Horizon View 3	0.13%	13.43%	0.01%	24.95%
Horizon View 3A	0.34%	21.92%	0.03%	35.58%
Lake Hills North	0.18%	10.27%	0.05%	10.83%
Lake Hills South	0.17%	10.37%	0.05%	10.83%
Meydenbauer N	0.39%	21.51%	0.41%	18.98%
Meydenbauer S	0.39%	21.51%	0.41%	18.98%
N.E. 40th	0.36%	8.16%	0.11%	10.02%
Newport	0.17%	21.84%	0.02%	35.58%
Parksite	4.66%	46.94%	1.26%	55.89%
Pikes Peak				28.08%
Sammamish				35.58%
Somerset 2	0.04%	21.93%	0.00%	38.19%
Woodridge	0.20%	17.32%	0.10%	15.14%
Kirkland 545 - South				23.96%
Kirkland 545 - North				1.80%
CCUD 580 East				55.89%
CCUD 580 West				55.89%
CCUD 440				55.89%
Inlets				
161st Inlet	0.03%	25.08%	0.00%	12.64%
Bel Red Inlet	0.05%	12.90%	0.02%	12.64%
Cherry Crest Inlet	0.03%	9.31%	0.01%	9.31%
Eastgate Inlet	0.05%	24.75%	0.00%	38.19%
Enatai	0.03%	25.41%	0.01%	24.75%
Inlet #11	0.03%	26.85%	0.00%	33.70%
Inlet #6	0.04%	17.77%	0.00%	38.19%
Inlet #8	0.02%	15.99%	0.00%	38.19%
NE 40th Inlet	0.05%	5.51%	0.01%	6.49%
NE 8th Inlet	0.06%	14.46%	0.01%	12.64%
Richards Road	0.07%	27.30%	0.02%	29.20%
SE 28th Inlet	0.04%	32.58%	0.01%	24.75%

Pump Stations	CSZ M9	SFZ East	SFZ West	Full SFZ
Cherry Crest	6.36%	54.67%	6.36%	55.32%
Clyde Hill	23.99%	75.50%	24.25%	76.83%
Cougar Mt. 1	4.24%	61.90%	1.12%	74.35%
Cougar Mt. 2	3.44%	62.29%	1.04%	74.35%
Cougar Mt. 3	2.79%	62.09%	0.90%	74.35%
Forest Hills	6.94%	61.00%	1.74%	75.35%
Horizon View 1 - NEW	0.63%	25.11%	0.09%	37.65%
Horizon View 2	20.06%	83.11%	6.92%	91.17%
Horizon View 3	0.03%	19.92%	0.00%	38.19%
Lake Hills (Crossroads)	6.22%	55.80%	2.65%	57.02%
Meydenbauer	0.82%	25.55%	0.82%	22.92%
NE 8th Inlet	0.06%	14.46%	0.01%	12.64%
NE 40th	6.42%	37.96%	3.07%	42.08%
Newport	4.27%	62.30%	1.05%	75.35%
Parksite	21.70%	86.22%	7.43%	91.17%
Pikes Peak				72.49%
SE 28th Inlet	0.04%	32.80%	0.01%	24.75%
Somerset Inlet	0.03%	25.85%	0.00%	38.19%
Somerset 2	0.04%	21.93%	0.00%	38.19%
Woodridge	6.75%	68.28%	0.01%	65.01%
161st Ave Inlet	0.03%	25.08%	0.00%	33.70%
670/NE 40th	23.37%	66.85%	15.03%	69.05%
CCUD 475/580				
Wells				
WD97 Well No. 3	1.68%	41.29%	1.09%	38.95%
WD97 Well No. 5	1.90%	33.83%	0.68%	34.95%
WD97 Well No. 6	1.90%	33.83%	0.68%	34.95%
WD97 Well No. 7	1.90%	33.83%	0.68%	34.95%

Figure 6. Facility Comparison – Probability of Extensive or Complete Damage Relative to Initial Earthquake Scenarios

5. Scenario Selection

The evaluation described above suggests that the CSZ (M_W 9.0) and the SFZ East (M_W 6.6) scenarios are appropriate as representative scenarios for the remainder of the seismic vulnerability analysis of the Bellevue Water System. The primary rationale behind the selection of these scenarios are as follows.

- CSZ is a commonly used scenario for evaluation of expected performance of lifelines in the Pacific Northwest
- CSZ and SFZ West have similar ground motions and resulting consequence expectations, but the CSZ has a more frequent return period and is expected to result in a higher overall risk contribution when considerations relative to event likelihood and expected consequence are compounded.
- SFZ Full and SFZ East have similar ground motions and resulting consequence expectations, but the SFZ East has a higher probability of occurrence and is expected to result in a higher overall risk contribution when considerations relative to event likelihood and expected consequence are compounded. While the SFZ full produces the highest ground motions currently projected in the Bellevue water system, its low likelihood of occurrence make the slightly smaller SFZ East scenario more valuable for this evaluation.

As a result the project team selected the following earthquakes for detailed analysis as part of this project:

1) Cascadia Subduction Zone (CSZ) M9 scenario
2) Seattle Fault Zone East (SFZE) M6.6 scenario

Appendix B. Seismic Analysis Methodology

B.1 TM2: Seismic Analysis Methodology for Pipeline and Facilities Assessment

B.2 TM2A: Comparison of ALA Equations to Christchurch Earthquake Repair Data

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Technical Memorandum

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Subject	**FINAL DRAFT - TM 2: Seismic Analysis Methodology for Pipeline and Facilities Assessment**
Project Name	Bellevue Seismic Vulnerability Assessment
Attention	Doug Lane, City of Bellevue
From	Jacobs
Date	June 3rd, 2019

1. Background

The City of Bellevue water system seismic vulnerability assessment (SVA) will incorporate vulnerabilities of Bellevue water system pipelines and facilities into a comprehensive modeling analysis to predict the performance of the water system in seismic events and develop restoration expectations and mitigation alternatives. The facilities will be evaluated using Hazus facility fragility curves and the pipelines will be evaluated using the American Lifelines Alliance (ALA) fragility equations, modified to incorporate data from more recent earthquakes, as described in the American Lifelines Alliance 2001 Guideline titled *Seismic Fragility Formulations for Water Systems.*

2. Seismic Hazards

The seismic hazards that will be used for the Bellevue SVA are described in *TM 1: Geotechnical Data Refinement*. In summary, the seismic hazards have been developed based on publicly available data from the United States Geological Survey (USGS) and the State of Washington that was then refined to provide more precise predicted ground motions for the areas inside the Bellevue water system area.

Ground motions used to evaluate water system vulnerability were developed from two earthquake scenarios. These are the Mw 9.0 Cascadia Subduction Zone interface event (CSZ) and the Mw 6.6 Seattle Fault, East Side Rupture (~800 years). More details about seismic hazards are included in TM 1: Geotechnical Data Refinement and TM 1A: Earthquake Scenario Selection.

Technical Memo 1 also summarizes the development of permanent ground deformation (PGD) estimates for each of the above-mentioned earthquakes. This includes deformation from fault rupture, liquefaction, and landslides. This ground deformation data is used as described below to predict the performance of the pipelines.

3. Pipeline Fragility Analysis

A pipeline fragility analysis will be completed to determine the expected performance of the Bellevue water system pipelines. The goal is to determine the likelihood that pipelines would fail during a seismic event. The improvement analysis, which will be conducted later in the project, will evaluate proposed mitigation options, including the relative benefit of strengthening the pipelines with the greatest seismic risk.

3.1 Process and Parameters

The ALA seismic fragility equations for buried pipe express the repair rate per unit of length of pipe as a function of ground shaking or ground displacement. Peak ground velocity (PGV) is a measure of the speed of ground movement, while PGD measures the displacement of liquefaction settlement or lateral spread (in cm) and the displacement of landslide movement. PGD is also used to quantify ground rupture displacement in the fault zone.

The ALA equations are as follows:

Wave Propagation (PGV Equation): $RR = K_1 \times 0.00187 \times PGV$

Permanent Ground Deformation (PGD Equation): $RR = K_2 \times 1.06 \times PGD^{0.319}$

Where:

RR = repairs per 1,000 feet of pipe

K_1 = Coefficient specific to each pipe material for Wave Propagation Equation

K_2 = Coefficient specific to each pipe material for Permanent Ground Deformation Equation

PGV = peak ground velocity in inches/second

PGD = permanent ground deformation in inches

Repairs per 1,000 feet of pipe (RR) due to PGD and due to wave propagation are estimated using the appropriate equation for each hazard. The “K” values in the equations are a constant representing the relative fragility of the pipe, based on the ALA empirical data.

The results of the pipeline vulnerability analysis have been provided to the City in two electronic excel files (one for each earthquake scenario).

3.2 Data Source for ALA Empirical Equations

The ALA pipeline fragility equations are based on empirical evidence from the following earthquakes and water systems. The expected performance of various pipe materials is based on this data collected during post-earthquake response and restoration. As such the equations are only as good as the data set used to develop the empirical equations.

Table 1. Data Sources Used for ALA Empirical Equations

Earthquakes in Screened PGV Database	Earthquakes in PGD Database
1995 Hyogoken-nanbu (Kobe), Japan	1989 Loma Prieta, California
1994 Northridge, California	1983 Nihonkai-Chubu, Japan
1989 Loma Prieta, California	1971 San Fernando, California
1971 San Fernando, California	1906 San Francisco, California
1989 Mexico City, Mexico	
1983 Coalinga, California	
1979 Imperial Valley, California	
1965 Puget Sound, Washington	
1964 Niigata, Japan	
1949 Puget Sound, Washington	
1933 Long Beach, California	
1923 Kanto, Japan	

3.2.1 ALA Data for Asbestos Cement Pipe

As shown in Figure 1, the Bellevue water system comprises approximately 40 percent AC pipe (please refer to Table 4 for a complete list of pipe material abbreviations). Additionally, most pipelines in the Bellevue water system are not in liquefiable soil, thus PGV repair estimation equations will have a greater significance than PGD for the Bellevue water system.

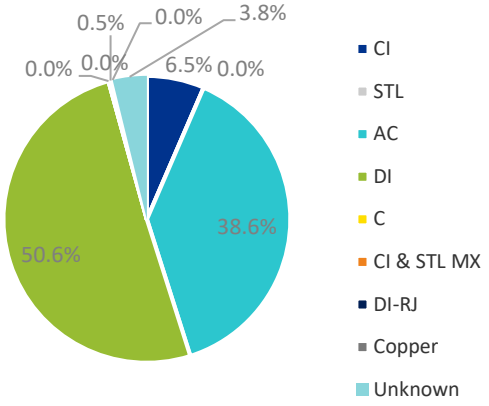

Figure 1. Pipe materials in Bellevue water system

In contrast, as shown in Figures 2 and 3, approximately 40 percent of data points used for the ALA PGD database were for AC pipe, but only 14 percent of the data points used for the ALA PGV database were for Asbestos Cement (AC) pipe. This limited data on AC pipe used for the empirical ALA equations alone introduces some uncertainty surrounding the accuracy of the ALA equations for use on the Bellevue water system which has a high percentage of AC pipe. To improve the accuracy of the pipeline fragility analysis for the Bellevue SVA project additional earthquake data was reviewed and compared with the ALA equations as described below.

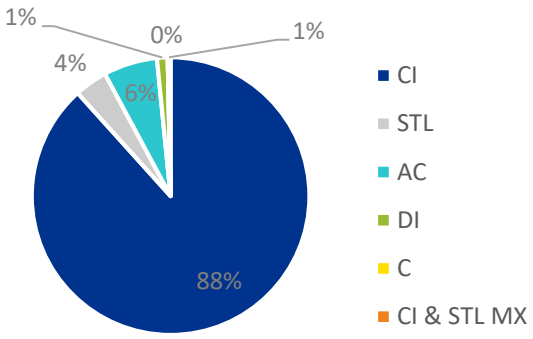

Figure 2. Pipe materials in ALA PGV Database based on length

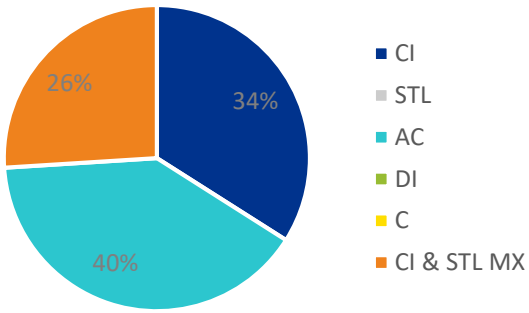

Figure 3. Pipe Materials in ALA PGD Database based on number of data points

The vulnerability of AC pipe is thought to be associated with the brittle nature of the AC material. The pipe is joined with couplings, a short section of larger diameter “pipe” with elastomeric gaskets in each end. These are used to couple the pipe. Older AC pipe couplings, prior to approximately 1950 are sealed with mortar rather than gaskets. It is not believed that the BWS has any of this older pipe. The gasketed couplings appear to provide additional flexibility compared to, for example cast iron pipe leaded joints.

3.2.2 Comparison of ALA empirical equations vs. earthquakes in Christchurch, New Zealand

TM 2A: Comparison of ALA Equations to Christchurch Earthquake Repair Data describes in detail the analysis completed to identify AC pipe repair coefficients for use in the Bellevue water system SVA. The result of this analysis was a recommendation to use the following coefficients with the ALA equations.

AC Pipe $K_1 = 4.0$

AC Pipe (6”-8”) $K_2 = 1.0$

AC Pipe (>8”) $K_2 = 0.8$

3.3 Equations and Coefficients for Pipe Analysis

“K” values use for analysis of the Bellevue water system were primarily taken from the ALA guidance document. Table 4 shows the pipe materials and the associated “K” values used for each material, including notes describing where the values used originated from. For some materials, not K values were available and the values used were derived based on engineering judgement based on relative comparisons or interpolation between similar materials.

Table 4. PIPE MATERIALS AND ASSOCIATED "K" VALUES FOR EACH MATERIAL[1]

Pipe Material Abbreviation	Pipe Material	Joint Type	PGV "K_1" Value	PGD "K_2" Value
AC (>8")	Asbestos Cement	Rubber Gasket	4.0[2]	0.8[1]
AC (6 – 8")			4.0[2]	1.0[2]
BRASS	Brass		0.15[3]	0.15[3]
BWC	Bar Wrapped Concrete		1.1[3]	1.0[3]
CI	Cast Iron	Leaded	3.5[2]	1.0[1]
DI (DI-RJ)	Ductile Iron	Rubber Gasket	0.5[1]	0.5[1]
ERDIP	Earthquake Resistant Ductile Iron Pipe		0.1[3]	0.1[3]
GLV (G, GST, GLV, Galvanized)	Galvanized Steel	Screwed	1.3[3]	1.3[3]
HDPE (PE)	High Density Polyethylene	Fused	0.2[3]	0.2[3]
PVC (POLY)	Polyvinyl Chloride	Rubber Gasket	0.5[1]	0.8[1]
STEEL (STL)	Steel		0.15[3]	0.15[3]
UNK (Unknown, Blank, N/A)	Unknown		1.1[3]	1.0[3]

[1] "K" value from ALA Guideline "Seismic Fragility Formulations for Water Systems"

[2] "K" value developed based on evaluation of AC pipe performance in Christchurch 2011 earthquake in consideration of data available from ALA "Seismic Fragility Formulations for Water Systems"

[3] "K" value estimated based on expected relative pipe performance in comparison to other pipes with published data

3.4 Application of ALA Equations to Bellevue water system

Pipes that are assumed to be subjected to PGD based on the geotechnical information developed as a part of TM 1 are analyzed using the ground deformation equation and the rest of the pipe is analyzed using the wave propagation equation. As described in TM 1, both probability and magnitude of landslide or liquefaction was developed for the designated hazard areas. This probability is used to calculate the percentage of the linear footage of pipe in the hazard area that is expected to be subjected to the described ground deformation. Then, pipe damage is calculated for wave propagation for all including areas not in liquefaction or steep slope areas and those subject to PGD.

The resulting number of leaks and breaks is an estimate with a large range of uncertainty that is useful and appropriate for planning level analysis only

For the probabilistic modeling described in TM 3, Modelling Methodology Development, each pipe is assigned a probability of failure based on the ALA equations. To do this a Poisson distribution is used with k=0 (number of breaks or leaks in the pipe) because only one break or leak is required to cause a pipe need repair. The equations for probability of leaks and breaks are as follows.

Probability of at least one pipe break:

$$P_{Break} = 1 - e^{\left(-\frac{K1 \times 0.00187 \times PGV \times L \times 0.2}{1{,}000} - \frac{K2 \times 1.068 \times PGD^{0.319} \times P_{PGD} \times L \times 0.8}{1{,}000}\right)}$$

[1] American Lifelines Alliance (ALA). 2001. *Seismic Fragility Formulations for Water Systems 2001 Report*, April.

Probability of at least one pipe leak:

$$P_{Leak} = 1 - e^{\left(-\frac{K1 \times 0.00187 \times PGV \times L \times 0.8}{1{,}000} - \frac{K2 \times 1.068 \times PGD^{0.319} \times P_{PGD} \times L \times 0.2}{1{,}000}\right)}$$

Where:

K_1 = PGV equation pipe material coefficient as defined in Table 4

K_2 = PGD equation pipe material coefficient as defined in Table 4

PGV = Average estimated scenario peak ground velocity for the pipe in inches per second (See TM1: Geotechnical Data Refinement)

PGD = Average estimated scenario permanent ground deformation in inches (See TM1: Geotechnical Data Refinement)

P_{PGD} = Probability that estimated scenario PGD affects a particular pipe (See TM1: Geotechnical Data Refinement)

L = Length of pipe or pipe segment in feet (ft)

The application of the resulting damage state probabilities from the facility fragility analysis to the modeling analysis for the Bellevue SVA is described in TM 3: Modeling Methodology Development.

4. Facility Fragility Analysis

For the purposes of this evaluation, the system was categorized into facilities and water distribution pipelines (described above). Facilities include all components that are not buried distribution pipelines, such as supply inlet stations, pressure reducing valve (PRV) vaults, emergency wells, pump stations, and reservoirs.

4.1 Process and Parameters

Expected facility performance was evaluated for each earthquake scenario in terms of its post-earthquake functionality. This process is based on the multi-hazard loss estimation methodology outlined in the Hazus technical manual. Each facility was assigned a building classification which groups similar performing buildings based on their expected damage and loss characteristics. Above-grade buildings were also assigned a code level based on when the facility was built and its condition. Parameters used to develop damage functions (fragility curves) for each facility are based on the building classification and code level. The damage functions for each facility were evaluated and adjusted as necessary based on site visits, review of previous seismic evaluations, fragility relationships included in HAZUS, and engineering judgement. For facilities that do not have a building type specifically described in HAZUS, a building fragility curve was determined using a combination of engineering judgement and comparing HAZUS data for similar standard structures. A summary of the building classification, code level, and damage function parameters for each facility is included in Attachment A.

The peak ground acceleration (PGA) for each facility was selected from the earthquake scenarios described in Section 2 above and TM 1, Geotechnical Data Refinement.

4.2 Damage States for Seismic Scenarios

The damage states used in the seismic scenarios are as follows:

- Slight/Minor – operable following the event.

- Moderate – sustained damage but safe and operable during repair.
- Extensive – inoperable but repairable. May be yellow or red tagged limiting access for an extended duration.
- Complete – not repairable. Replacement required.

4.3 Probability of Damage

The HAZUS fragility curves are in the form of a cumulative lognormal distribution. The shape of each curve is defined by the mean PGA (μ) and the standard deviation of the PGA values (β^2). The cumulative lognormal distribution is calculated with:

$$HAZUS = \frac{1}{2} + \frac{1}{2} * ERF\left(\frac{\ln(PGA) - \mu}{\beta * \sqrt{2}}\right)$$

In the equation above, ERF is the "error function" that is used when integrating the normal and lognormal distributions. The ERF is defined as:

$$ERF(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2}\, dt$$

The fragility curves describe the probability of reaching or exceeding different damage states for a given PGA. This can be used to indicate a facility's operability and/or extent of damage after a given seismic event. These equations were used to develop the probability of each damage state following a specific earthquake. The PGA was based on values from scenarios as described in section 2. The resulting probabilities of damage for each of the 4 earthquake scenarios are included in Attachment A.

These probabilities will be used in the Modelling as described in TM 3: Modelling Methodology to develop post-earthquake damage scenarios and associated water availability.

4.4 Valve and PRV Vaults

Buried Valve and PRV vaults fragilities have been estimated by applying the most applicable Hazus fragility formula to the pipes that come in and out of the vault. This allows the model to incorporate the slightly higher probability of failure that is associated with a rigid connection to a buried concrete structure, but also allows the damage to be modeled as a break or leak in the multi-break modeling scenario. This is more representative than listing these as a facility, since the repairs of these are likely to be of the same level of effort as a broken pipe and repair times would be measured in hours and not days, as would be expected from significant damage to a facility like a pump station.

5. Seattle Public Utilities Supply System Vulnerability

Seattle Public Utilities (SPU) recently completed a detailed seismic assessment of their entire water system, including the regional supply facilities and transmission pipelines that provide water to Bellevue. The City, Jacobs, Cascade Water Alliance, and SPU representatives met to discuss a preferred approach to developing outage probabilities and restoration times for the SPU Cedar Eastside Supply Line (CESSL) and Tolt Eastside Supply Line (TESSL). The result was a conclusion that due to the sensitive nature of the details of the SPU analysis and the lack of probability data specific to the ESSLs, it would be appropriate for the Jacobs team to prepare estimates of the probability of failure for each of the two supply lines for each earthquake scenario. To do this, the probability of failure of each segment of the TESSL and the CESSL was independently estimated and then the combined probability of failure was calculated. Hazards considered when estimating the probabilities for each segment included consideration of pipe vulnerability as identified in Figure 6-1 from the SPU Water System Seismic Study Summary Report, river crossings, steep slope/landslide prone areas, liquefaction hazard areas, and pipe

material. The resulting probability values are based on the team's understanding of the SPU supply system, the vulnerabilities identified in the public version of the SPU Seismic VA report, experience with more detailed analysis of similar systems, and engineering judgement.

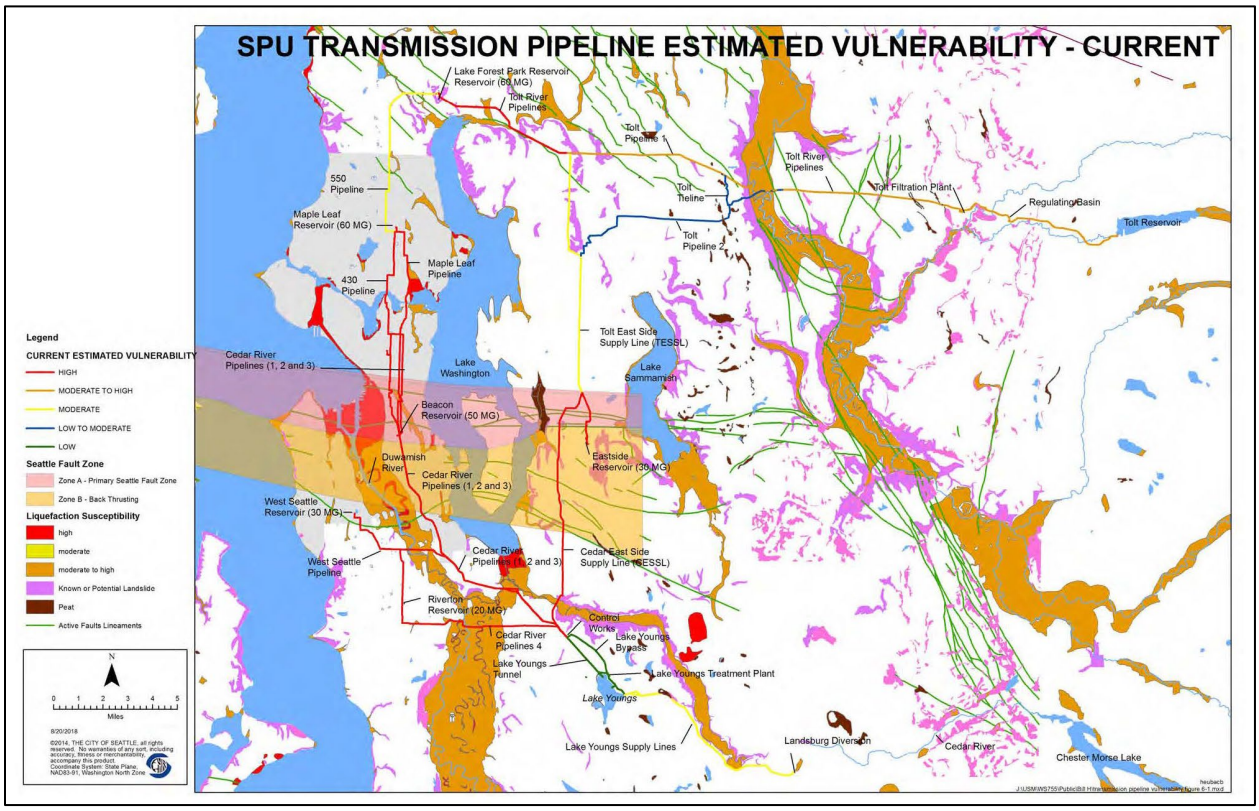

Figure 4. SPU Transmision System Current Vulnerability (Reprinted from Seattle Public Utilities Water System Seismic Study Summary Report, 2018)

Table 5 shows the assumed probabilities of pipeline supplies remaining in-service and the expected restoration times for each of the two seismic events being analyzed as a part of this project. Note that the in-service probability values are assumed to include the supply lines and facilities feeding into the TESSL or CESSL as well as the TESSL and CESSL themselves.

Table 5. SPU Supply System In-Service Probability and Expected Restoration Time

Supply	Probability In-Service (SFZ East)	Probability In-Service (CSZ)	Assumed Restoration Time (SFZ East), days	Assumed Restoration Time (CSZ), days
TESSL	65%	69%	14	14
CESSL	13%	19%	90	30

6. Critical Customer and Customer Group Identification

To collect more detailed water supply and restoration availability on specific customers and customer groups, the output data from the modeling exercise described in TM 3: Modeling Methodology Development will be presented for critical customers and certain customer groups. These subsets of the Bellevue water system customers are described below.

6.1 Critical Customers

Critical customers have been identified for this evaluation based on the priority of maintaining or restoring water service as soon as possible after an earthquake. ***NOTE: This list is not intended to establish an operational or policy priority, but rather serves as a boundary condition to help identify impacts to critical customers after an earthquake for the sake of this evaluation. Level of Service goals will be considered later in this project and will begin to consider restoration priorities and goals for restoring water service to various customers and customer groups.***

Potential critical customers were grouped into categories 1 through 3. Customers in category 1 (highest priority of customers) will be included as individual locations in the multi-break hydraulic analysis so that the probability of water availability to these points after an earthquake can be tracked. The critical infrastructure that could impact delivering supply to category 1 customers if a failure occurs will also be identified. Categories 2 and 3 are also considered to be critical customers, however the need to provide water to these locations does not have the same importance as providing service to those customers category 1 and adding these locations to the analysis would dilute the importance of the critical customers in category 1. Category 2 customers are important, but water supply is not critical to their operation or they are not as well suited as emergency shelters. Category 3 customers are important, but too numerous and widespread to be tracked individually or do not require water service for functionality.

Category 1 Critical Customers:

- Overlake Hospital Campus
- Kaiser Permanente Bellevue Medical Center
- Seattle Children's Bellevue Clinic and Surgery Center
- High Schools (Emergency Shelter Locations)
    - Newport High School
    - Bellevue High School
    - Sammamish High School
    - Interlake High School
- Community Centers (Emergency Shelter Locations)
    - North Bellevue Community Center
    - South Bellevue Community Center
    - Crossroads Community Center
- Washington State DOT EOC and Road Maintenance Facility
- Washington State DOT Bridge Maintenance Facility
- Bellevue City Hall

Category 2 Critical Customers:

- Bellevue Fire Stations 1 through 9
- Washington State Patrol Bellevue – Emergency Response Center
- Bellevue School District Elementary and Middle Schools
- Bellevue College Campus
- Bellevue Service Center – Emergency Management Center
- Bellevue Utilities - Eastgate Yard

Category 3 Critical Customers:

- Local Medical and Urgent Care Clinics
- Malls and Shopping Centers
- Assisted Living Centers
- 520 Reservoir and Pump Station – Utilities Maintenance District Assembly Point
- Clyde Hill Reservoir – Utilities Maintenance District Assembly Point

6.2 Customer Grouping

In addition to tracking water availability to the critical customers listed above, the modeling will also track water available to customer groups. Typically, customer grouping will start with distribution zones. In some cases, the distribution zones are discrete enough to allow tracking at the zone level. However, other zones are too large to be used to group customers and the zones have been subdivided into smaller subzones for tracking of water availability to customers. These smaller subareas consist of zones that have been divided along section and quarter section lines to keep things simple. Figure 5 shows the customer grouping with zones and subzones that will be used for the modeling analysis.

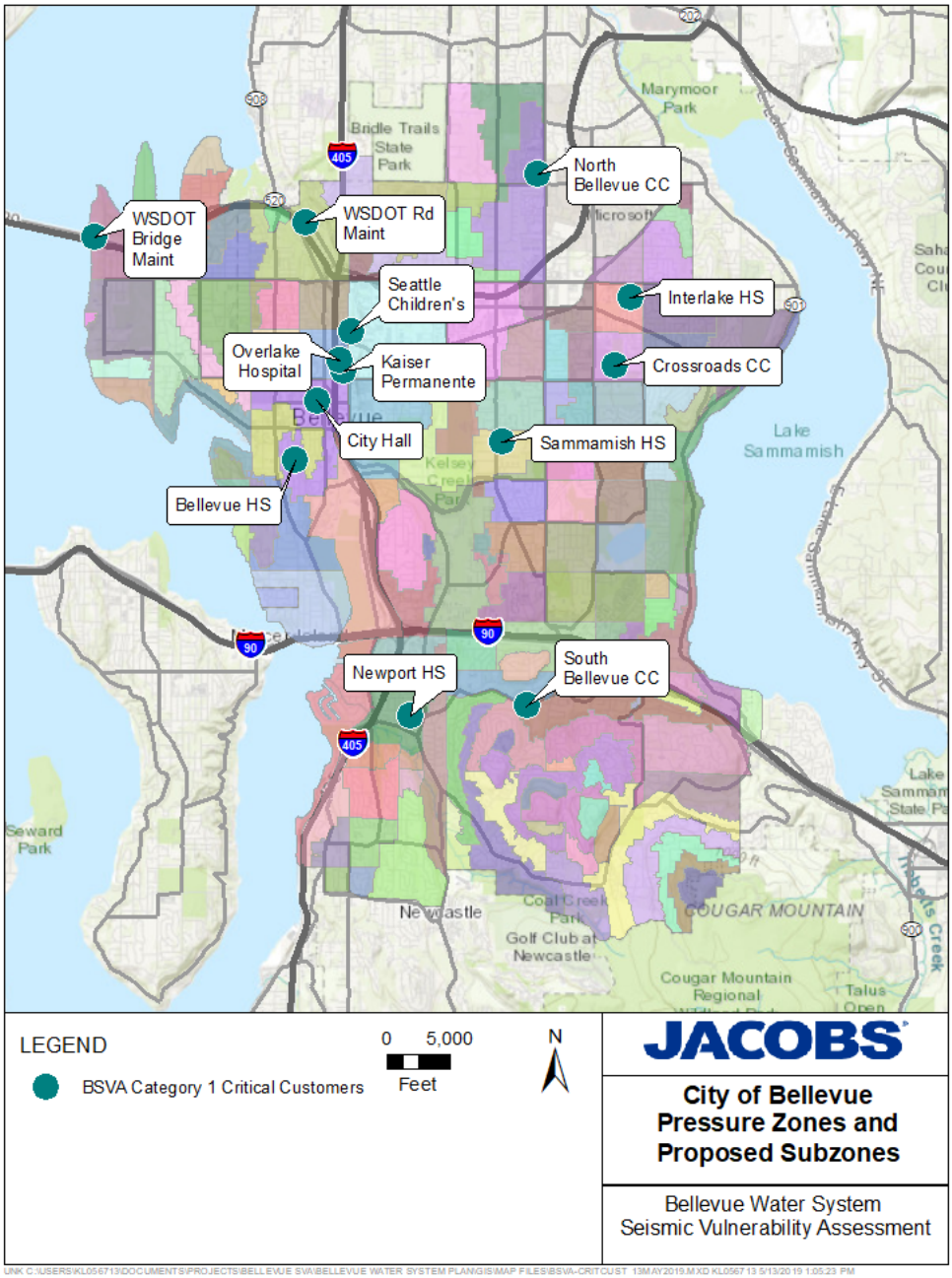

Figure 5. Bellevue Water System Category 1 Critical Customers and SVA Subareas

Attachment A

Facility	Structural Fragility Data								Additional Geotechnical Hazards			Modified Combined Failure Probability based on Additional Geotechnical Hazards	
	Hazus Classification			Damage State	Beta	Median PGA	Probability of Damage		Structural Fragility Notes	CSZ Geotech Hazard Prob	SFZE Geotech Hazard Prob	Geotechnical Hazard Notes	CSZ Damage Probability	SFZE Damage Probability
							CSZ_M9	SFZ_East						
Reservoirs														
Cherry Crest	PST1		On-Ground Anchored Concrete Tank	PGA (%g)			0.187 g	0.474 g						
				No Damage			70.03%	12.20%						
				Minor	0.55	0.25	22.76%	43.05%						
				Moderate	0.70	0.52	6.87%	32.38%						
				Extensive	0.60	0.95	0.24%	8.56%						
				Complete	0.70	1.64	0.10%	3.81%						
Clyde Hill 465	PST3		On-Ground Anchored Steel Tank	PGA (%g)			0.191 g	0.465 g						
				No Damage			77.36%	23.26%						
				Minor	0.60	0.3	21.11%	51.97%						
				Moderate	0.60	0.7	1.33%	18.37%						
				Extensive	0.65	1.25	0.17%	4.43%						
				Complete	0.60	1.6	0.02%	1.97%						
Clyde Hill 390	PST1		On-Ground Anchored Concrete Tank	PGA (%g)			0.19 g	0.467 g				Geotechnical Hazard added to account for potential undermining of foundation due to adjacent track.		
				No Damage			68.71%	12.75%						
				Minor	0.55	0.25	23.66%	43.33%						
				Moderate	0.70	0.52	7.25%	32.04%		22.5%	45.0%		**28.1%**	**62.6%**
				Extensive	0.60	0.95	0.27%	8.24%		14.5%	29.0%		**14.7%**	**34.8%**
				Complete	0.70	1.64	0.11%	3.64%		0.5%	1.0%		**0.6%**	**4.6%**
Clyde Hill 335 Rd	PST4		On-Ground Unanchored Steel Tank	PGA (%g)			0.19 g	0.493 g						
				No Damage			36.82%	4.47%						
				Minor	0.70	0.15	42.41%	27.93%						
				Moderate	0.75	0.35	16.31%	34.20%						
				Extensive	0.75	0.68	3.38%	15.98%						
				Complete	0.70	0.95	1.07%	17.42%						
Clyde Hill 335 Sq	PST1 - Shifted		On-Ground Anchored Concrete Tank	PGA (%g)			0.19 g	0.493 g						
				No Damage			79.52%	18.35%						
				Minor	0.55	0.25	15.83%	44.83%						
				Moderate	0.70	0.52	4.33%	28.70%						
				Extensive	0.60	0.95	0.28%	5.85%						
				Complete	0.70	1.64	0.04%	2.27%						
Cougar Mt. 1	PST1		On-Ground Anchored Concrete Tank	PGA (%g)			0.166 g	0.607 g						
				No Damage			76.99%	5.32%						
				Minor	0.55	0.25	17.83%	35.92%						
				Moderate	0.70	0.52	5.00%	35.92%						
				Extensive	0.60	0.95	0.13%	15.05%						
				Complete	0.70	1.64	0.05%	7.78%						
Cougar Mt. 2	PST1		On-Ground Anchored Concrete Tank	PGA (%g)			0.156 g	0.611 g						
				No Damage			80.20%	5.19%						
				Minor	0.55	0.25	15.47%	35.69%						
				Moderate	0.70	0.52	4.19%	35.96%						
				Extensive	0.60	0.95	0.09%	15.25%						
				Complete	0.70	1.64	0.04%	7.92%						

Facility	Structural Fragility Data								Additional Geotechnical Hazards			Modified Combined Failure Probability based on Additional Geotechnical Hazards	
	Hazus Classification			Damage State	Beta	Median PGA	Probability of Damage		Structural Fragility Notes	CSZ Geotech Hazard Prob	SFZE Geotech Hazard Prob	Geotechnical Hazard Notes	CSZ Damage Probability	SFZE Damage Probability
							CSZ_M9	SFZ_East						
Cougar Mt. 3	PST4		On-Ground Unanchored Steel Tank	PGA (%g)			0.147 g	0.615 g	This facility is defined as an unanchored tank because there is no positive connection between the tank wall and concrete ring wall. The median PGAs at each damage state for unanchored steel tanks are approximately 0.5*PGAs for anchored steel tanks. We would expect to see more damage at lower ground motions for the unanchored steel tanks.					
				No Damage			50.99%	2.20%						
				Minor	0.70	0.15	36.54%	20.42%						
				Moderate	0.75	0.35	10.39%	32.71%						
				Extensive	0.75	0.68	1.69%	17.97%						
				Complete	0.70	0.95	0.39%	26.70%						
Cougar Mt. 3A	PST4		On-Ground Unanchored Steel Tank	PGA (%g)			0.147 g	0.609 g	This facility is defined as an unanchored tank because there is no positive connection between the tank wall and concrete ring wall. The median PGAs at each damage state for unanchored steel tanks are approximately 0.5*PGAs for anchored steel tanks. We would expect to see more damage at lower ground motions for the unanchored steel tanks.					
				No Damage			51.02%	2.27%						
				Minor	0.70	0.15	36.52%	20.74%						
				Moderate	0.75	0.35	10.38%	32.84%						
				Extensive	0.75	0.68	1.69%	17.91%						
				Complete	0.70	0.95	0.39%	26.24%						
Factoria	PST4		On-Ground Unanchored Steel Tank	PGA (%g)			0.205 g	0.627 g	This facility is defined as an unanchored tank because there is no positive connection between the tank wall and concrete ring wall. The median PGAs at each damage state for unanchored steel tanks are approximately 0.5*PGAs for anchored steel tanks. We would expect to see more damage at lower ground motions for the unanchored steel tanks.			Additional geotechnical hazard added to account for construction on sandy soil with potential for high groundwater levels		
				No Damage			33.75%	2.06%						
				Minor	0.70	0.15	42.41%	19.79%						
				Moderate	0.75	0.35	18.32%	32.46%		30%	30%		**42.8%**	**52.7%**
				Extensive	0.75	0.68	4.08%	18.07%		20%	30%		**23.3%**	**42.7%**
				Complete	0.70	0.95	1.43%	27.61%		20%	30%		**21.1%**	**49.3%**
Forest Hills	PST1		On-Ground Anchored Concrete Tank	PGA (%g)			0.19 g	0.586 g				Additional geotechnical hazard added to account for construction on significant slope.		
				No Damage			69.04%	6.05%						
				Minor	0.55	0.25	23.44%	37.16%						
				Moderate	0.70	0.52	7.16%	35.69%		18%	35%		**23.9%**	**58.2%**
				Extensive	0.60	0.95	0.26%	14.02%		5%	10%		**5.3%**	**22.6%**
				Complete	0.70	1.64	0.10%	7.08%		2%	5%		**2.1%**	**11.7%**
Horizon View 1 - NEW	PST3		On-Ground Anchored Steel Tank	PGA (%g)			0.188 g	0.606 g						
				No Damage			78.20%	12.06%						
				Minor	0.60	0.3	20.38%	47.43%						
				Moderate	0.60	0.7	1.24%	27.25%						
				Extensive	0.65	1.25	0.16%	7.97%						
				Complete	0.60	1.6	0.02%	5.28%						
Horizon View 2	PST4		On-Ground Unanchored Steel Tank	PGA (%g)			0.187 g	0.591 g	This facility is defined as an unanchored tank because there is no positive connection between the tank wall and concrete ring wall. The median PGAs at each damage state for unanchored steel tanks are approximately 0.5*PGAs for anchored steel tanks. We would expect to see more damage at lower ground motions for the unanchored steel tanks.					
				No Damage			37.69%	2.51%						
				Minor	0.70	0.15	42.15%	21.73%						
				Moderate	0.75	0.35	15.90%	33.18%						
				Extensive	0.75	0.68	3.25%	17.71%						
				Complete	0.70	0.95	1.01%	24.86%						
Horizon View 3	PST1 - Shifted		On-Ground Anchored Concrete Tank	PGA (%g)			0.187 g	0.587 g						
				No Damage			80.52%	11.13%						
				Minor	0.55	0.25	15.22%	42.34%						
				Moderate	0.70	0.52	4.13%	33.10%						
				Extensive	0.60	0.95	0.09%	9.44%						
				Complete	0.70	1.64	0.04%	3.99%						
Horizon View 3A	PST1		On-Ground Anchored Concrete Tank	PGA (%g)			0.187 g	0.596 g						
				No Damage			70.03%	5.69%						
				Minor	0.55	0.25	22.76%	36.57%						
				Moderate	0.70	0.52	6.87%	35.82%						
				Extensive	0.60	0.95	0.24%	14.52%						
				Complete	0.70	1.64	0.10%	7.41%						

Facility	Structural Fragility Data								Additional Geotechnical Hazards			Modified Combined Failure Probability based on Additional Geotechnical Hazards	
	Hazus Classification			Damage State	Beta	Median PGA	Probability of Damage		Structural Fragility Notes	CSZ Geotech Hazard Prob	SFZE Geotech Hazard Prob	Geotechnical Hazard Notes	CSZ Damage Probability	SFZE Damage Probability
							CSZ_M9	SFZ_East						
Lake Hills North	PST3		On-Ground Anchored Steel Tank	PGA (%g)			0.187 g	0.549 g						
				No Damage			78.29%	15.69%						
				Minor	0.60	0.3	20.30%	50.03%						
				Moderate	0.60	0.7	1.24%	24.01%						
				Extensive	0.65	1.25	0.16%	6.54%						
				Complete	0.60	1.6	0.02%	3.73%						
Lake Hills South	PST3		On-Ground Anchored Steel Tank	PGA (%g)			0.187 g	0.551 g						
				No Damage			78.45%	15.55%						
				Minor	0.60	0.3	20.16%	49.95%						
				Moderate	0.60	0.7	1.22%	24.13%						
				Extensive	0.65	1.25	0.16%	6.59%						
				Complete	0.60	1.6	0.02%	3.78%						
Meydenbauer N	PST1		On-Ground Anchored Concrete Tank	PGA (%g)			0.192 g	0.591 g						
				No Damage			68.37%	5.86%						
				Minor	0.55	0.25	23.89%	36.87%						
				Moderate	0.70	0.52	7.35%	35.76%						
				Extensive	0.60	0.95	0.28%	14.27%						
				Complete	0.70	1.64	0.11%	7.24%						
Meydenbauer S	PST1		On-Ground Anchored Concrete Tank	PGA (%g)			0.192 g	0.591 g						
				No Damage			68.37%	5.86%						
				Minor	0.55	0.25	23.89%	36.87%						
				Moderate	0.70	0.52	7.35%	35.76%						
				Extensive	0.60	0.95	0.28%	14.27%						
				Complete	0.70	1.64	0.11%	7.24%						
N.E. 40th	PST1		On-Ground Anchored Concrete Tank	PGA (%g)			0.189 g	0.411 g						
				No Damage			69.32%	18.25%						
				Minor	0.55	0.25	23.24%	44.89%						
				Moderate	0.70	0.52	7.07%	28.69%						
				Extensive	0.60	0.95	0.26%	5.76%						
				Complete	0.70	1.64	0.10%	2.40%						
Newport	PST1		On-Ground Anchored Concrete Tank	PGA (%g)			0.162 g	0.595 g						
				No Damage			77.93%	5.72%						
				Minor	0.55	0.25	17.15%	36.63%						
				Moderate	0.70	0.52	4.75%	35.81%						
				Extensive	0.60	0.95	0.12%	14.47%						
				Complete	0.70	1.64	0.05%	7.37%						
Parksite	PST4		On-Ground Unanchored Steel Tank	PGA (%g)			0.192 g	0.642 g	This facility is defined as an unanchored tank because there is no positive connection between the tank wall and concrete ring wall. The median PGAs at each damage state for unanchored steel tanks are approximately 0.5*PGAs for anchored steel tanks. We would expect to see more damage at lower ground motions for the unanchored steel tanks.			Additional geotechnical hazard added to account for potential impact of uphill slope and vegetation damaging tank from outside.		
				No Damage			35.98%	1.90%						
				Minor	0.70	0.15	42.65%	19.04%						
				Moderate	0.75	0.35	16.72%	32.13%		15%	40%		**29.2%**	**59.3%**
				Extensive	0.75	0.68	3.52%	18.18%		9%	35%		**12.2%**	**46.8%**
				Complete	0.70	0.95	1.14%	28.76%		1%	5%		**2.1%**	**32.3%**
Pikes Peak	PST4		On-Ground Unanchored Steel Tank	PGA (%g)			0.181 g	0.418 g						
				No Damage			39.47%	7.18%						
				Minor	0.70	0.15	41.57%	33.47%						
				Moderate	0.75	0.35	15.08%	33.53%						
				Extensive	0.75	0.68	2.99%	13.79%						
				Complete	0.70	0.95	0.89%	12.03%						

Facility	Structural Fragility Data								Additional Geotechnical Hazards			Modified Combined Failure Probability based on Additional Geotechnical Hazards	
	Hazus Classification			Damage State	Beta	Median PGA	Probability of Damage		Structural Fragility Notes	CSZ Geotech Hazard Prob	SFZE Geotech Hazard Prob	Geotechnical Hazard Notes	CSZ Damage Probability	SFZE Damage Probability
							CSZ_M9	SFZ_East						
Sammamish	PST1		On-Ground Anchored Concrete Tank	PGA (%g)			0.138 g	0.528 g						
				No Damage			85.96%	8.67%						
				Minor	0.55	0.25	11.14%	40.44%						
				Moderate	0.70	0.52	2.84%	34.45%						
				Extensive	0.60	0.95	0.05%	11.17%						
				Complete	0.70	1.64	0.02%	5.27%						
Somerset 2	PWT5		Large Water Treatment Plants, Anchored	PGA (%g)			0.191 g	0.614 g						
				No Damage			98.15%	20.24%						
				Minor	0.40	0.44	1.57%	24.09%						
				Moderate	0.40	0.58	0.24%	33.74%						
				Extensive	0.45	0.87	0.04%	20.09%						
				Complete	0.45	1.57	0.00%	1.85%						
Woodridge	PST3		On-Ground Anchored Steel Tank	PGA (%g)			0.192 g	0.678 g						
				No Damage			77.13%	8.71%						
				Minor	0.60	0.3	21.31%	43.41%						
				Moderate	0.60	0.7	1.36%	30.56%						
				Extensive	0.65	1.25	0.18%	9.70%						
				Complete	0.60	1.6	0.02%	7.62%						
Kirkland 545 - South	PST4		On-Ground Unanchored Steel Tank	PGA (%g)			0.196 g	0.373 g						
				No Damage			35.17%	9.68%						
				Minor	0.70	0.15	42.86%	36.94%						
				Moderate	0.75	0.35	17.11%	32.21%						
				Extensive	0.75	0.68	3.65%	12.09%						
				Complete	0.70	0.95	1.21%	9.07%						
CCUD 580 East	PST4		On-Ground Unanchored Steel Tank	PGA (%g)			0.193 g	0.576 g	This facility is not owned by the City of Bellevue. Design drawings were not available for review. Limited information available suggests the facility is an On-Ground Unanchored steel tank					
				No Damage			35.99%	2.74%						
				Minor	0.70	0.15	42.65%	22.59%						
				Moderate	0.75	0.35	16.71%	33.43%						
				Extensive	0.75	0.68	3.52%	17.52%						
				Complete	0.70	0.95	1.14%	23.71%						
CCUD 580 West	PST4		On-Ground Unanchored Steel Tank	PGA (%g)			0.193 g	0.576 g	This facility is not owned by the City of Bellevue. Design drawings were not available for review. Limited information available suggests the facility is an On-Ground Unanchored steel tank					
				No Damage			35.99%	2.74%						
				Minor	0.70	0.15	42.65%	22.59%						
				Moderate	0.75	0.35	16.71%	33.43%						
				Extensive	0.75	0.68	3.52%	17.52%						
				Complete	0.70	0.95	1.14%	23.71%						

Facility	Structural Fragility Data									Additional Geotechnical Hazards			Modified Combined Failure Probability based on Additional Geotechnical Hazards	
	Hazus Classification			Damage State	Beta	Median PGA	Probability of Damage		Structural Fragility Notes	CSZ Geotech Hazard Prob	SFZE Geotech Hazard Prob	Geotechnical Hazard Notes	CSZ Damage Probability	SFZE Damage Probability
							CSZ_M9	SFZ_East						
CCUD 440	PST4		On-Ground Unanchored Steel Tank	PGA (%g)			0.189 g	0.574 g	This facility is not owned by the City of Bellevue. Design drawings were not available for review. Limited information available suggests the facility is an On-Ground Unanchored steel tank					
				No Damage			37.11%	2.77%						
				Minor	0.70	0.15	42.32%	22.71%						
				Moderate	0.75	0.35	16.17%	33.46%						
				Extensive	0.75	0.68	3.34%	17.50%						
				Complete	0.70	0.95	1.05%	23.56%						
CCUD 700	PST1		On-Ground Anchored Concrete Tank	PGA (%g)			0.193 g	0.576 g	This facility is not owned by the City of Bellevue. Design drawings were not available for review. Limited information available suggests the facility is an On-Ground concrete tank					
				No Damage			68.03%	6.43%						
				Minor	0.55	0.25	24.12%	37.74%						
				Moderate	0.70	0.52	7.45%	35.54%						
				Extensive	0.60	0.95	0.29%	13.53%						
				Complete	0.70	1.64	0.11%	6.75%						
Eastside	PWT5		Large Water Treatment Plants, Anchored	PGA (%g)			0.202 g	0.64 g						
				No Damage			97.42%	17.44%						
				Minor	0.40	0.44	2.16%	22.83%						
				Moderate	0.40	0.58	0.36%	34.97%						
				Extensive	0.45	0.87	0.06%	22.45%						
				Complete	0.45	1.57	0.00%	2.31%						

Facility	Structural Fragility Data								Additional Geotechnical Hazards			Modified Combined Failure Probability based on Additional Geotechnical Hazards	
	Hazus Classification			Damage State	Beta	Median PGA	Probability of Damage		Structural Fragility Notes	CSZ Geotech Hazard Prob	SFZE Geotech Hazard Prob	Geotechnical Hazard Notes	CSZ Damage Probability	SFZE Damage Probability
							CSZ_M9	SFZ_East						
Pump Stations														
Cherry Crest	PC1	Moderate	Precast concrete Tilt-Up Walls	PGA (%g)			0.186 g	0.475 g	Based on the date of construction, this facility was classified as 'Moderate Code' level. There are 4 code levels within Hazus (Pre, Low, Moderate, & High Code) that are selected based on the design timeframe. These code levels account for evolving design requirements and seismic maps within the Building Codes. We would expect to see more damage at higher ground motions for the Moderate Code Precast concrete tilt-up walls.					
				No Damage			53.59%	6.48%						
				Minor	0.64	0.18	17.52%	7.83%						
				Moderate	0.64	0.24	21.87%	31.02%						
				Extensive	0.64	0.44	5.20%	28.17%						
				Complete	0.64	0.71	1.82%	26.50%						
Clyde Hill	C2L	Low	Concrete Shear Walls, Low-Rise	PGA (%g)			0.191 g	0.467 g	Based on the date of construction, this facility was classified as 'Low Code' level. There are 4 code levels within Hazus (Pre, Low, Moderate, & High Code) that are selected based on the design timeframe. These code levels account for evolving design requirements and seismic maps within the Building Codes. We would expect to see more damage at higher ground motions for the Low Code concrete shear walls.					
				No Damage			31.37%	2.99%						
				Minor	0.64	0.14	18.30%	5.01%						
				Moderate	0.64	0.19	26.33%	16.50%						
				Extensive	0.64	0.3	18.11%	32.17%						
				Complete	0.64	0.52	5.88%	43.34%						
Cougar Mt. 1	RM1L	Moderate	Reinforced Masonry Bearing walls w/ Wood Diaphragms	PGA (%g)			0.166 g	0.607 g	Based on the date of construction, this facility was classified as 'Moderate Code' level. There are 4 code levels within Hazus (Pre, Low, Moderate, & High Code) that are selected based on the design timeframe. These code levels account for evolving design requirements and seismic maps within the Building Codes. We would expect to see more damage at higher ground motions for the Moderate Code reinforced masonry walls.					
				No Damage			67.01%	5.64%						
				Minor	0.64	0.22	15.24%	7.91%						
				Moderate	0.64	0.3	13.51%	24.56%						
				Extensive	0.64	0.5	3.71%	32.03%						
				Complete	0.64	0.85	0.53%	29.87%						
Cougar Mt. 2	RM1L	Moderate	Reinforced Masonry Bearing walls w/ Wood Diaphragms	PGA (%g)			0.156 g	0.611 g	Based on the date of construction, this facility was classified as 'Moderate Code' level. There are 4 code levels within Hazus (Pre, Low, Moderate, & High Code) that are selected based on the design timeframe. These code levels account for evolving design requirements and seismic maps within the Building Codes. We would expect to see more damage at higher ground motions for the Moderate Code reinforced masonry walls.					
				No Damage			70.45%	5.53%						
				Minor	0.64	0.22	14.21%	7.80%						
				Moderate	0.64	0.3	11.90%	24.39%						
				Extensive	0.64	0.5	3.04%	32.06%						
				Complete	0.64	0.85	0.40%	30.22%						
Cougar Mt. 3	RM1L	Moderate	Reinforced Masonry Bearing walls w/ Wood Diaphragms	PGA (%g)			0.147 g	0.609 g	Based on the date of construction, this facility was classified as 'Moderate Code' level. There are 4 code levels within Hazus (Pre, Low, Moderate, & High Code) that are selected based on the design timeframe. These code levels account for evolving design requirements and seismic maps within the Building Codes. We would expect to see more damage at higher ground motions for the Moderate Code reinforced masonry walls.					
				No Damage			73.57%	5.58%						
				Minor	0.64	0.22	13.18%	7.85%						
				Moderate	0.64	0.3	10.46%	24.47%						
				Extensive	0.64	0.5	2.48%	32.05%						
				Complete	0.64	0.85	0.30%	30.05%						
Forest Hills	C2L	Moderate	Concrete Shear Walls, Low-Rise	PGA (%g)			0.19 g	0.586 g	Based on the date of construction, this facility was classified as 'Moderate Code' level. There are 4 code levels within Hazus (Pre, Low, Moderate, & High Code) that are selected based on the design timeframe. These code levels account for evolving design requirements and seismic maps within the Building Codes. We would expect to see more damage at higher ground motions for the Moderate Code concrete shear walls.			Additional geotechnical hazard added to account for location of pump station on significant hill and construction of pump station on structural fill with steep fill slopes.		
				No Damage			46.64%	3.26%						
				Minor	0.64	0.18	29.60%	11.52%						
				Moderate	0.64	0.3	16.83%	24.22%		30%	30%		**41.8%**	**47.0%**
				Extensive	0.64	0.49	6.07%	34.20%		15%	30%		**20.2%**	**53.9%**
				Complete	0.64	0.87	0.87%	26.80%		15%	25%		**15.7%**	**45.1%**
Horizon View 1 - NEW	RM1L	High	Reinforced Masonry Bearing walls w/ Wood Diaphragms	PGA (%g)			0.188 g	0.605 g						
				No Damage			76.69%	13.62%						
				Minor	0.64	0.3	15.20%	19.79%						
				Moderate	0.64	0.46	7.48%	41.48%						
				Extensive	0.64	0.93	0.58%	18.27%						
				Complete	0.64	1.57	0.05%	6.84%						

Facility	Structural Fragility Data								Additional Geotechnical Hazards			Modified Combined Failure Probability based on Additional Geotechnical Hazards	
	Hazus Classification			Damage State	Beta	Median PGA	Probability of Damage		Structural Fragility Notes	CSZ Geotech Hazard Prob	SFZE Geotech Hazard Prob	Geotechnical Hazard Notes	CSZ Damage Probability	SFZE Damage Probability
							CSZ_M9	SFZ_East						
Horizon View 2	URML	Low	Unreinforced Masonry Bearing Wall, Low-Rise	PGA (%g)			0.187 g	0.591 g	Based on the date of construction, this facility was classified as 'Low Code' level. There are 4 code levels within Hazus (Pre, Low, Moderate, & High Code) that are selected based on the design timeframe. These code levels account for evolving design requirements and seismic maps within the Building Codes. We would expect to see more damage at lower ground motions for the Low Code unreinforced masonry walls.					
				No Damage			32.55%	1.22%						
				Minor	0.64	0.14	21.73%	3.33%						
				Moderate	0.64	0.2	25.66%	12.35%						
				Extensive	0.64	0.32	12.07%	17.87%						
				Complete	0.64	0.46	7.98%	65.24%						
Horizon View 3	PWT5	NA	Large Water Treatment Plants, Anchored	PGA (%g)			0.187 g	0.595 g						
				No Damage			98.38%	22.53%						
				Minor	0.40	0.44	1.39%	24.92%						
				Moderate	0.40	0.58	0.20%	32.63%						
				Extensive	0.45	0.87	0.03%	18.37%						
				Complete	0.45	1.57	0.00%	1.55%						
Lake Hills (Crossroads)	RM1L	Moderate	Reinforced Masonry Bearing walls w/ Wood Diaphragms	PGA (%g)			0.187 g	0.549 g	Based on the date of construction, this facility was classified as 'Moderate Code' level. There are 4 code levels within Hazus (Pre, Low, Moderate, & High Code) that are selected based on the design timeframe. These code levels account for evolving design requirements and seismic maps within the Building Codes. We would expect to see more damage at higher ground motions for the Moderate Code reinforced masonry walls.					
				No Damage			60.03%	7.66%						
				Minor	0.64	0.22	16.97%	9.60%						
				Moderate	0.64	0.3	16.78%	26.94%						
				Extensive	0.64	0.5	5.32%	31.14%						
				Complete	0.64	0.85	0.89%	24.66%						
Meydenbauer	C2L	High	Concrete Shear Walls, Low-Rise	PGA (%g)			0.194 g	0.591 g						
				No Damage			63.02%	7.96%						
				Minor	0.64	0.24	27.55%	25.55%						
				Moderate	0.64	0.45	8.61%	40.94%						
				Extensive	0.64	0.9	0.77%	18.96%						
				Complete	0.64	1.55	0.06%	6.60%						
NE 8th Inlet	PWT5	NA	Large Water Treatment Plants, Anchored	PGA (%g)			0.203 g	0.54 g						
				No Damage			97.34%	30.43%						
				Minor	0.40	0.44	2.22%	26.65%						
				Moderate	0.40	0.58	0.37%	28.46%						
				Extensive	0.45	0.87	0.06%	13.58%						
				Complete	0.45	1.57	0.00%	0.88%						
NE 40th	RM1L	Moderate	Reinforced Masonry Bearing walls w/ Wood Diaphragms	PGA (%g)			0.189 g	0.411 g						
				No Damage			59.39%	16.45%						
				Minor	0.64	0.22	17.11%	14.70%						
				Moderate	0.64	0.3	17.09%	30.89%						
				Extensive	0.64	0.5	5.49%	25.20%						
				Complete	0.64	0.85	0.94%	12.77%						
Newport	C2L	Moderate	Concrete Shear Walls, Low-Rise	PGA (%g)			0.163 g	0.599 g	Based on the date of construction, this facility was classified as 'Moderate Code' level. There are 4 code levels within Hazus (Pre, Low, Moderate, & High Code) that are selected based on the design timeframe. These code levels account for evolving design requirements and seismic maps within the Building Codes. We would expect to see more damage at higher ground motions for the Moderate Code concrete shear walls.					
				No Damage			56.16%	3.02%						
				Minor	0.64	0.18	26.82%	10.99%						
				Moderate	0.64	0.3	12.75%	23.69%						
				Extensive	0.64	0.49	3.83%	34.37%						
				Complete	0.64	0.87	0.44%	27.94%						
Parksite	URML	Low	Unreinforced Masonry Bearing Wall, Low-Rise	PGA (%g)			0.194 g	0.643 g	Based on the date of construction, this facility was classified as 'Low Code' level. There are 4 code levels within Hazus (Pre, Low, Moderate, & High Code) that are selected based on the design timeframe. These code levels account for evolving design requirements and seismic maps within the Building Codes. We would expect to see more damage at lower ground motions for the Low Code unreinforced masonry walls.					
				No Damage			30.51%	0.86%						
				Minor	0.64	0.14	21.49%	2.56%						
				Moderate	0.64	0.2	26.30%	10.36%						
				Extensive	0.64	0.32	12.83%	16.25%						
				Complete	0.64	0.46	8.87%	69.97%						

Facility	Structural Fragility Data								Additional Geotechnical Hazards			Modified Combined Failure Probability based on Additional Geotechnical Hazards	
	Hazus Classification			Damage State	Beta	Median PGA	Probability of Damage		Structural Fragility Notes	CSZ Geotech Hazard Prob	SFZE Geotech Hazard Prob	Geotechnical Hazard Notes	CSZ Damage Probability	SFZE Damage Probability
							CSZ_M9	SFZ_East						
Pikes Peak	C2L	Low	Concrete Shear Walls, Low-Rise	PGA (%g)			0.181 g	0.418 g	Based on the date of construction, this facility was classified as 'Low Code' level. There are 4 code levels within Hazus (Pre, Low, Moderate, & High Code) that are selected based on the design timeframe. These code levels account for evolving design requirements and seismic maps within the Building Codes. We would expect to see more damage at higher ground motions for the Low Code concrete shear walls.					
				No Damage			34.41%	4.37%						
				Minor	0.64	0.18	18.61%	6.53%						
				Moderate	0.64	0.3	25.52%	19.35%						
				Extensive	0.64	0.49	16.50%	33.10%						
				Complete	0.64	0.87	4.96%	36.66%						
SE 28th Inlet	PWT5	NA	Large Water Treatment Plants, Anchored	PGA (%g)			0.193 g	0.712 g						
				No Damage			98.03%	11.44%						
				Minor	0.40	0.44	1.67%	18.96%						
				Moderate	0.40	0.58	0.26%	36.79%						
				Extensive	0.45	0.87	0.04%	28.86%						
				Complete	0.45	1.57	0.00%	3.94%						
Somerset Inlet	PWT5	NA	Large Water Treatment Plants, Anchored	PGA (%g)			0.189 g	0.65 g						
				No Damage			98.27%	16.47%						
				Minor	0.40	0.44	1.48%	22.32%						
				Moderate	0.40	0.58	0.22%	35.37%						
				Extensive	0.45	0.87	0.03%	23.35%						
				Complete	0.45	1.57	0.00%	2.50%						
Somerset 2	PWT5	NA	Large Water Treatment Plants, Anchored	PGA (%g)			0.191 g	0.614 g						
				No Damage			98.15%	20.24%						
				Minor	0.40	0.44	1.57%	24.09%						
				Moderate	0.40	0.58	0.24%	33.74%						
				Extensive	0.45	0.87	0.04%	20.09%						
				Complete	0.45	1.57	0.00%	1.85%						
Woodridge	RM1L	Moderate	Reinforced Masonry Bearing walls w/ Wood Diaphragms	PGA (%g)			0.191 g	0.678 g	Based on the date of construction, this facility was classified as 'Moderate Code' level. There are 4 code levels within Hazus (Pre, Low, Moderate, & High Code) that are selected based on the design timeframe. These code levels account for evolving design requirements and seismic maps within the Building Codes. We would expect to see more damage at higher ground motions for the Moderate Code reinforced masonry walls.					
				No Damage			58.40%	3.93%						
				Minor	0.64	0.22	17.30%	6.20%						
				Moderate	0.64	0.3	17.55%	21.58%						
				Extensive	0.64	0.5	5.75%	32.17%						
				Complete	0.64	0.85	1.00%	36.11%						
161st Ave Inlet	PWT5	NA	Large Water Treatment Plants, Anchored	PGA (%g)			0.189 g	0.643 g						
				No Damage			98.27%	17.15%						
				Minor	0.40	0.44	1.48%	22.68%						
				Moderate	0.40	0.58	0.22%	35.10%						
				Extensive	0.45	0.87	0.03%	22.72%						
				Complete	0.45	1.57	0.00%	2.36%						
670/NE 40th	URML	Low	Unreinforced Masonry Bearing Wall, Low-Rise	PGA (%g)			0.201 g	0.423 g	Based on the date of construction, this facility was classified as 'Low Code' level. There are 4 code levels within Hazus (Pre, Low, Moderate, & High Code) that are selected based on the design timeframe. These code levels account for evolving design requirements and seismic maps within the Building Codes. We would expect to see more damage at lower ground motions for the Low Code unreinforced masonry walls.					
				No Damage			28.60%	4.20%						
				Minor	0.64	0.14	21.19%	7.94%						
				Moderate	0.64	0.2	26.85%	21.01%						
				Extensive	0.64	0.32	13.57%	22.05%						
				Complete	0.64	0.46	9.79%	44.80%						

Facility	Structural Fragility Data								Additional Geotechnical Hazards			Modified Combined Failure Probability based on Additional Geotechnical Hazards	
	Hazus Classification			Damage State	Beta	Median PGA	Probability of Damage		Structural Fragility Notes	CSZ Geotech Hazard Prob	SFZE Geotech Hazard Prob	Geotechnical Hazard Notes	CSZ Damage Probability	SFZE Damage Probability
							CSZ_M9	SFZ_East						
CCUD 475/580	C2L	Moderate	Concrete Shear Walls, Low-Rise	PGA (%g)			0.189 g	0.574 g						
				No Damage			46.97%	3.50%						
				Minor	0.64	0.18	29.53%	12.04%						
				Moderate	0.64	0.3	16.68%	24.71%						
				Extensive	0.64	0.49	5.98%	34.01%						
				Complete	0.64	0.87	0.85%	25.74%						
CCUD Hazelwood	PWT5	NA	Large Water Treatment Plants, Anchored	PGA (%g)			0.193 g	0.576 g						
				No Damage			98.03%	25.04%						
				Minor	0.40	0.44	1.67%	25.65%						
				Moderate	0.40	0.58	0.26%	31.35%						
				Extensive	0.45	0.87	0.041%	16.68%						
				Complete	0.45	1.57	0.00016%	1.29%						
Wells														
WD97 Well No. 3	PWE1		Wells	PGA (%g)			0.181 g	0.624 g						
				No Damage			40.15%	2.87%						
				Minor	0.75	0.15	45.35%	17.00%						
				Moderate	0.65	0.36	12.82%	38.84%						
				Extensive	0.65	0.72	1.27%	27.63%						
				Complete	0.80	1.5	0.41%	13.66%						
WD97 Well No. 5	PWE1		Wells	PGA (%g)			0.187 g	0.549 g						
				No Damage			38.48%	4.19%						
				Minor	0.75	0.15	45.85%	21.62%						
				Moderate	0.65	0.36	13.77%	40.36%						
				Extensive	0.65	0.72	1.44%	23.37%						
				Complete	0.80	1.5	0.46%	10.46%						
WD97 Well No. 6	PWE1		Wells	PGA (%g)			0.187 g	0.549 g						
				No Damage			38.48%	4.19%						
				Minor	0.75	0.15	45.85%	21.62%						
				Moderate	0.65	0.36	13.77%	40.36%						
				Extensive	0.65	0.72	1.44%	23.37%						
				Complete	0.80	1.5	0.46%	10.46%						
WD97 Well No. 7	PWE1		Wells	PGA (%g)			0.187 g	0.549 g						
				No Damage			38.48%	4.19%						
				Minor	0.75	0.15	45.85%	21.62%						
				Moderate	0.65	0.36	13.77%	40.36%						
				Extensive	0.65	0.72	1.44%	23.37%						
				Complete	0.80	1.5	0.46%	10.46%						

Facility	Structural Fragility Data								Additional Geotechnical Hazards			Modified Combined Failure Probability based on Additional Geotechnical Hazards	
	Hazus Classification			Damage State	Beta	Median PGA	Probability of Damage		Structural Fragility Notes	CSZ Geotech Hazard Prob	SFZE Geotech Hazard Prob	Geotechnical Hazard Notes	CSZ Damage Probability	SFZE Damage Probability
							CSZ_M9	SFZ_East						
Inlets														
161st Inlet	PWT5		Large Water Treatment Plants, Anchored	PGA (%g)			0.189 g	0.643 g						
				No Damage			98.27%	17.15%						
				Minor	0.40	0.44	1.48%	22.68%						
				Moderate	0.40	0.58	0.22%	35.10%						
				Extensive	0.45	0.87	0.03%	22.72%						
				Complete	0.45	1.57	0.00%	2.36%						
Bel Red Inlet	PWT5		Large Water Treatment Plants, Anchored	PGA (%g)			0.199 g	0.523 g						
				No Damage			97.64%	33.29%						
				Minor	0.40	0.44	1.99%	26.91%						
				Moderate	0.40	0.58	0.32%	26.90%						
				Extensive	0.45	0.87	0.05%	12.18%						
				Complete	0.45	1.57	0.00%	0.73%						
Cherry Crest Inlet	PWT5		Large Water Treatment Plants, Anchored	PGA (%g)			0.187 g	0.48 g						
				No Damage			98.38%	41.39%						
				Minor	0.40	0.44	1.39%	26.80%						
				Moderate	0.40	0.58	0.20%	22.50%						
				Extensive	0.45	0.87	0.03%	8.89%						
				Complete	0.45	1.57	0.00%	0.42%						
Eastgate Inlet	PWT5		Large Water Treatment Plants, Anchored	PGA (%g)			0.2 g	0.64 g						
				No Damage			97.56%	17.44%						
				Minor	0.40	0.44	2.05%	22.83%						
				Moderate	0.40	0.58	0.33%	34.97%						
				Extensive	0.45	0.87	0.05%	22.45%						
				Complete	0.45	1.57	0.00%	2.31%						
Enatai	PWT5		Large Water Treatment Plants, Anchored	PGA (%g)			0.183 g	0.646 g						
				No Damage			98.59%	16.85%						
				Minor	0.40	0.44	1.22%	22.52%						
				Moderate	0.40	0.58	0.17%	35.21%						
				Extensive	0.45	0.87	0.03%	22.99%						
				Complete	0.45	1.57	0.00%	2.42%						
Inlet #11	PWT5		Large Water Treatment Plants, Anchored	PGA (%g)			0.189 g	0.659 g						
				No Damage			98.27%	15.63%						
				Minor	0.40	0.44	1.48%	21.84%						
				Moderate	0.40	0.58	0.22%	35.68%						
				Extensive	0.45	0.87	0.03%	24.17%						
				Complete	0.45	1.57	0.00%	2.68%						
Inlet #6	PWT5		Large Water Treatment Plants, Anchored	PGA (%g)			0.191 g	0.574 g						
				No Damage			98.15%	25.31%						
				Minor	0.40	0.44	1.57%	25.72%						
				Moderate	0.40	0.58	0.24%	31.20%						
				Extensive	0.45	0.87	0.04%	16.50%						
				Complete	0.45	1.57	0.00%	1.27%						

Facility	Structural Fragility Data								Additional Geotechnical Hazards			Modified Combined Failure Probability based on Additional Geotechnical Hazards	
	Hazus Classification			Damage State	Beta	Median PGA	Probability of Damage		Structural Fragility Notes	CSZ Geotech Hazard Prob	SFZE Geotech Hazard Prob	Geotechnical Hazard Notes	CSZ Damage Probability	SFZE Damage Probability
							CSZ_M9	SFZ_East						
Inlet #8	PWT5		Large Water Treatment Plants, Anchored	PGA (%g)			0.179 g	0.556 g						
				No Damage			98.77%	27.93%						
				Minor	0.40	0.44	1.06%	26.27%						
				Moderate	0.40	0.58	0.14%	29.81%						
				Extensive	0.45	0.87	0.02%	14.93%						
				Complete	0.45	1.57	0.00%	1.05%						
NE 40th Inlet	PWT5		Large Water Treatment Plants, Anchored	PGA (%g)			0.2 g	0.424 g						
				No Damage			97.56%	53.69%						
				Minor	0.40	0.44	2.05%	24.63%						
				Moderate	0.40	0.58	0.33%	16.17%						
				Extensive	0.45	0.87	0.05%	5.33%						
				Complete	0.45	1.57	0.00%	0.18%						
NE 8th Inlet	PWT5		Large Water Treatment Plants, Anchored	PGA (%g)			0.203 g	0.54 g						
				No Damage			97.34%	30.43%						
				Minor	0.40	0.44	2.22%	26.65%						
				Moderate	0.40	0.58	0.37%	28.46%						
				Extensive	0.45	0.87	0.06%	13.58%						
				Complete	0.45	1.57	0.00%	0.88%						
Richards Road	PWT5		Large Water Treatment Plants, Anchored	PGA (%g)			0.207 g	0.663 g						
				No Damage			97.03%	15.27%						
				Minor	0.40	0.44	2.47%	21.63%						
				Moderate	0.40	0.58	0.43%	35.80%						
				Extensive	0.45	0.87	0.07%	24.53%						
				Complete	0.45	1.57	0.00%	2.77%						
SE 28th Inlet	PWT5		Large Water Treatment Plants, Anchored	PGA (%g)			0.192 g	0.71 g						
				No Damage			98.09%	11.58%						
				Minor	0.40	0.44	1.62%	19.07%						
				Moderate	0.40	0.58	0.25%	36.77%						
				Extensive	0.45	0.87	0.04%	28.69%						
				Complete	0.45	1.57	0.00%	3.89%						

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Technical Memorandum

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Subject	**DRAFT - TM 2A: Comparison of ALA Equations to Christchurch Earthquake Repair Data**
Project Name	Bellevue Seismic Vulnerability Assessment
Attention	Doug Lane, City of Bellevue
From	Jacobs
Date	November 27th, 2019

1. Background

The City of Bellevue water system seismic vulnerability assessment (SVA) will incorporate vulnerabilities of Bellevue water system pipelines and facilities into a comprehensive modeling analysis to predict the performance of the water system in seismic events and develop restoration expectations and mitigation alternatives. Elements of the water system will be evaluated using Hazus fragility curves for major facilities and modified American Lifelines Alliance (ALA) fragility equations for pipelines (See TM2 for further detail on the analysis methodology).

Approximately 40 percent of the pipe in the Bellevue water system is Asbestos Cement (AC) and the data used for the ALA empirical equation development contained limited information for AC pipe. In order to provide more certainty regarding the application of fragility curves to the Bellevue water system, the following analysis of available information from the Christchurch water system following the 2010–-2011 earthquakes was completed.

2. ALA Equations

The American Lifelines Alliance (ALA) was created in 1998 by the American Society of Civil Engineers (ASCE) and the Federal Emergency Management Agency (FEMA). In 1999, ALA commissioned a group of experts to prepare methods that describe the potential for damage to water transmission system components from earthquake hazards. [1] The resulting damage algorithms can be used to perform earthquake loss estimates.

The ALA seismic fragility equations for buried pipe express the repair rate per unit length of pipe as a function of ground shaking or ground displacement. Peak ground velocity (PGV) is a measure of the speed of ground movement, while PGD measures the displacement of liquefaction settlement or lateral spread (in cm) and the displacement of landslide movement. PGD is also used to quantify ground rupture displacement in the fault zone.

The ALA equations are as follows:

Wave Propagation (PGV Equation): $RR = K_1 \times 0.00187 \times PGV$

Permanent Ground Deformation (PGD Equation): $RR = K_2 \times 1.06 \times PGD^{0.319}$

Where:

[1] American Lifelines Alliance (ALA). 2001. *Seismic Fragility Formulations for Water Systems 2001 Report*, April.

RR = repairs per 1,000 feet of pipe

K_1 = Coefficient specific to each pipe material for Wave Propagation Equation

K_2 = Coefficient specific to each pipe material for Permanent Ground Deformation Equation

PGV = peak ground velocity in inches/second

PGD = permanent ground deformation in inches

Repairs per 1,000 feet of pipe (RR) due to PGD and due to wave propagation are estimated using the appropriate equation for each hazard. The total number of leaks and total number of breaks are then estimated by adding results from both equations (due to PGD and due to wave propagation). The "K" values in the equations are a constant representing the relative fragility of the pipe, based on the ALA empirical data. The original coefficients relied on limited empirical data available at the time. In their 2001 report, the ALA acknowledges the limitations of their method and that "a complete empirical database for all pipe materials under all levels of shaking still does not exist.[2]

3. Comparison of ALA equations to earthquakes in Christchurch, New Zealand

Given the lack of significant data used to create the ALA fragilities for wave propagation (PGV) impacts on AC, more recent data with significant quantities of AC pipe was reviewed to compare to the ALA fragilities. The watermains in Christchurch, NZ are 52.7 percent AC pipes[3] and between September 2010 and December 2011 Christchurch was affected by several earthquakes now referred to as the Canterbury Earthquake Sequence (CES). These included the Mw 7.1 September 2010 (south of Christchurch) and M_W 6.2 February 2011 earthquakes. The February 2011 event resulted in the most significant damage to infrastructure in the City of Christchurch as its epicenter was in the heart of the City. The Christchurch earthquakes were shallow crustal events with high shaking intensity and low duration. Thus, there are some limitations to this analysis when applied to other types of earthquakes that are likely to impact the City of Bellevue. For example, while the South Whidbey Island Fault and the Seattle fault zone are shallow, the CSZ is a crustal interface fault that would have a longer duration but lower shaking intensity in Bellevue when compared to the CES. The actual impact on the pipes will depend on the type of earthquake and related variables such as duration of shaking. However, the analysis for this project is based only on PGD and PGV as defined by the ALA fragility equations.

Significant research has been completed on the CES by the University of Canterbury and the University of Delaware. The combination of significant proportions of AC pipe and the detailed data collected following the earthquakes made Christchurch a good candidate for analysis to compare the ALA fragilities to systems constructed with significant quantities of AC pipe. AC pipe products in Christchurch followed a similar progression of composition and construction changes as AC pipe in the United States. This includes the conversion from concrete collars to rubber gasketed joints during the time when AC pipe was primarily used. Specific data on exactly when product transitions occurred in each water system is not well documented, so this level of detail has not been included in the analysis. Given lack of original manufacturing specifications, for the purposes of this assessment it is assumed that AC pipe in Christchurch at the time of the earthquakes were comparable to AC pipe in the Bellevue water system.

The analysis of the AC pipe failure rates and repair data form the Christchurch earthquake was completed in two phases. The first phase was focused on the ground deformation equation (PGD) and the on the ground shaking (PGV) equation. The second phase was more in depth analysis of ground

[2] American Lifelines Alliance (ALA). 2001. *Seismic Fragility Formulations for Water Systems 2001 Report*, April.

[3] Cubrinovski, MIsko, Matthew Hughes, Brendon Bradley,Ian McCahon, Yvonne McDonald, Howard Simpson, Rod Cameron, Mark Christison, Bruce Henderson, Rolando Orense, and Thomas O'Rourke. 2011. Liquefaction Impacts on Pipe Networks: Short Term Recovery Project No. 6 Natural Hazards Research Platform. Dec 2011. University of Canterbury.

shaking (PGV) repair data described in *Earthquake Response of Underground Pipeline Networks in Christchurch, NZ*[4] by O'Rourke et al.

3.1 Permanent Ground Deformation Repairs

The first phase included a cursory review of the overall repair rate data from two studies - *Liquefaction Impacts on Pipe Networks*[3] and *Performance of Horizontal Infrastructure in Christchurch City through the 2010 – 2011 Canterbury Earthquake Sequence*[5] (Cubrinovski et al. 2014) to consider the relative difference between the expected performance based on the ALA equations and the actual performance in the Christchurch earthquake. The former study classified land in Christchurch City into five main zones, from 0 - areas of most ground displacement and lowest Liquefaction Resistance Index (LRI), to 4 - areas of least ground displacement (Zone 4) and highest LRIs. The remaining zones where no observations were taken, were classified as "No Liquefaction Observations". This study also recorded the total pipes in each zone, classified by material and diameter.

This analysis was completed by using the ALA equations to calculate the estimated repair rate for pipe in Christchurch using the actual length of pipe in Christchurch. This was then compared to the empirical data representing the number of repairs that occurred after the Christchurch earthquake. The estimated and actual repairs were compared to determine how accurate the ALA equations were at predicting repairs for this earthquake. Additionally, the ALA report provides different K_1 and K_2 values for AC pipe depending on the joint type (rubber gasket or cement). Thus, estimates were calculated for both joint types.

3.1.1 Review of Ground Deformation Repair Data

Ranges of PGD values for each LRI zone were recorded in the 2011 report, so these were used for the comparison based on the PGD equation for pipes in LRI zones 0, 1, 2 and 3.[2] Zones designated as 4 or No Liquefaction Observations were not analyzed with the PGD equation because, based on how they are defined, most damage in these areas is assumed to not be due to liquefaction.

Figure 4 shows that the actual damage experienced in the February 2011 Christchurch earthquake from pipe sizes greater than 4 inches compared to the ALA equation estimations with the ALA K_2 value of 0.8 (for rubber gasketed joints), as well as two other potential K_2 value alternatives (1.2 and 0.5). The ALA equations tend to overpredict the number of repairs for lower liquefaction magnitudes (LRI zones 3 and 2) and underpredict the number of repairs for higher liquefaction magnitudes (LRI zones 1 and 0).

[4] O'Rourke, et al., Earthquake Response of Underground Pipeline Networks in Christchurch, NZ

[5] Cubrinovski, MIsko, Matthew Hughes, Brendon Bradley, John Noonan, Rex Hopkins, Steve McNeill, and Geoff English. 2014. Performance of Horizontal Infrastructure in Christchurch City through the 2010-2011 Canterbury Earthquake Sequence, March 2014. University of Canterbury.

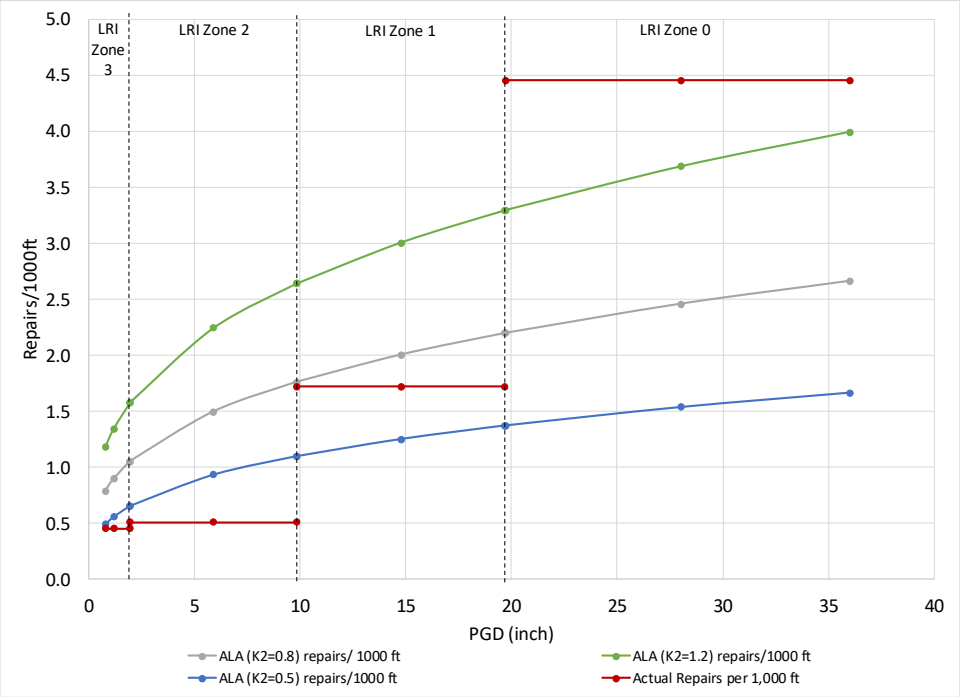

Figure 4. Actual 2011 Christchurch Repairs in Liquefaction Zones Compared to ALA

Figure 5 shows the same data, but with the actual repairs categorized between smaller pipe (6 and 8 inch diameter) and larger pipe (greater than 8 inch diameter).

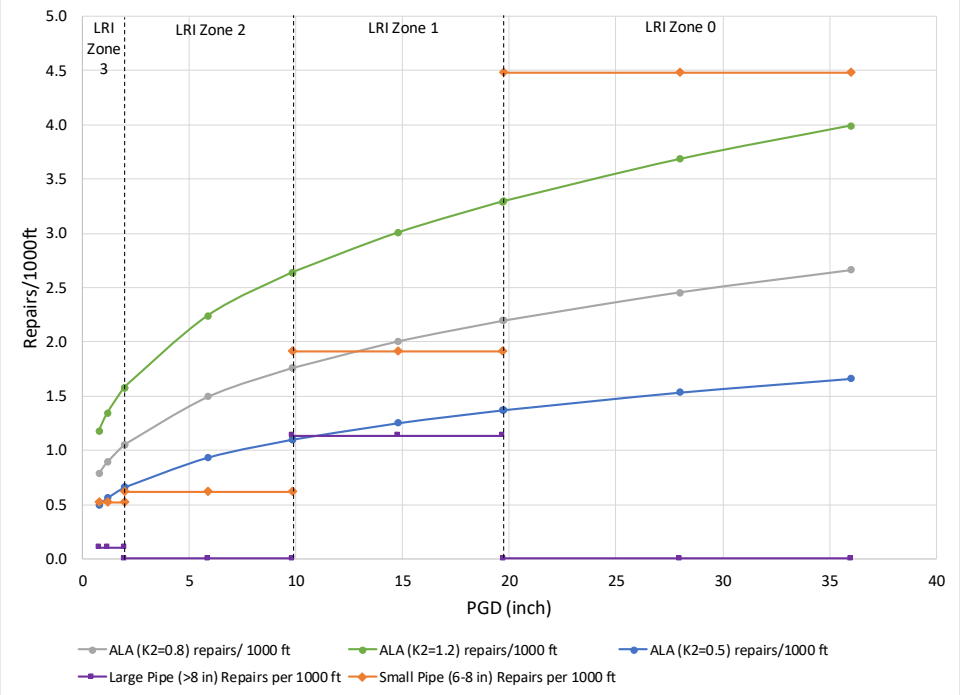

Figure 5. Actual 2011 Christchurch Repairs in Liquefaction Zones by Pipe Size Compared to ALA

3.1.2 Recommendations for Ground Deformation (PGD) Repair Equations

Based on the evaluation of pipe repairs in liquefactions zones, compared to ALA estimates for repairs due to PGD, the ALA equations appear to be on the same order of magnitude as the actual repairs from

Christchurch. The recommend modification to the K_2 values for use in the Bellevue water system analysis is to increase the K_2 value to 1.0 for AC pipe less than or equal to 8 inches in diameter.

3.1.3 Review of Ground Shaking (PGV) Repair Data

Phase 1 also included a review of the Cubrinovski data related to PGV. The PGV values for each LRI zone were obtained from USGS Shake map GIS data for the 2011 Mw 6.2 Christchurch earthquake. This earthquake was chosen because it resulted in higher ground motions and more damage to the Christchurch water system than the Mw 7.1 earthquake. Representative low, medium, and high PGV values for each zone were obtained from the Shake map and tabulated. This data review did not result in meaningful results and so determination of analysis for PGV was placed on hold until the phase 2 analysis.

3.2 Christchurch PGV repair data compared to ALA equations

Phase 2 of the comparison of ALA equations to the Christchurch earthquakes looked at a more in-depth analysis of ground shaking (PGV) repair data described in *Earthquake Response of Underground Pipeline Networks in Christchurch, NZ*[6] (O'Rourke et al. 2014) The data collected from the Christchurch earthquakes showed substantially greater repair rates at high PGVs than had been observed in the data set use for development of the ALA equations. The original empirical data originally used to develop the ALA equations was shown to significantly underpredict the actual failures in Christchurch. Additionally, the expected PGVs in the Bellevue water system during the Seattle Fault Zone earthquake scenario are greater than the highest recorded in the Christchurch earthquake. As such any repair rates in that area are extrapolations from all available data. An additional challenge in comparing the repair data from Christchurch to the ALA equations is that the Christchurch data appears to follow a distinct exponential curve, where the ALA curves for PGV are linear.

To compare this data and develop a revised empirical relationship for use on AC pipe in the Bellevue water system, the exponential curve developed by O'Rourke et al. was compared to the ALA linear curve for AC pipe. The actual data points for both Christchurch and the ALA dataset were also combined to determine what K_1 value for the ALA equations would provide the best fit for the combined data.

The final step of the analysis was to develop a "modified" exponential curve, based on the curve provided by O'Rourke et al., which is capped at a maximum repair rate of 0.7 repairs per 1000 ft of pipe, corresponding to the highest repair rates observed in post-earthquake reconnaissance.

The total number of repairs predicted for the Bellevue water system were compared for each of the two earthquake scenarios of the original exponential curve from O'Rourke et al., the modified exponential curve, the ALA linear curve with K_1=1.0 and the ALA linear curve with K_1=4.0. These are shown compared to the actual data used in the ALA equations and the actual 2011 Christchurch data in Figure 6.

Table 1 shows the comparison of the total repairs for each earthquake scenario and the combination of the two earthquake scenarios. As shown, the ALA linear equation with a K_1=4.0 provides a similar number of repairs as the modified exponential equation for the combination of the two scenarios. Additionally, it only slightly overpredicts repairs for the Cascadia Subduction Zone scenario and only slightly underpredicts the Seattle Fault Zone repairs

[6] O'Rourke, et al. 2014. "Earthquake Response of Underground Pipeline Networks in Christchurch, NZ" Earthquake Spectra. Vol. 30, No. 1 Feb 2014. pp. 183-204

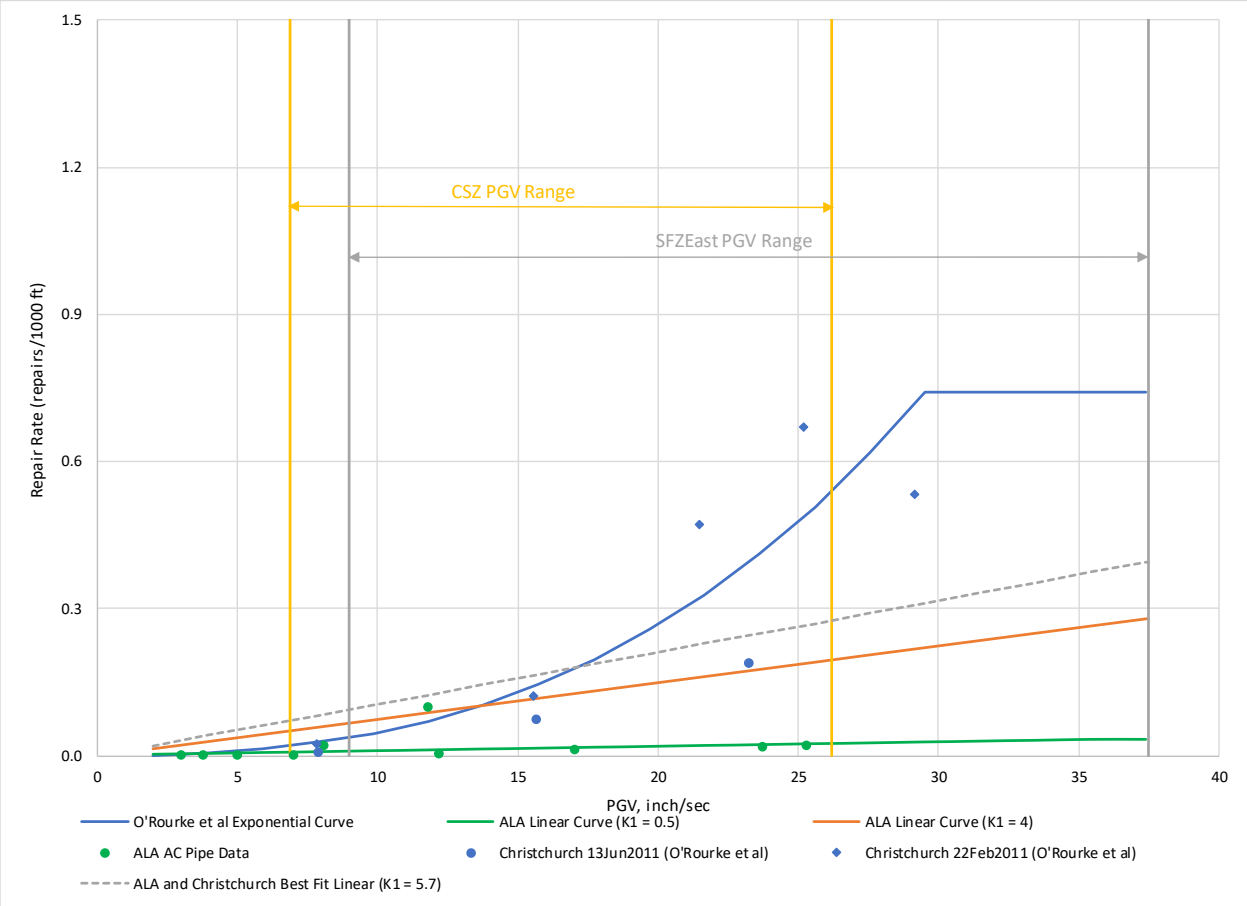

Figure 6. ALA and O'Rourke PGV equations compared to data from ALA development and 2011 Christchurch Earthquakes

Table 1. EARTHQUAKE SCENARIOS AND PREDICTED REPAIRS

Earthquake Scenario	ALA Linear Equation Predicted Repairs (K_1 = 1.0)	ALA Linear Equation (K_1 = 4.0)	Modified Exponential Equation	Exponential Equation
Cascadia Subduction Zone	30	137	82	83
Seattle Fault Zone East	56	224	288	482
Total	86	361	371	565

4. Recommendations for AC Pipe Repair Estimations

Based on the review of the AC pipe repair data available from the Christchurch earthquakes, it is recommended that the ALA fragility equations be used with the following coefficients for AC pipe.

Table 2. ALA AND BELLEVUE SEISMIC VULNERABILITY ASSESSMENT (BSVA) "K" VALUES FOR AC PIPE

Pipe Material Abbreviation	ALA PGV "K_1" Value	ALA PGD "K_2" Value	BSVA PGV "K_1" Value	BSVA PGD "K_2" Value
AC, Rubber Gasketed (>8")	0.5	0.8[1]	4.0[2]	0.8[1]
AC, Rubber Gasketed (6 – 8")	0.5	0.8[1]	4.0[2]	1.0[2]

[1] "K" value from ALA Guideline "Seismic Fragility Formulations for Water Systems"

[2] "K" value developed based on evaluation of AC pipe performance in Christchurch 2011 earthquake in consideration of data available from ALA "Seismic Fragility Formulations for Water Systems"

These K values are based on available empirical data and analysis. As available data may change over time, the City could also keep up to date on other major studies and additional earthquake data that better characterize K values.

Appendix C. System Modeling Methodology

C.1 TM3: Modeling Methodology

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Technical Memorandum

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Subject	**FINAL DRAFT - TM3: Modeling Methodology**
Project Name	Bellevue Seismic Vulnerability Assessment
Attention	Doug Lane, City of Bellevue
From	Jacobs
Date	June 3rd, 2019

1. Background

As part of the City of Bellevue (City) Water System Seismic Vulnerability Assessment (SVA), Jacobs will be completing hydraulic and failure probability modeling of the Bellevue water system under selected earthquake scenarios. This modeling will estimate the potential damage to the system, customer service impacts, the probable restoration times following a seismic scenario event, and improvement alternatives to address system resiliency needs. To support the analysis, assumed likelihood and expected duration of outage for the Seattle Public Utilities (SPU) Tolt Eastside Supply Line (TESSL) and Cedar Eastside Supply Line (CESSL) will be incorporated to the model at the point where the TESSL and CESSL enter the Bellevue water service area.

2. Modeling Approach and Tools

The approach for the hydraulic modeling is outlined below in Figure 1. The matrix shows the phases of the analysis and the specific tools that are applied in each phase of the analysis. The approach is founded on leveraging the City's existing hydraulic model to assess hydraulic performance and water supply throughout the distribution system and includes an overlay of spatial geotechnical information to develop vulnerability parameters for pipelines and facilities in the City's system. The approach identifies each phase of the modeling process and how information from one phase informs the next phase of the modeling with the outcomes from the prior phase. This step-wise approach to modeling allows for focus of analysis on areas of the system that supply assumed critical customers (described in TM2) and those that impact large areas of the system if damaged. The inputs for each phase are listed and are described in detail in the next section (Modeling Inputs), and the information gained from each phase of the modeling analysis (Modeling Goals and Expected Outcomes) are also described in a later section.

2.1 Hydraulic Modeling

The tools used in the modeling analysis start with the City's existing hydraulic model in InfoWater. This hydraulic model is exported to EPANet for use with OptiCritical and Optimizer by Optimatics. OptiCritical is used to perform a hydraulic consequence of failure analysis and identifies the most critical pipes within the pipe network based upon the areas impacted both during a break event and then also during the repair period when the break is isolated. Optimizer is used to develop the optimal approach for restoration of the distribution system and evaluate improvement alternatives. To incorporate the probability of breaks and/or leaks into the OptiCritical analysis, a shapefile of the pipes in the hydraulic model will be exported from the InfoWater model to use with overlays of the geotechnical information and with the isolation valves from the City's geodatabase.

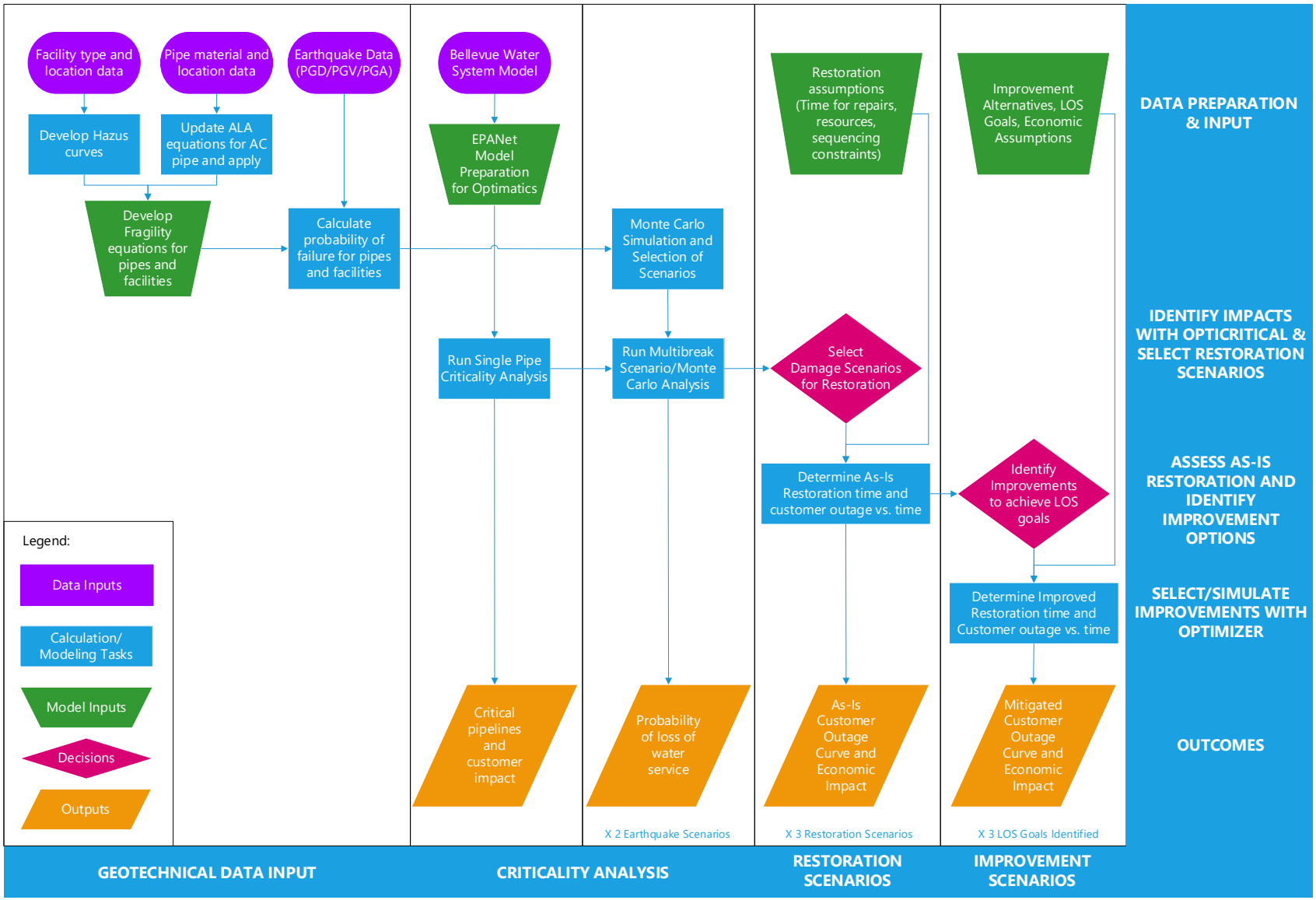


Figure 1. Modeling Approach

The City's existing hydraulic model include all pipelines within the City's distribution system, relevant (simplified) pipelines in adjacent inter-connected distribution systems (e.g. CCUD, Redmond), and pipelines of the SPU transmission systems that are within the City's boundaries. The SPU pipelines inside the Bellevue water service area will be incorporated into the overlays with the geotechnical information and will be incorporated into the system-wide analysis. The nodes where the SPU transmission pipelines enter the system will be represented as reservoirs (or similar) with water available based on the probability and expected restoration duration for each supply line for each earthquake.

The distribution of pipe segment length within the City's hydraulic model was assessed to determine if there was a minimum pipe length that should be excluded from the analysis or if skeletonization of the model based upon pipe diameter, material, and roughness would be beneficial for the analysis. Skeletonization joins pipes in series if a specified set of parameters (like pipe diameter, material, and roughness) are the same. Since the hydraulic model is an "all pipes" model derived from the City's GIS, there are many pipe segments for pipes in series that share the same physical attributes. For the Bellevue model, skeletonization was performed based upon the pipe diameter, material, and roughness parameters, and this reduced the total number of pipes in the Bellevue model by approximately fifty percent. The same pipe length remained in the model, but the number of pipe segments was reduced. The hydraulic model performance of the skeletonized model was confirmed to provide the same results as the full-pipe model.

The SPU supply operability will be considered. The control settings of inlet valves to the City's system from the SPU supplies were reviewed. After discussions with City staff, it was decided that all inlet valves would be set to operate in PRV mode (none in flow control mode), so that inlets would open if an adjacent inlet was isolated and could not supply water. This verification was performed so that supply from SPU is maintained from inlets that may not be impacted during a break scenario. If inlets were forced to be closed based upon a previous operational scheme, the criticality of some locations in the City's distribution system may be overstated.

After skeletonization of the model, the model is exported to EPANET for use with OptiCritical. To validate the performance of the exported EPANet model with the InfoWater model, the selected scenario will be run in EPANet and compared to the model output in InfoWater. InfoWater uses EPANet as the hydraulic engine, so it is anticipated that results from the InfoWater model, and the EPANet file will be similar. Tank level variation, supply from inlets, pump station flows, and overall system pressure will be compared to confirm that the EPANet file is comparably simulating the City's system as is observed with the InfoWater model. Valve types that are not available in EPANet such as altitude valves will be modified to a throttle control valve for simulation in the EPANet model. A final step to prepare the model in OptiCritical is to link the City's valves to the model network. After an initial review of the City's valves GIS and spatial alignment with the model network, the City updated locations of valves in areas where pipe replacements had been made. These adjustments by the City staff improved the linkage of the valves to the correct pipe segment in the hydraulic model. In addition, the City's hydraulic model is managed in a projection that is different than the projection used for the City's GIS. To improve the valve alignment of the valves from the City's geodatabase with the model pipes, the valves will be reprojected in ArcGIS to the projection used with the City's hydraulic model.

Excel will be used to track information that is passed to the Optimatics software, including the generation of the fragility and probability data, development of cost profiles, and development of the objective function for optimization. Excel is an efficient option to manage data for use with Optimatics software as the data updates can be streamlined based upon changing input factors and can be quickly updated and changed to support sensitivity analyses of parameters.

2.2 Multi-break Scenario Generation

The input for the multi-break scenarios will be generated with a Monte Carlo style approach that will randomly assign facility damage states and pipe breaks or leaks based on the probability of failure developed for each earthquake scenario in the vulnerability analysis described in TM 2.

Multi-break scenarios will be created using a custom python script that assigns facility damage states and pipe break and leak conditions to individual assets based upon the probability of the event occurring for that asset. Since failure is defined randomly for each scenario in accordance with the probability of failure, each scenario will have a unique combination of facility damage states or pipe breaks and leaks occurring. The overall distribution of damage, across all scenarios generated, will be consistent with the underlying probability of failure of the individual assets (for instance, assets with a higher probability of failure will fail in more multi-break failure scenarios).

For each earthquake scenario, up to ten thousand simulations will be generated using a custom python programming script run to provide a representative simulation set for hydraulic criticality analysis. Simulations will be based on a normal distribution and the mean probability of occurrence of failure for each system element modeled.

3. Modeling Inputs

A summary of the information developed and provided to the modeling team to be used in each phase of the modeling is described below. Many of the inputs will be defined spatially in GIS and assigned to the pipes within the hydraulic model and imported into the Optimatics modeling software.

3.1 Geotechnical and Vulnerability Data Input

Seismic hazard mapping for two earthquake scenarios (described in TM 1A) will be developed in GIS format. The data will include peak ground acceleration (PGA) and peak ground velocity (PGV), as well as expected permanent ground deformation magnitude and probability. This hazard mapping data will be overlaid with the facilities and pipe network to identify the simulation parameters for probability of failure for the multiple break scenarios by applying the ALA and HAZUS equations in a probabilistic manner. See TM 2 for more details on this methodology.

The probability of damage for pipes and facilities will be input into the Monte-Carlo simulation process for use in creating the multi-break simulations. This will result in a listing of specific facilities and pipes with their respective status for each selected earthquake scenario.

3.2 Criticality Analysis Input

The initial hydraulic modeling will be to perform a criticality analysis for the water system. To complete this analysis, the following data sources will be provided:

- City's water system hydraulic model: provides water system connectivity and hydraulic details, water demand distribution, and operational information for the distribution system.
- GIS Shapefiles of system valves, water mains and laterals, and facilities within the distribution system: Valves are used to provide isolation during pipe and facility failure events. Supplemental shapefiles provide guidance for valve alignment in areas where the valves are not physically close to the model pipes.
- Damage state scenarios with pipe and facility status for each of the multi-break scenarios
- Availability of TESSL and CESSL supplies for each scenario
- Critical customer types and locations: provides spatial assignment of assumed critical customers (as described in TM2) to junctions so that the delivery of water for consumption and fire protection can be assessed during criticality assessment.

- Water system population spatial distribution: provides basis for estimating the extent of the distribution system population likely to be affected under criticality and pipe failure scenarios.

3.3 Restoration Scenarios Input

In developing the initial restoration timeline for the selected system restoration scenarios, an objective function will be developed to guide analysis of prioritization of activities for restoration. The objective function is a mathematical representation of the activities to be optimized given defined constraints and with variables (time, cost, customers impacted, economic impacts) that are to be minimized or maximized. The input will include the following:

- Expected restoration time for each of the SPU transmission lines (CESSL and TESSL) for each scenario as estimated based on available information from SPU seismic study.
- Tabular summary of restoration resources (number of crews) and repair durations (crew allocation) required to repair pipe leaks, pipe breaks, and extensively damaged (non-functional) facilities.
- An optimization objective function for analysis within Optimizer that prioritizes restoration activities and actions within the distribution system that supports prioritization of restoring service to assumed critical customers and large population groups.

3.4 Improvement Scenarios Input

As shown above in Figure 1, three improvement scenarios that are varied by the Level of Service (LOS) goal will be developed for each of the three restoration scenarios. The improvement scenarios as shown in Figure 1 will build upon the data compiled during the single and multi-pipe break analysis that identify the most efficient valve closure plan for isolation. The improvement scenarios will also consider the information developed for the restoration scenarios and identification of both temporary solutions for restoring service and the potential areas where permanent hardening or looping the system could improve the initial state of the system after a seismic event. Depending upon the number of improvement options that are identified to support hardening of the system with the goal of attaining an improved initial state after a seismic event, the opportunity for applying optimization to compare and phase improvement options will be reviewed.

With optimization, the development of an objective function to use for identification of the optimal set of improvements to meet each of the level of service (LOS) goals will be developed. The level of investment of improvements for each LOS goal will allow for comparison of the cost-benefit for improving the initial state of the system and decreasing the restoration time. To generate the optimized cost profile using Optimizer for each LOS goal, the following information will be provided:

- Identification of improvement options for each improvement scenario assessed. These will include mitigation alternatives such as pipe replacement and facility hardening, as well as operational and managerial changes such as increasing pipe stockpiles and purchasing more equipment or temporary repair materials.
- Tabular summary of cost functions for seismic improvements including pipe replacement cost and order of magnitude costs for improvements to facilities. Pipe replacement costs will be summarized and assigned based upon the type of land/right of way (ROW) where the pipe is installed and will include both traditional restrained ductile iron pipe (DIP) and earthquake resistant ductile iron pipe (ERDIP).
- Tabular summary of LOS goals.
- Definition of objective function for optimizing improvement scenarios based upon LOS goals.

4. Modeling Goals and Expected Outcomes

The expected outcome for each phase of the modeling analysis is described below. As noted above, the analysis will be conducted in phases, and information generated in each phase is structured to achieve the modeling goals for that phase and provide input and information for the next phase.

4.1 Vulnerability Phase Output

The result of the vulnerability phase modeling will be used as inputs for the criticality phase and include visual representations to allow for checking of results prior to the next phase. These include:

- Damage state scenarios identifying the state of each pipe or facility for use in the multi-break analysis
- A spatial representation that shows the recurrence of failure for specific pipe segments being identified for the multi-break analysis will be generated that displays the recurrence of damage to various pipes in each of the simulations.

4.2 Criticality Phase Output

The output from the criticality phase, including both the single pipe criticality and the multiple break criticality that incorporates the geotechnical data input and includes the following:

- Probability of outage for each assumed critical customer for the single pipe break analysis
- Identification of critical facilities and pipes based upon the population (demand) disconnection during a break event and after break isolation for the single pipe break analysis
- Identification of critical facilities and pipes based upon model predicted low pressure during a break event and after break isolation for the single pipe break analysis
- Probability of outage for each assumed critical customer and each customer group for each seismic scenario from the multi-break analysis
- Damage state for three selected damage scenarios (25th, 50th and 75th percentile probability states from Monte Carlo analysis) for each of the two seismic scenarios.
    - Summary of individual pipe segments and system areas that are offline or damaged
    - Summary of facilities that are offline or damaged

4.3 Restoration Phase Output

The output from the restoration phase provides information that is used to develop improvements for system hardening and to set the time baseline and operational response assumptions for restoring service to customers. The output includes the following information on facilities:

- As-is customer outage curves and economic impact
- Optimized list of prioritized activities for restoring service to customers

4.4 Improvement Phase Output

As shown in Figure 1, the output from the improvement phase includes analysis results of system performance with improvements to mitigate the “as-is” water system damage state and a restoration analysis to develop the phasing of activities still needed to restore service to customers. The assessment of improvements and consideration of optimization will be driven by the type and number of improvements to consider. Analysis of the multi-break scenarios will be repeated with a revised break scenario, incorporating system improvements that are identified and incrementally assessed for their performance in the multi-pipe break analysis. Like the restoration phase evaluation, activities that are required to restore service for the improved system state will be optimized and prioritized. The optimization problem statement driving the improvement implementation during the restoration period (or

before) is to restore service to maximize the service restored based on population (demand) served. A summary of the output from the improvement phase includes:

- Summary of restoration analysis with seismic improvements incorporated (improved system state), demonstrating the benefit that the seismic improvements make
- Identification of seismic improvements that reduce the initial outage probability and allow for efficient restoration of service to customers
- Optimized list of prioritized activities to restore service to customers from the improved state
    - Identification of improvements/restoration actions that restore service to assumed critical customers
    - Identification of improvements/restoration actions to incrementally restore service to the broad customer base.

Appendix D. Existing System Performance

D.1 TM4: Existing System Vulnerability and Customer Outage Probability

Subject	**DRAFT – TM4: Existing System Vulnerability and Customer Outage Probability**
Project Name	Bellevue Water System Seismic Vulnerability Assessment
Attention	Doug Lane, City of Bellevue
From	Jacobs
Date	August 27, 2019

1. Background

The City of Bellevue Water System Seismic Vulnerability Assessment (SVA) includes criticality and Monte Carlo modeling of the water distribution system to identify system components that present the highest risk for customer outages. The development of the methodology used and the determination of the vulnerability of existing system components can be found in TM 2: Seismic Vulnerability Assessment for Pipelines and Facilities and TM 3: Modeling Methodology. This document describes the results of the two phases of vulnerability modeling described in TM 3. The analysis presented in this document also identifies, based on single pipe criticality analysis, the most "vulnerable" system components. The system components that are considered the most "vulnerable" are those that would be likely to have the highest impact on the number of customers without water service or with significantly curtailed service immediately following an earthquake should they fail or be damaged as a result of seismic events.

The results presented in this document include the following items:

- Pipe Vulnerability Analysis: Identification of the relative vulnerability of the pipes within the distribution system as identified by the probability of failure during an earthquake event
- Single Pipe Criticality Analysis: Identification of the individual pipe segments within the distribution system that are the most vulnerable and have potential to impact the greatest number of customers
- Monte Carlo Simulation: Development of the leak and break distribution with a randomized, Monte Carlo approach based upon the probability of pipe and facility failure to use in performing the multi-break criticality analysis
- Multi-Break Criticality Analysis: Development of the distribution of the impact of water system failures on water service interruption

2. Pipe Vulnerability Analysis

The pipe vulnerability analysis methodology and approach are described in TM 2: Seismic Vulnerability Assessment for Pipelines and Facilities. The end result of this analysis can be found in two tables titled "Pipe Vulnerability Data_CSZ.xlsx" and "Pipe Vulnerability Data_SFZE.xlsx". The vulnerability was calculated to estimate the probability of failure of each pipe in the water system as well as the expected number of leaks and breaks in each "subarea" of the system as defined in TM 2. Generally, subareas were developed based on subdividing areas around quarter sections, with the goal of keeping the total length of pipe in each subarea within a reasonable range of each other. The following figures show the results of this pipe vulnerability analysis summarized by the entire system for each earthquake scenario, and then geospatially to provide perspective on the areas of the system most impacted by each earthquake scenario.

Figure 1 shows the total number of water pipe breaks and leaks expected for each of the two earthquake scenarios evaluated as a part of this study. The Seattle Fault Zone East (SFZE) event has substantially more leaks and breaks expected than the Cascadia Subduction Zone (CSZ) event due to the more intense localized shaking associated with the SFZE event. The fault rupture from the SFZE event is likely to impact multiple pipes in the southern portion of the system as compared to the CSZ event where

potential damage is more likely to be more evenly distributed throughout the system and would involve substantially lower numbers of pipe repairs of leaks and breaks in total.

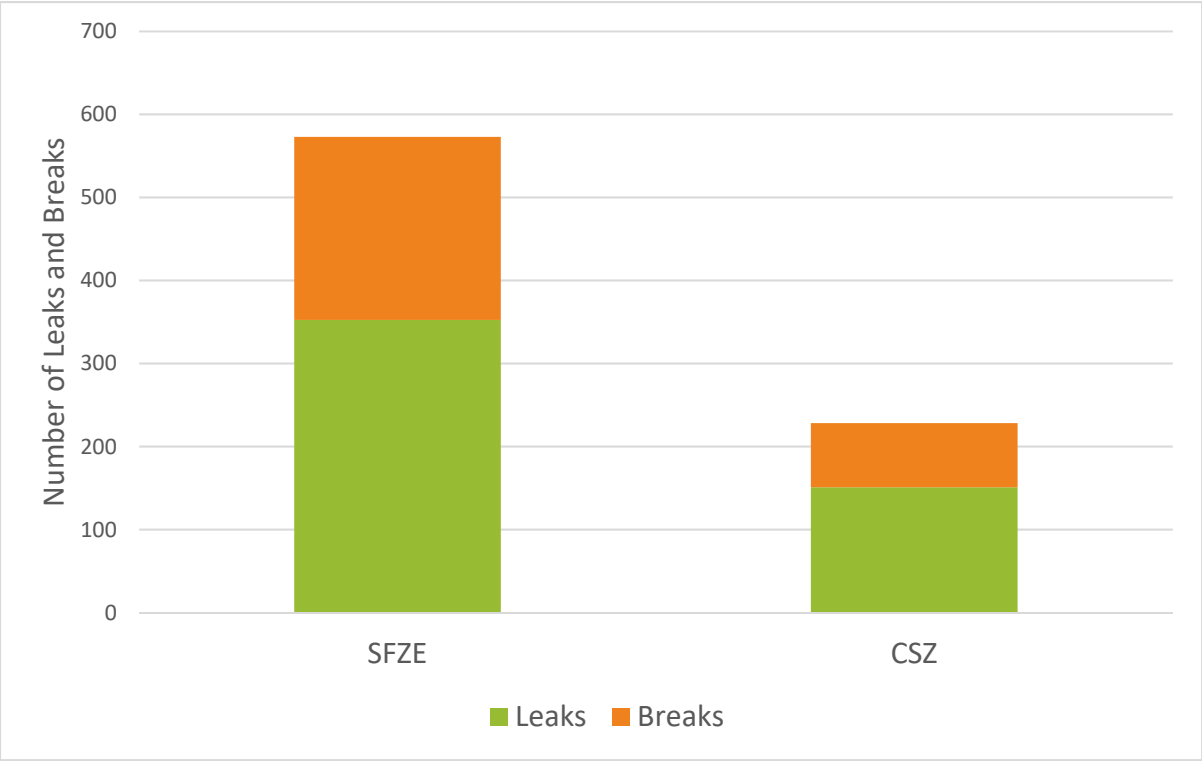


Figure 1. Pipeline ALA Vulnerability Analysis Summary

2.1 Probability of Pipe Repairs

Figures 2 and 3 show the water system pipe network with the pipes color coded by their probability of leaks in the SFZE and CSZ events, respectively. The highest probability of leaks is driven by areas where significant permanent ground deformation (liquefaction or landslide) is likely. However, because the data is shown on a per pipe basis, and the probability of leaks is based on the length of the pipe, the data is heavily influenced by the length of each pipe segment in the system.

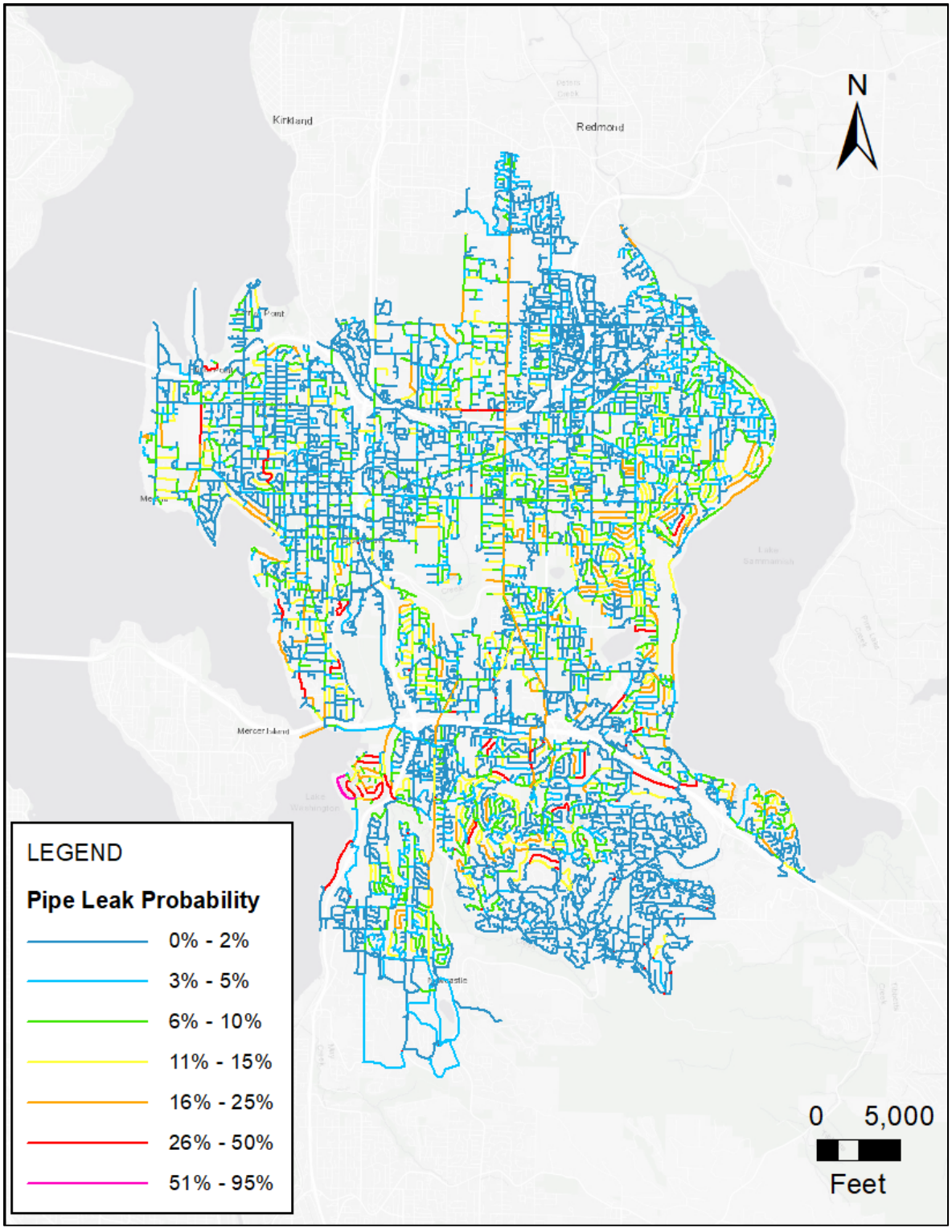


Figure 2. Seattle Fault Zone East – Pipe Leak Probabilities

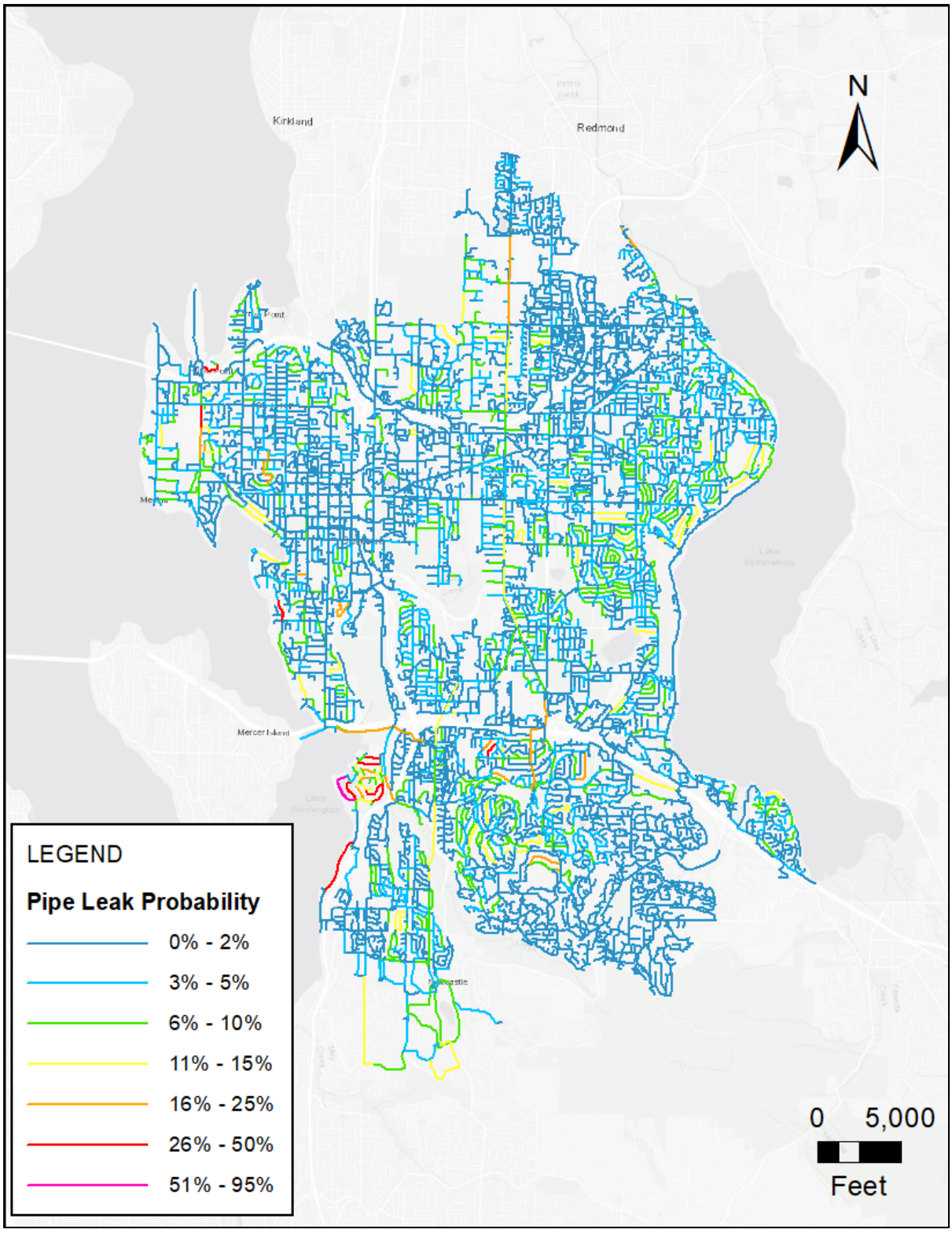


Figure 3. Cascadia Subduction Zone – Pipe Leak Probabilities

Figures 4 and 5 show the water system pipes color coded by the probability of breaks in each pipe segment for the SFZE and CSZ events, respectively. For the SFZE event, the probability of breaks is highest right along the potential fault line, followed by areas where liquefaction is likely to occur.

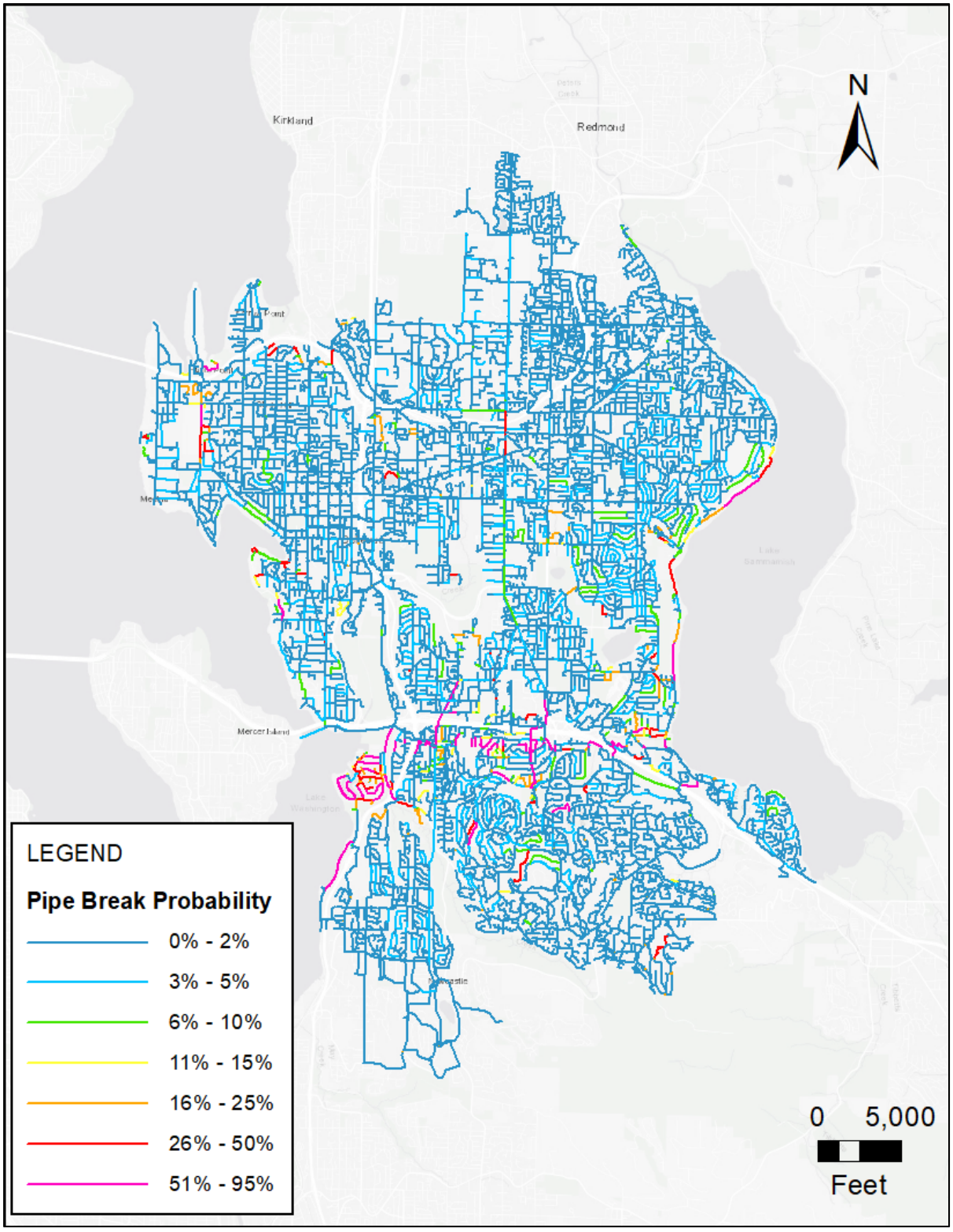


Figure 4. Seattle Fault Zone East – Pipe Break Probabilities

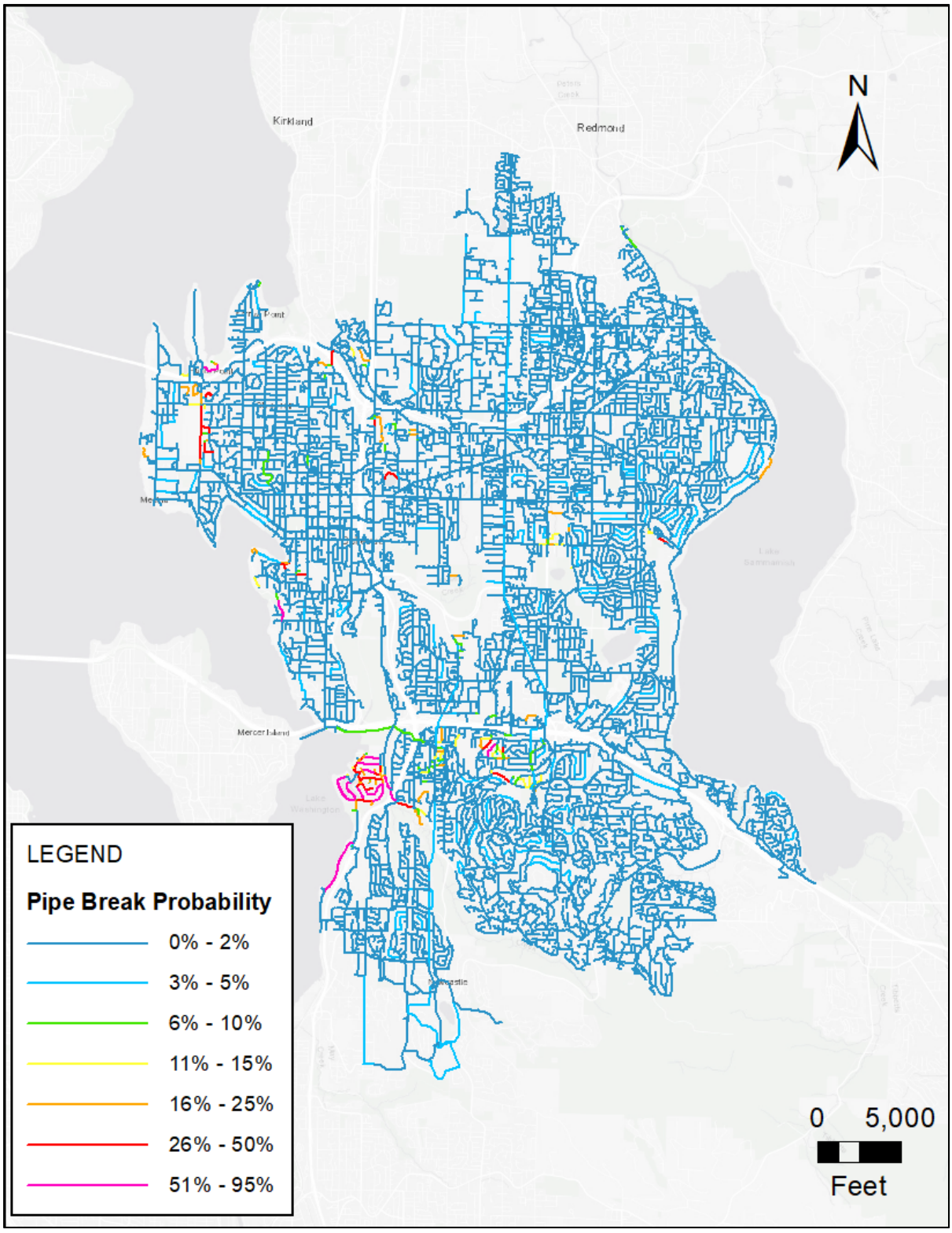


Figure 5. Cascadia Subduction Zone – Pipe Break Probabilities

2.2 Expected Number of Pipe Repairs

Figures 6 and 7 show the total probable number of repairs (breaks and leaks) for the water system in the SFZE and CSZ events, respectively. The graphic shows repairs based on the total counts of repairs likely for each subarea. Similar to the pipe probability maps above, the subareas with more repairs are typically a result of liquefiable soils as the repair rate substantially increases in liquefiable soils.

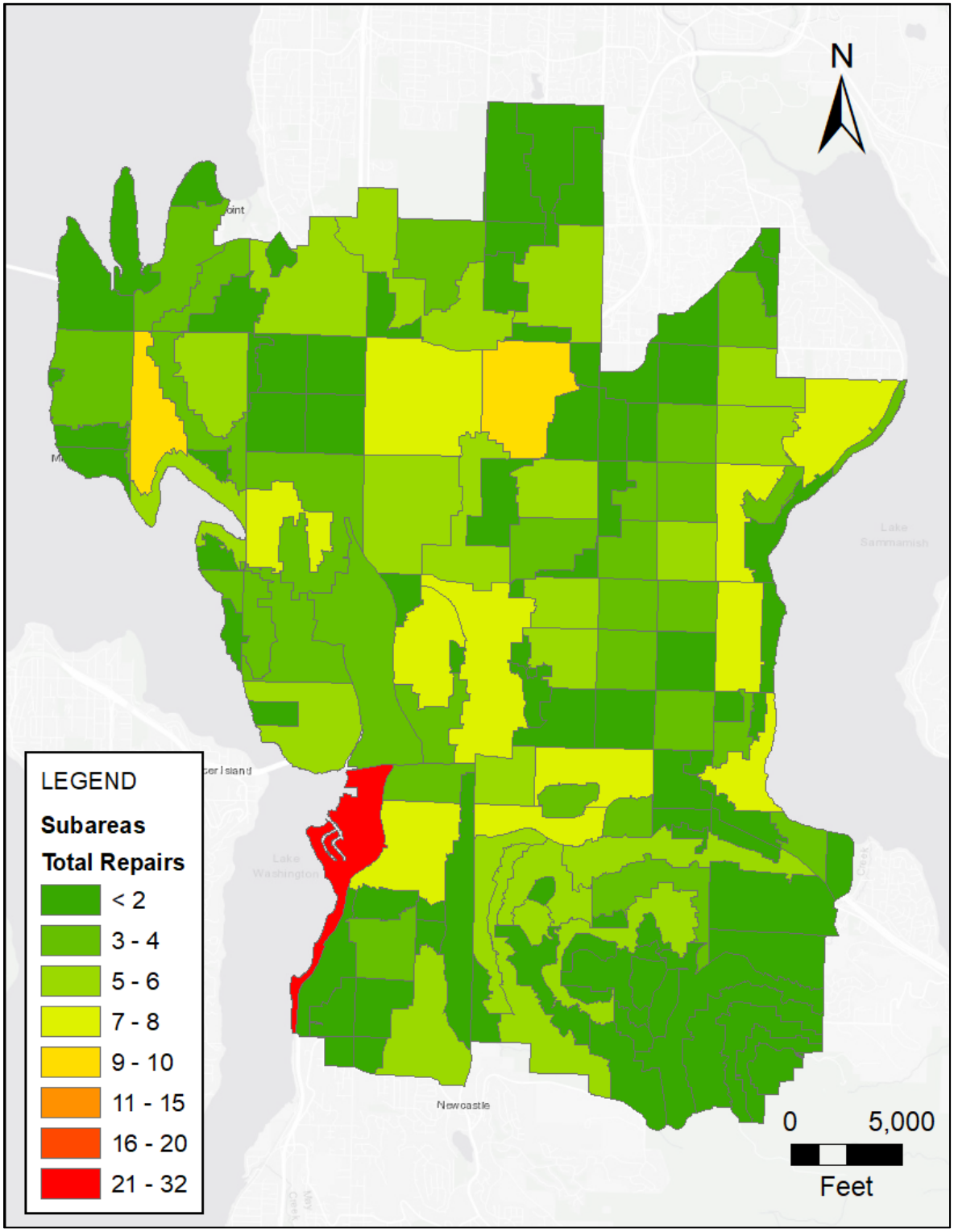


Figure 6. Seattle Fault Zone East – Pipe Failure Distribution. Combined Probable Pipe Breaks and Leak Counts by Analysis Area

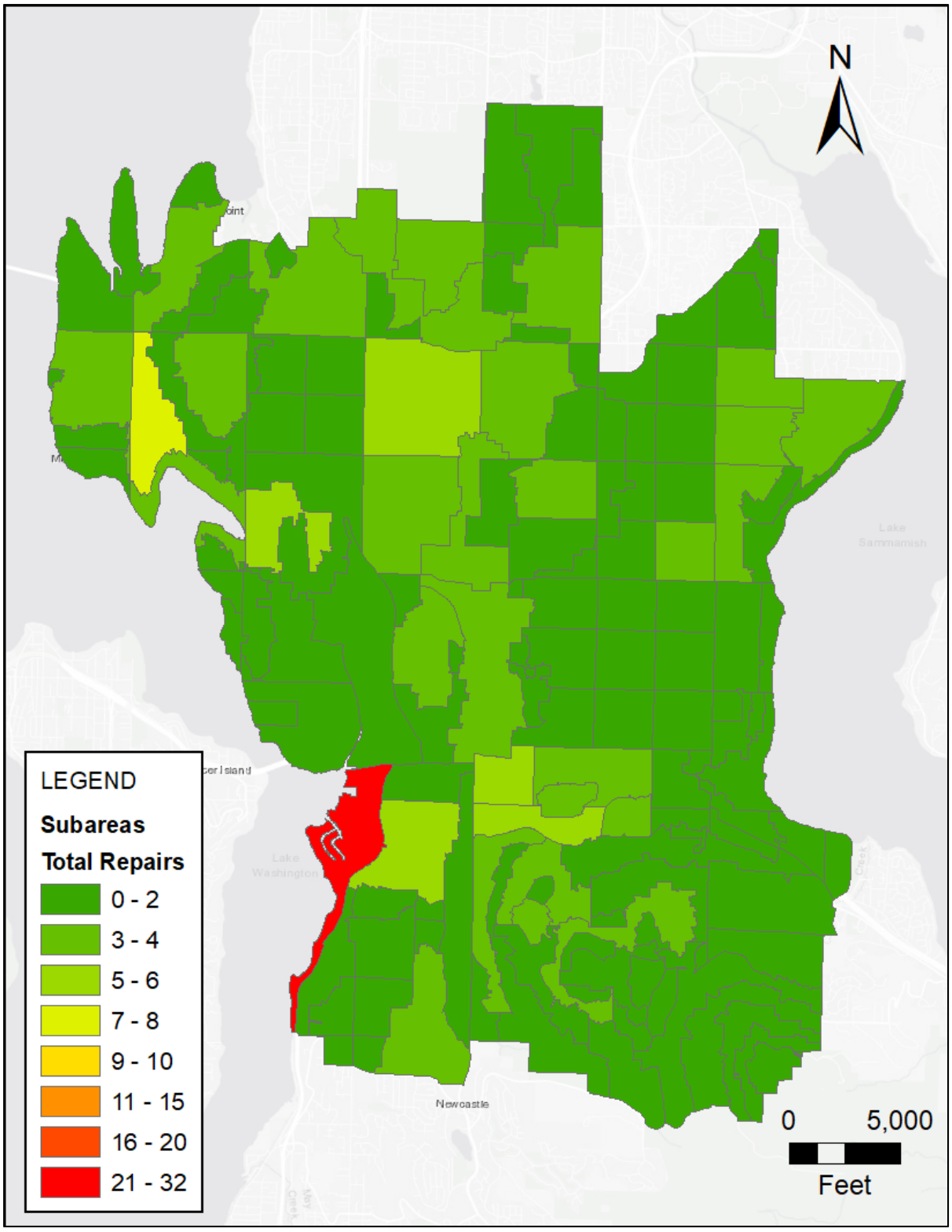


Figure 7. Cascadia Subduction Zone – Pipe Failure Distribution. Combined Probable Pipe Breaks and Leak Counts by Analysis Area

Figures 8 and 9 show the expected number of breaks only by subarea for the SFZE and CSZ events, respectively. Looking at only breaks further accentuates the impact of liquefiable soils because it is expected that 80% of the repairs in liquefiable soils will result from pipe breaks.

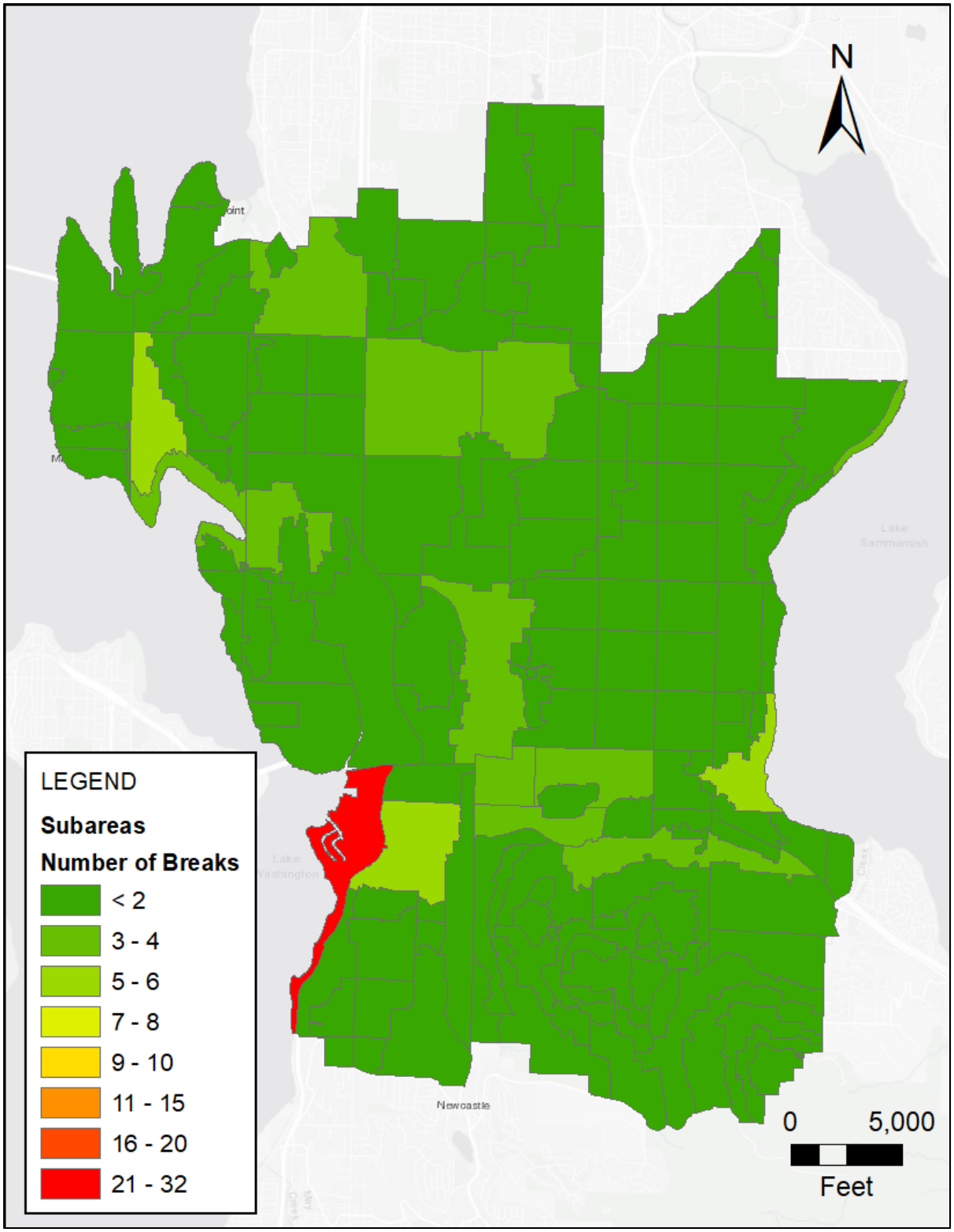


Figure 8. Seattle Fault Zone East – Pipe Failure Distribution. Probable Pipe Break Counts by Analysis Area

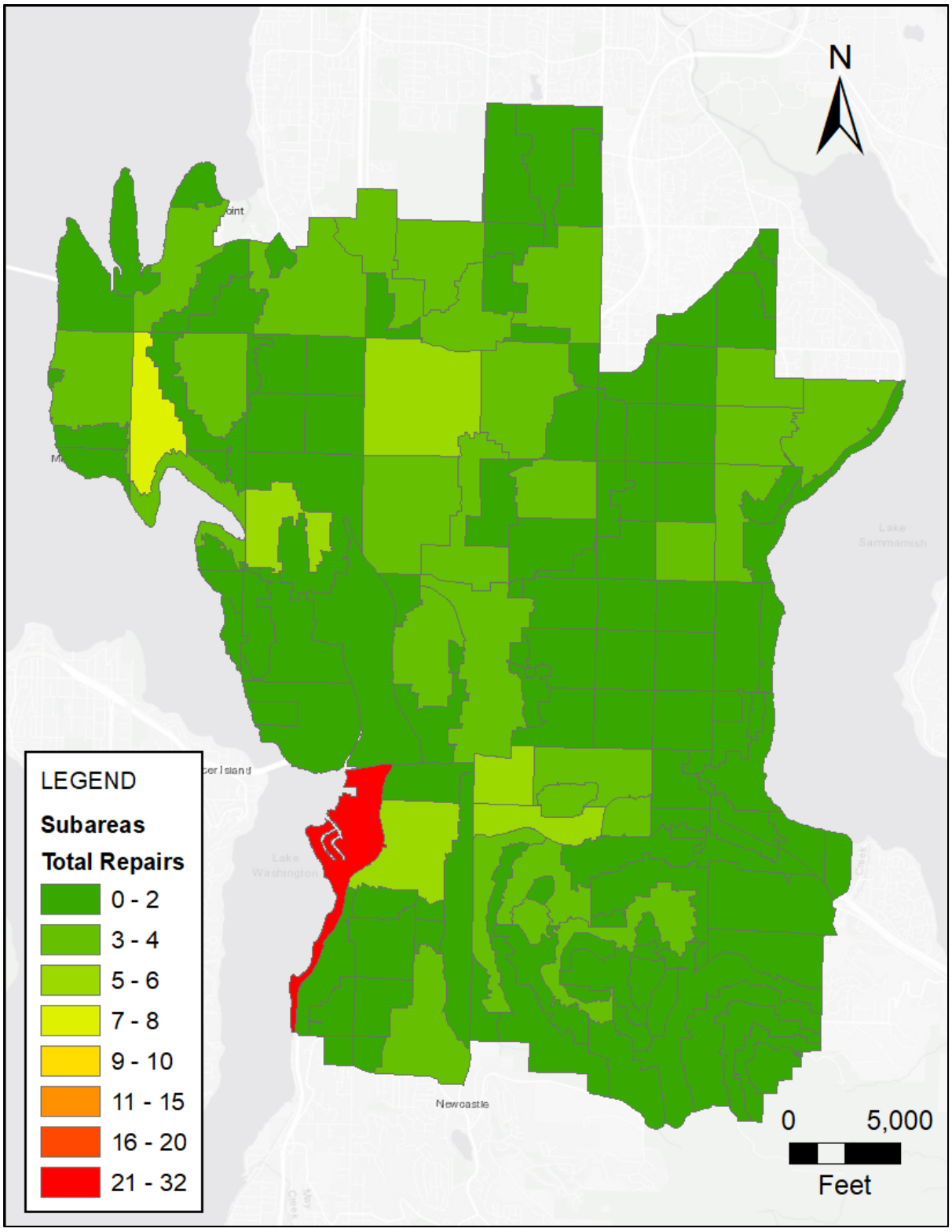


Figure 9. Cascadia Subduction Zone – Pipe Failure Distribution. Probable Pipe Break Counts by Analysis Area

As demonstrated by the information in this section, the majority of the pipe in the Bellevue Water System is in competent soils and has a relatively low probability of failure for the potential seismic events considered. Due to the nature of the analysis, the pipe segments with longer individual sections resulted in the highest probability of repairs, as probability of repairs is linearly proportional to the length of the

pipe segment. Even considering this nuance, the primary driver for high repair probability is the presence of potential permanent ground deformation as a result of seismically induced liquefaction or landslides.

3. Single Pipe Criticality Analysis

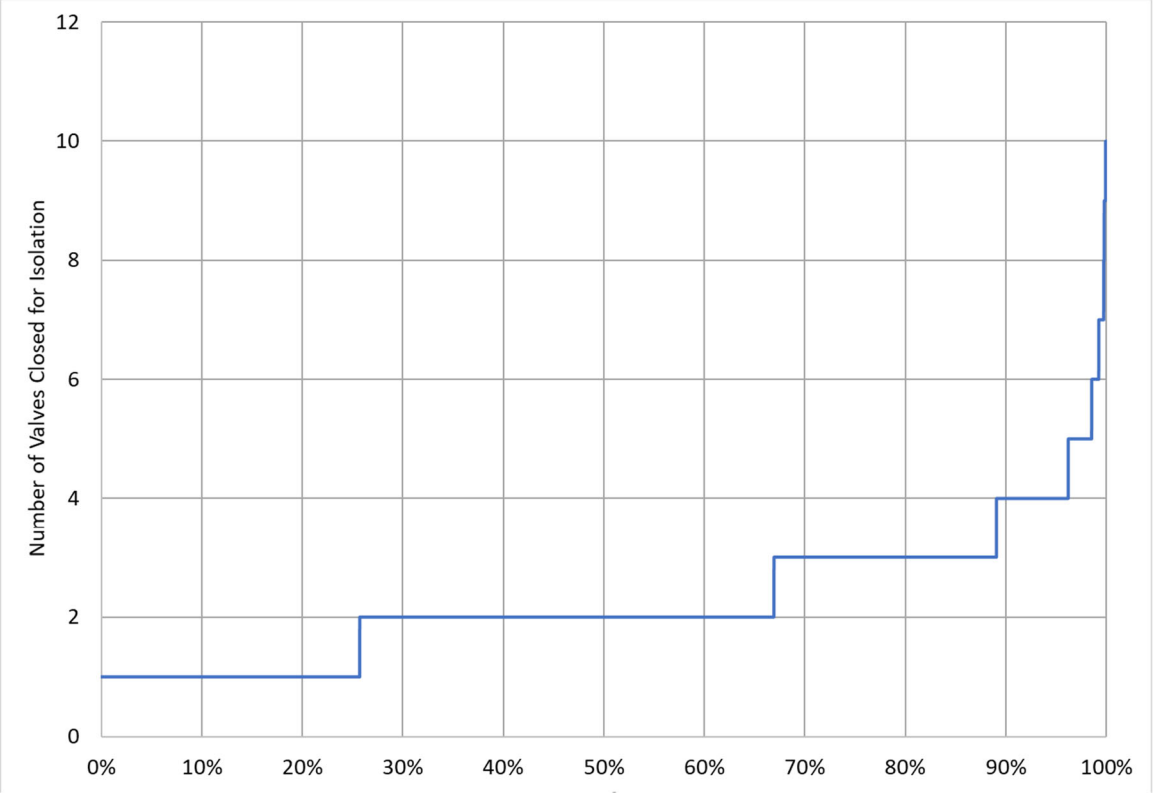
The single pipe criticality analysis was conducted to identify specific pipe sections within the Bellevue system that have potential for the greatest impacts during pipe break events. Each pipe within the system was simulated as experiencing a break, and the impact to the system was quantified based upon the following criteria:

- Number of valves that need to be closed to isolate the pipe break
- The demand (in gpm) that was impacted with pressures of less than 30 psi during the initial pipe break
- The demand (in gpm) that was impacted with pressures of less than 30 psi after the pipe break is isolated for repair

The single pipe criticality results are summarized below in a series of figures that show a distribution for each of the criteria above both in a system-wide evaluation followed by a spatial presentation of the results.

3.1 Valve Closures required for Pipe Break Isolation

The results of the criticality analysis for valve closure are shown in Figure 10a and 10b. The number of valve closures to isolate individual pipe breaks throughout the Bellevue water system ranged from 1 valve to a maximum of 10 valves. For nearly 90 percent of the pipes in the Bellevue system, no more than three valves are needed to provide isolation for repair of a pipe break. This distribution of required valve closures demonstrates that the Bellevue system has a good distribution of valves throughout the system to allow for efficient isolation and repair of single pipe incidents without significant impact to large areas of the system.



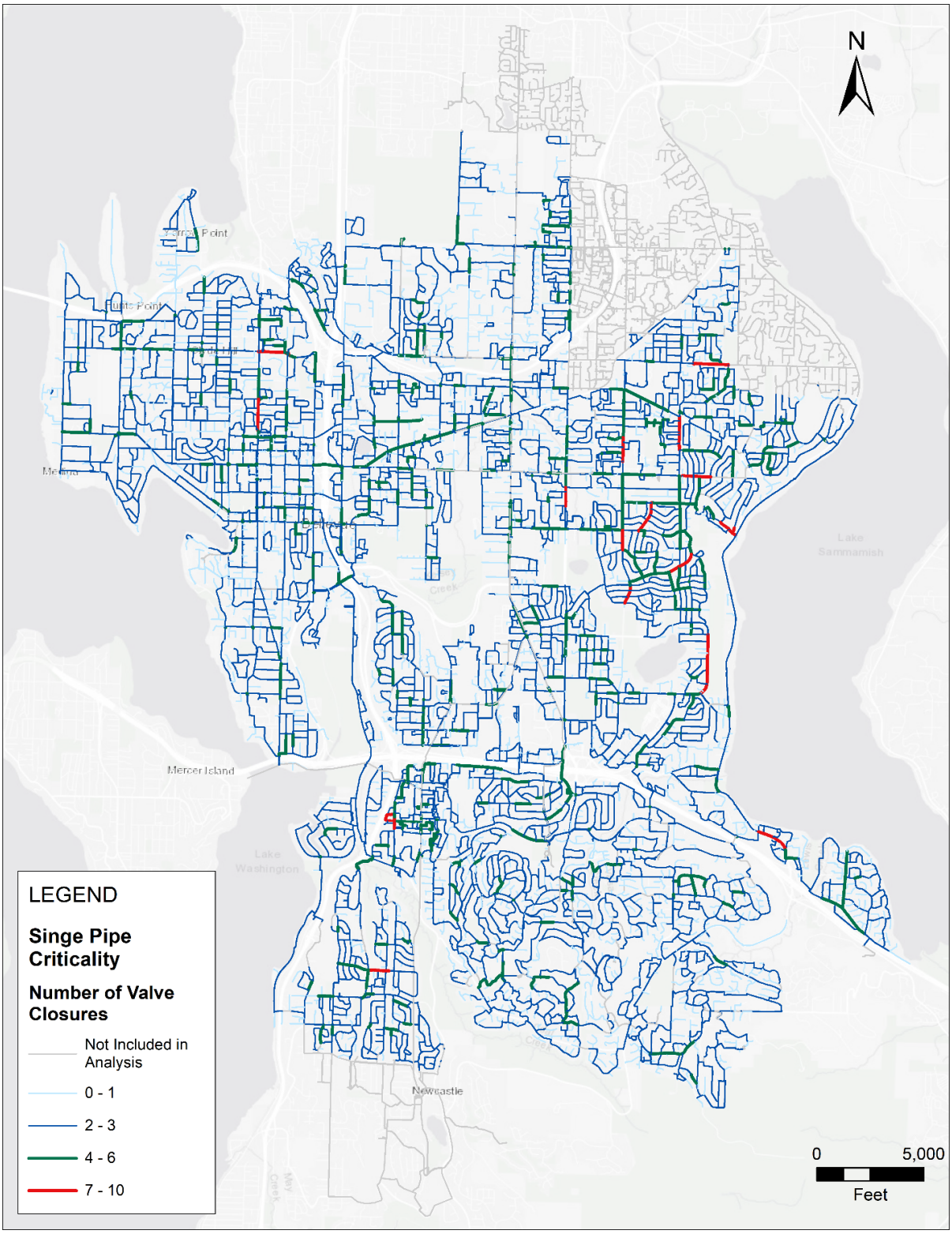
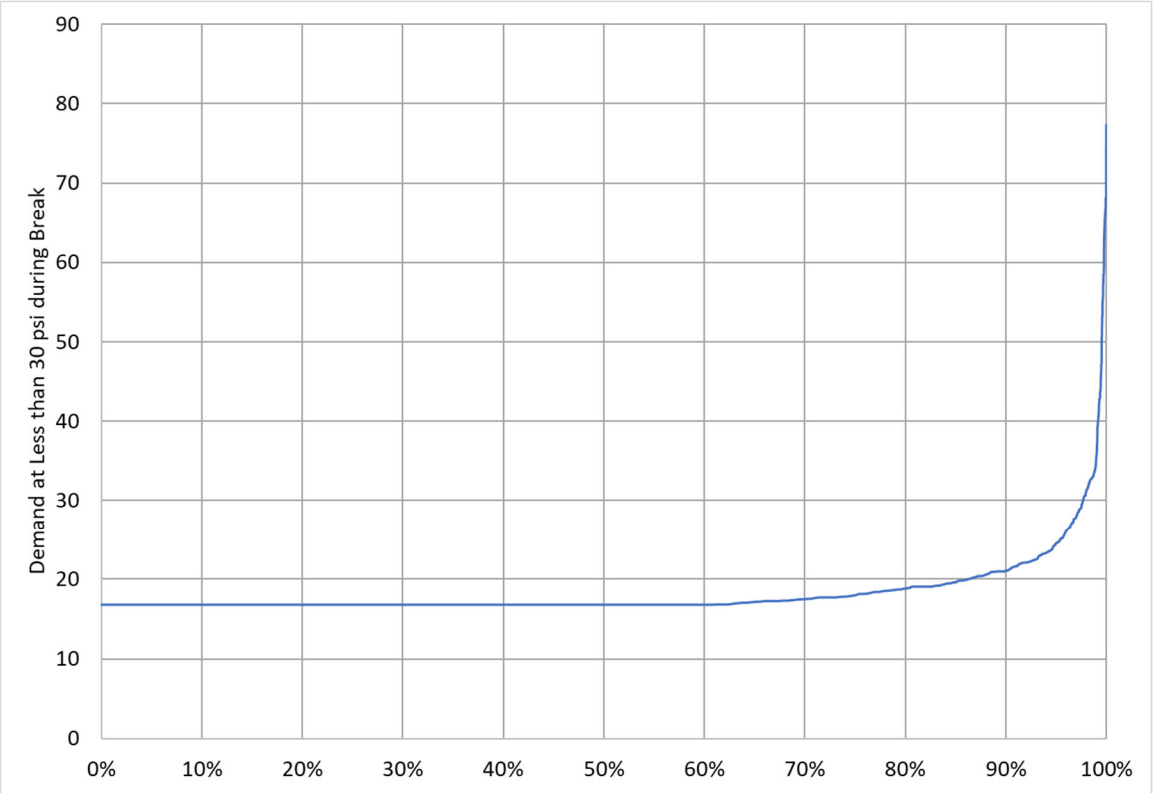


Figure 10. a) Number of Valve Closures Required for Pipe Failure Isolation; b) Map

3.2 Demand below 30 psi during the Initial Pipe Break

The results of the quantity of demand in the Bellevue system that experiences modeled pressures less than 30 psi during a single pipe break are shown in Figure 11a and 11b. From a review of Figure 11a, approximately 18 gpm in the Bellevue system is shown to be impacted for up to about 65 percent of the system. This flat distribution is most likely due to a few locations in the system that are predicted to be below 30 psi under the simulated condition, and the 18 gpm is always calculated as being lower than 30 psi. The amount of demand impacted increases somewhat linearly to 21 gpm for 90 percent of the system. For the remaining 10 percent of the system, the amount of demand impacted increases to a maximum of 78 gpm. The location of the pipes that have the most impact on delivering demand during a break are shown in Figure 11b. The pipes that are shown to have the most impact are pipes that are at the highest elevations of the system and pipes that are at the ends of pressure zones and are the only source of supply to isolated areas.



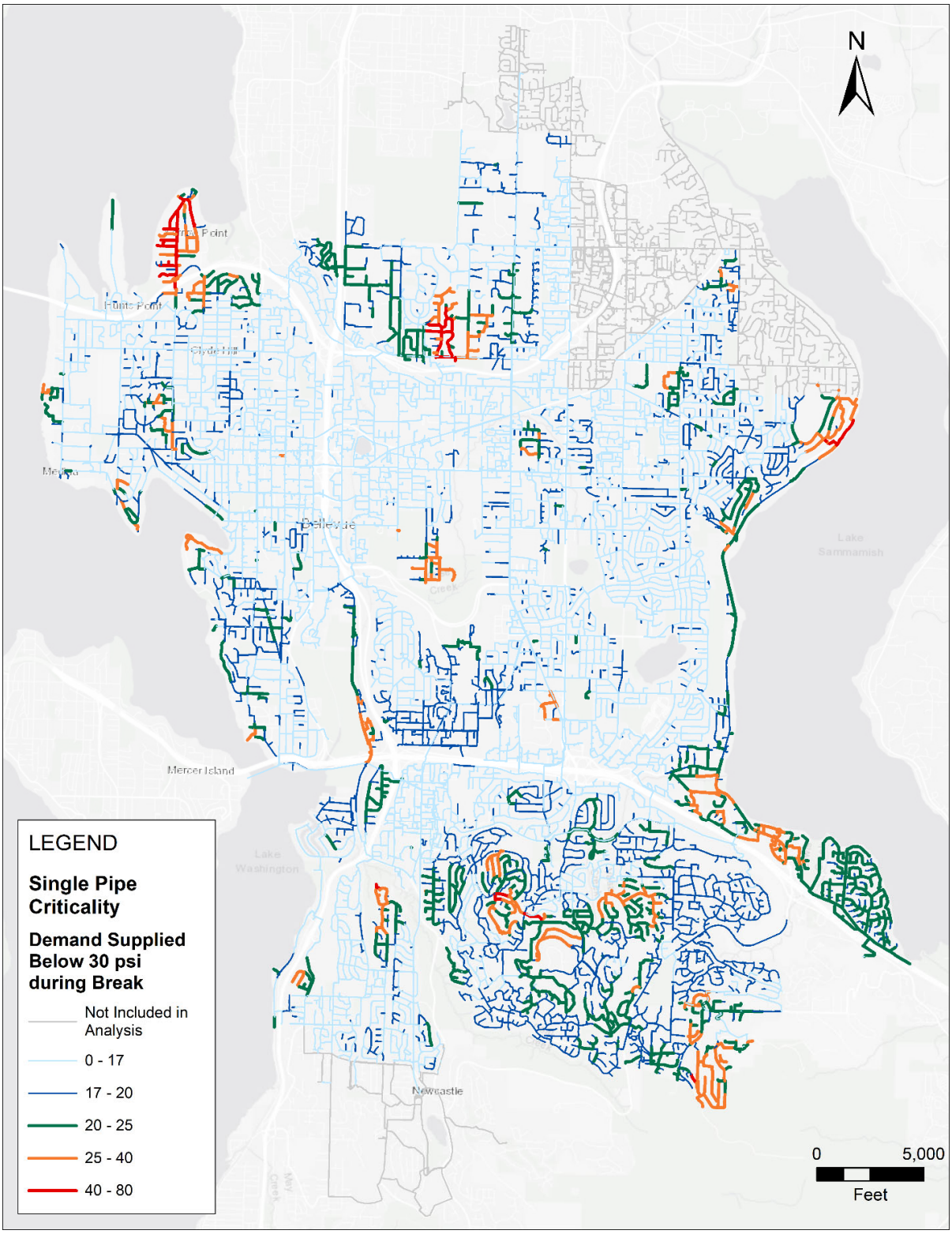
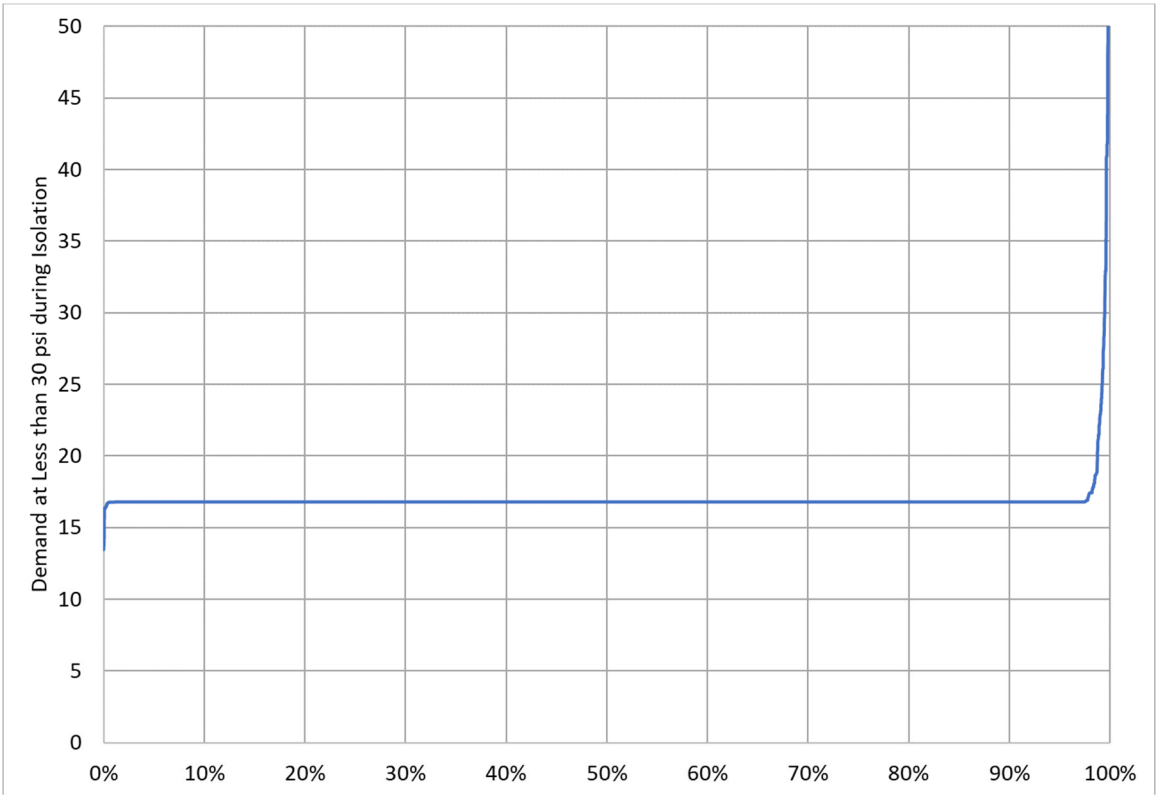


Figure 11. a) Demands Supplied below 30 psi during Pipe Breaks Events; b) Map

3.3 Demand below 30 psi after Break Isolation

The analysis of quantifying the demand that is delivered at pressures below 30 psi after isolation of a single pipe break is presented in Figures 12a and 12b. In comparing these results to the results for low pressure areas during a break, there is less impact across the system. Approximately 16 gpm is impacted up to the 97 percent level. From that point, the level of demand impacted increases to 1,600 gpm. This elevated demand value is due to the delivery point for CWA and can be excluded from the analysis. The pipes that isolate this demand are also shown in red in Figure 12b. The other pipes that isolate higher demand levels when a break is isolated are shown in Figure 12b.



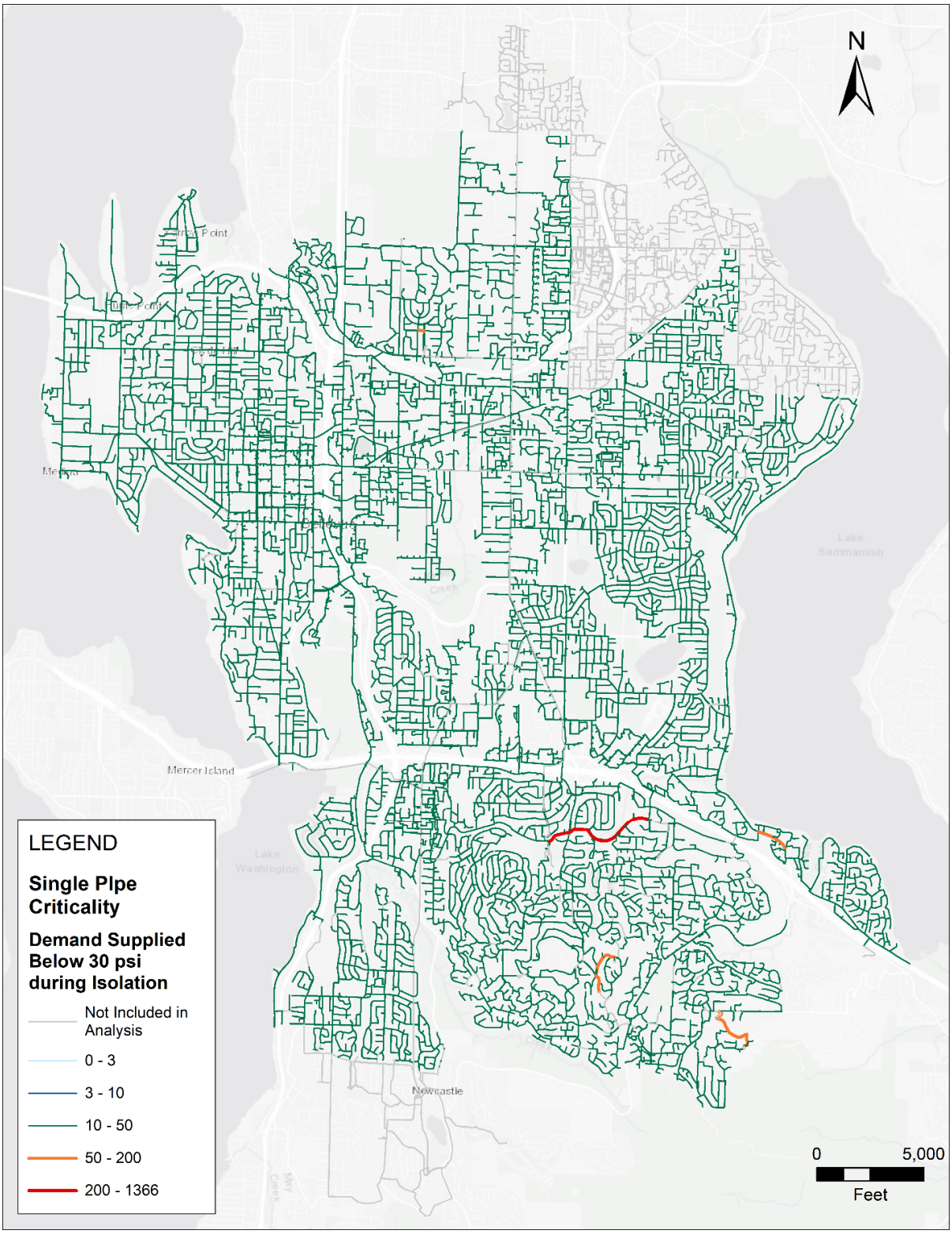


Figure 12. a) Demands Supplied Below 30 psi during Pipe Break Isolation; b) Map

4. Monte Carlo Simulations

In order to determine the probability that a given customer or subarea of the system will have water service after either of the two earthquake events, Monte Carlo based simulations were performed to develop scenarios that represent the distribution of probably damage to the water system as a result of an earthquake. The simulations were performed using a custom Python script that generated an individual random variable between 0 and 1 based on a normal distribution for each water system pipe segment and facility and compared that random value to the probability of a specific damage state for the element. For pipes, the damage states were “leak” or “break”, and for facilities the damage states were “extensive damage” or “collapsed”. These terms are defined in TM 2: Seismic Analysis Methodology for Pipeline and Facilities Assessment.

Determination of whether an element was likely to experience a leak or break, or extensive damage or collapsed state, were determined independently. If an element had both possible damage states, the higher (break or collapsed) was applied to the element. If the element had only leak or extensive damage, that state was applied. If neither damage state occurred for the facility, then it was considered to be online.

After the damage states were determined for each facility (i.e., Cougar Mountain PS # 1) in each simulation, the damage states were applied to all the hydraulic model elements associated with that facility (i.e., Cougar Mountain PS #1, Pumps 1, 2, and 3). This allows the hydraulic model to deactivate each element in the hydraulic model necessary to represent the entire facility being offline.

4.1 Number of Simulations and Simulation Results

To determine the normality of the resulting Monte Carlo simulations and confirm an adequate and statistically significant number of simulations were being used, histograms were reviewed to look at the distribution of pipe or facility damage across all the simulations. Initial trial runs using only 1,000 Monte Carlo simulations resulted in noticeably inconsistent distribution of pipe repairs as shown in Figure 13. Final runs used for the multi-break analysis used 10,000 simulations, which produced a substantially cleaner normal distribution as shown in Figure 14.

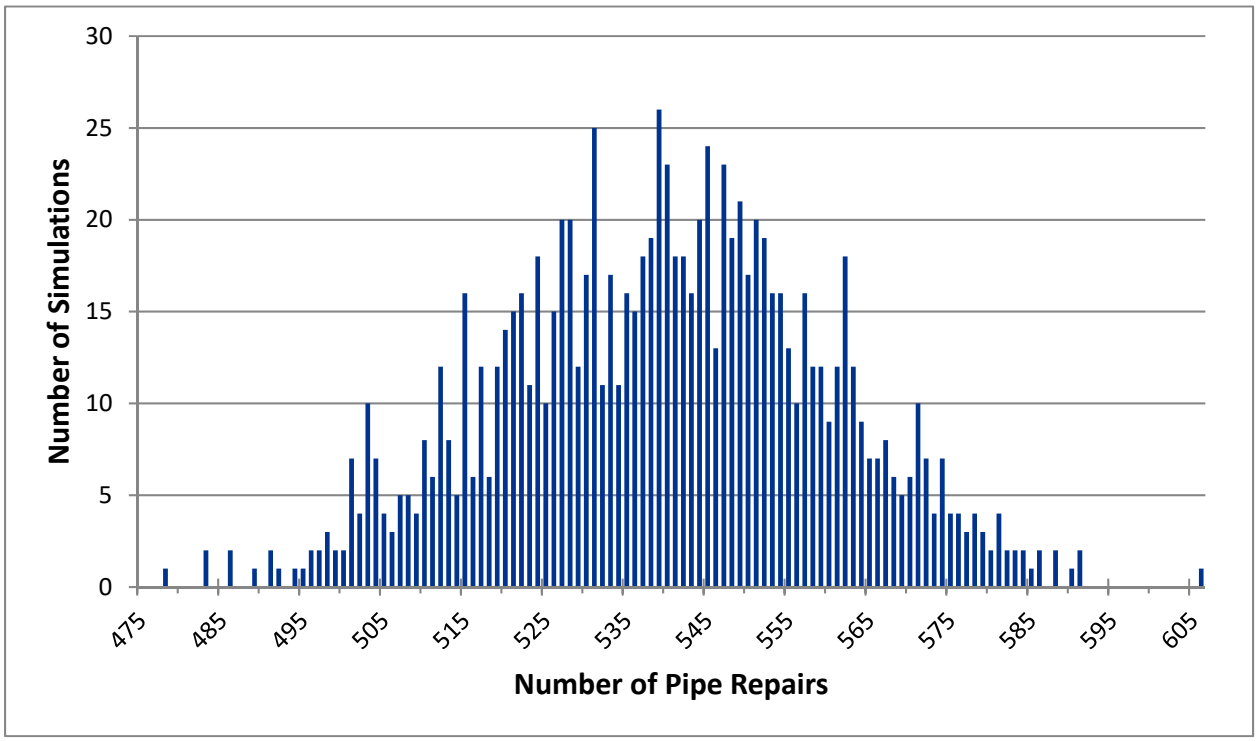


Figure 13. SFZE Pipe Repair Histogram based on 1,000 Monte Carlo Simulations during Testing

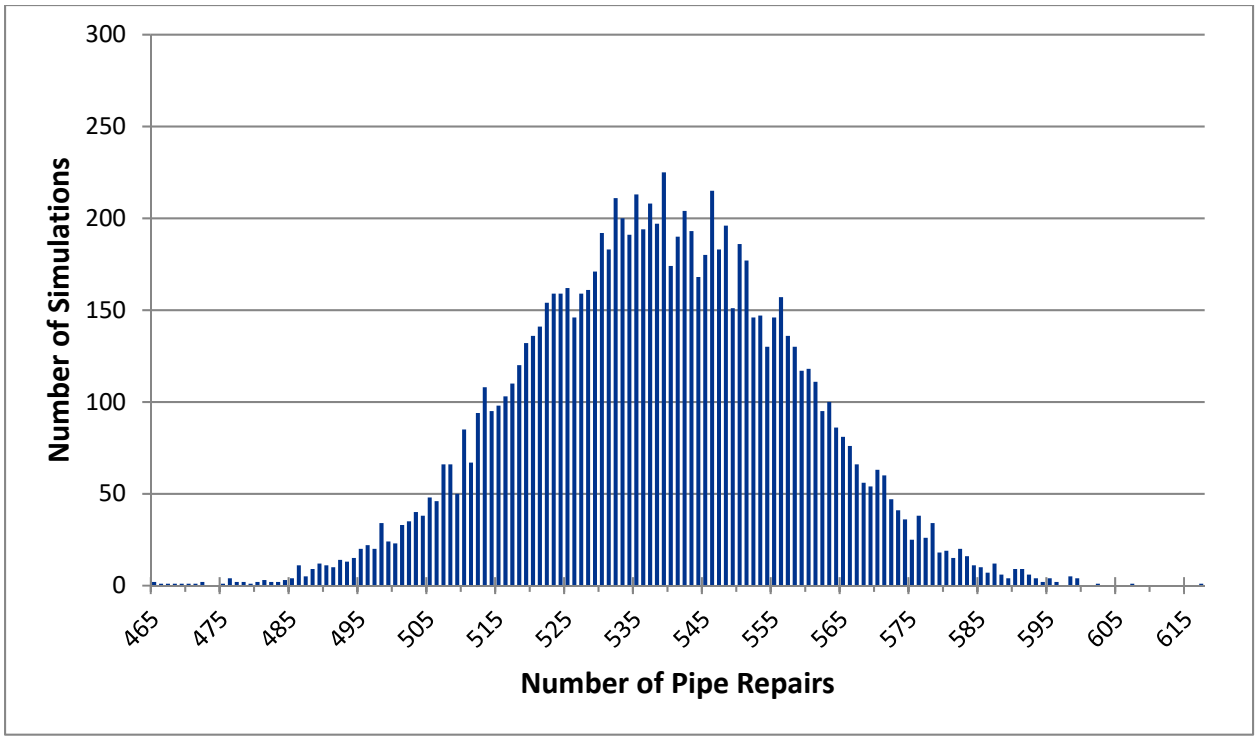


Figure 14. 10,000 Monte Carlo simulation histogram of pipe repairs developed through Multi-break Analysis for SFZE Event

4.2 Simulation Outputs

The output from the Monte Carlo simulation process was reviewed to confirm that the results matched the expected distribution and probabilities of damage for water system pipes and facilities. Figures 15 and 16 show the distribution of pipe repairs for the SFZE and CSZ events.

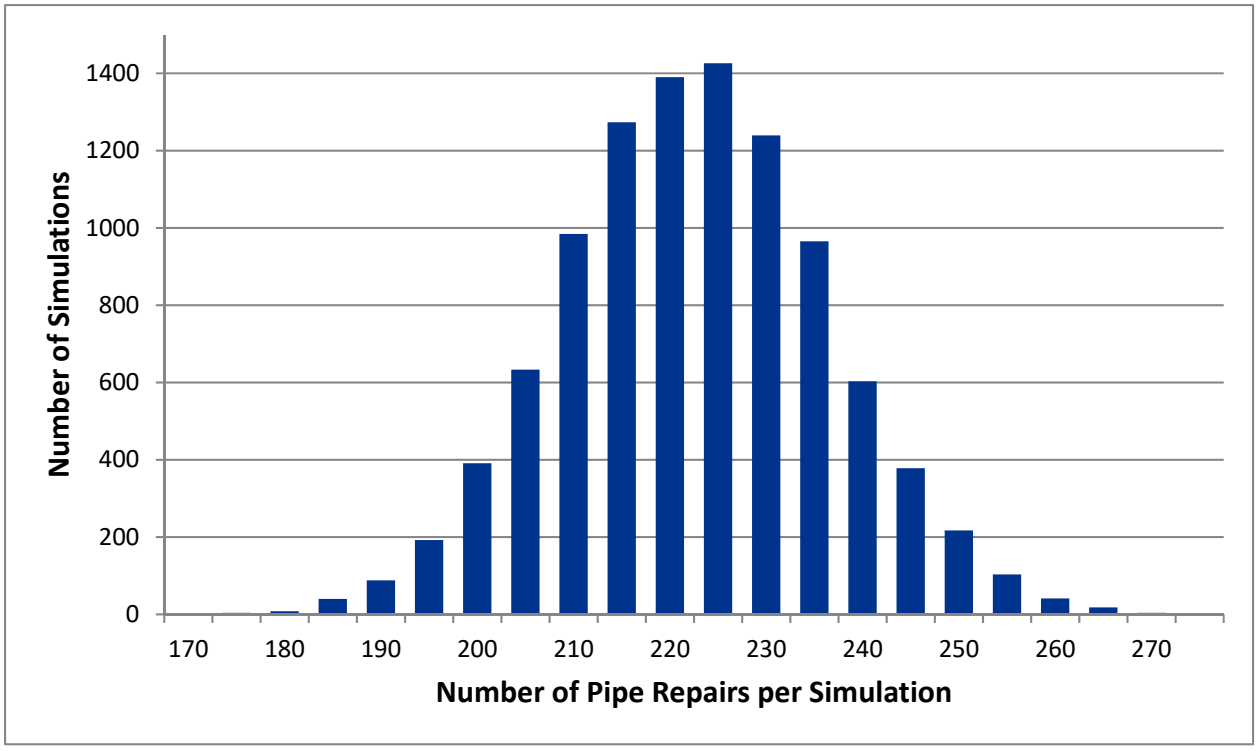


Figure 15. CSZ Monte Carlo Simulation Pipe Repair Histogram

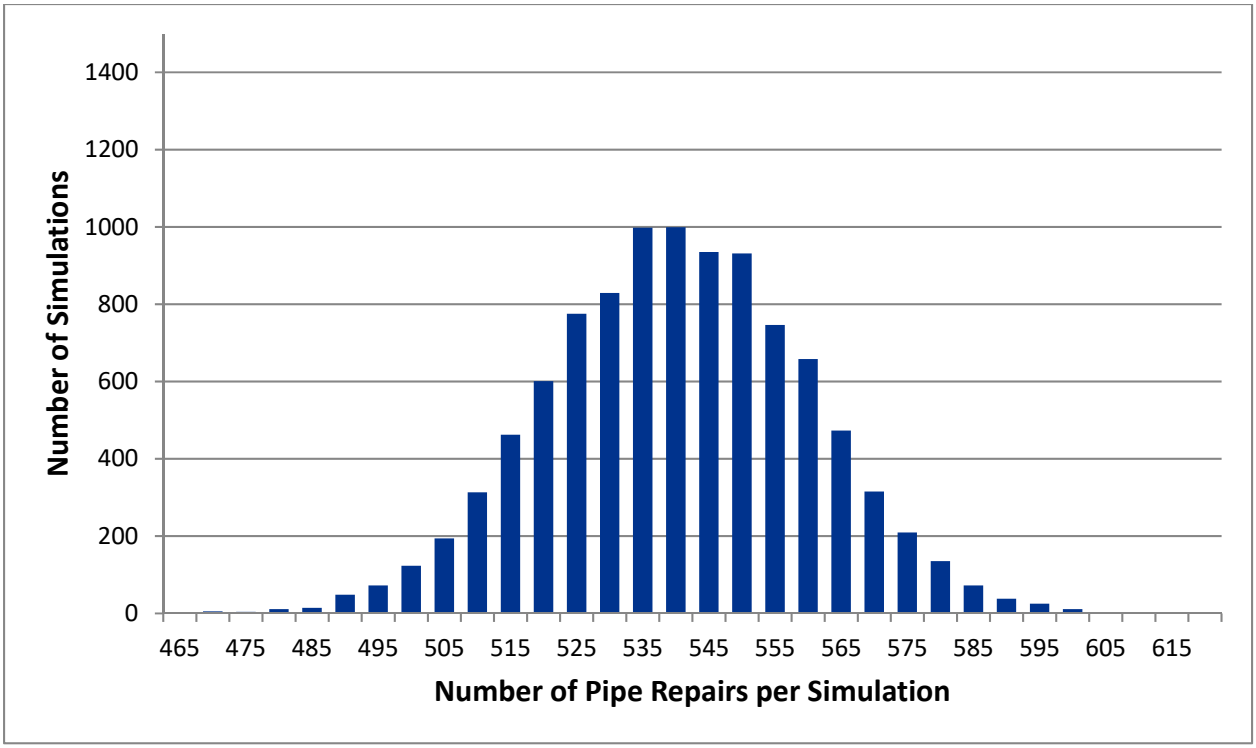


Figure 16. SFZE Monte Carlo Simulation Pipe Repair Histogram

Table 1 shows a comparison of the total number of facilities expected to be online based on estimated probabilities compared against the results of the Monte Carlo simulations. These results show that the average number of facilities online for each type of facility is almost identical to the probabilities input into the simulation.

Table 1. Comparison of Facility Damage Probabilities to Monte Carlo Simulation Results

Facility Type	Total Number of Facilities in Simulation	SFZE Average Number of Facilities Online		CSZ Average Number of Facilities Online	
		Expected	Monte Carlo Results	Expected	Monte Carlo Results
Pump Stations	24	13.5	13.5	22.1	22.1
Reservoirs	32	24.1	24.1	30.9	30.8
Inlets	13	8.5	8.5	13.0	13.0
SPU Supplies	2	0.8	0.8	0.9	0.9

The simulation results information provided above demonstrates that the Monte Carlo simulations conducted to generate the multi break scenarios for water system performance were successful in producing 1) an adequate number of simulations to result in a normal statistical distribution for pipes and facilities failures, 2) the expected average number of pipe repairs for all simulations, and 3) the expected number of facilities online for each event over all the simulations. These results indicate that the Monte Carlo simulation results are statistically consistent with the estimated probabilities of failure for pipe and facilities within the water system.

5. Multi-Break Hydraulic Analysis

The multi-break criticality analysis was conducted to identify the impact of multiple pipe breaks and leaks on the capability of the Bellevue system to deliver water supply to customers following the evaluated

seismic events. For both the SFZE and the CSZ scenarios, a set of 10,000 simulations with varied broken pipes and leaks, select facilities out of service, and variation of water supply sources from SPU out of service were developed. The broken pipes, facility status, and water supply status was established for each simulation based upon probability of failure and was derived through the Monte Carlo approach described above. The status of broken pipes as well as facilities and supplies identified to be offline for each simulation were set in the Bellevue hydraulic model, and then each simulation was run to identify the areas most likely to be impacted across each set of simulations. Impact was quantified through a tabulation of the demand within each subarea of the Bellevue water system not being delivered at 30 psi. The total demand impact was also summarized for each simulation. The results for the multi-break hydraulic simulation are summarized in the following sections and figures.

This analysis assumes that all reservoirs are at their normal operating state when the earthquake occurs, and the resulting hydraulic conditions does not account for drain down of the reservoirs due to excessive water loss from leaks and breaks in the system. The analysis does account for reservoirs which are damaged in each simulation. With this regard, the results are representative of the state of the system immediately (within the first 30 minutes to an hour) after a seismic event, such that the situation will get worse as time goes on as water continues to exit the system via pipe and facility failures.

5.1 Seattle Fault Zone East Multi-Break Results

The demand impacts for the SFZE simulations were compiled by subarea, and Figure 12 and Figure 13 show the quantity and percent of demand by subarea that cannot be met with pressures above 30 psi for the SFZE. The data presented in Figure 12 and Figure 13 is a compilation (average) of all of the 10,000 simulations developed for the SFZE event. The information presented in Figure 13 is particularly striking given that the results predict that the majority of the water system has more than 60 percent demand not being met on an average basis across the 10,000 simulations. Figure 14 shows the distribution of demand impacts for all of the SFZE simulations. As shown in Figure 14, the median demand impact is between 8,500 and 9,000 gpm (12.2 mgd – 13.0 mgd), which is greater than one-half of the demand of the water system for the average day demand condition used in the analysis. The distribution of demand in Figure 14 aligns with the spatial distribution of demand impacts shown in Figure 13.

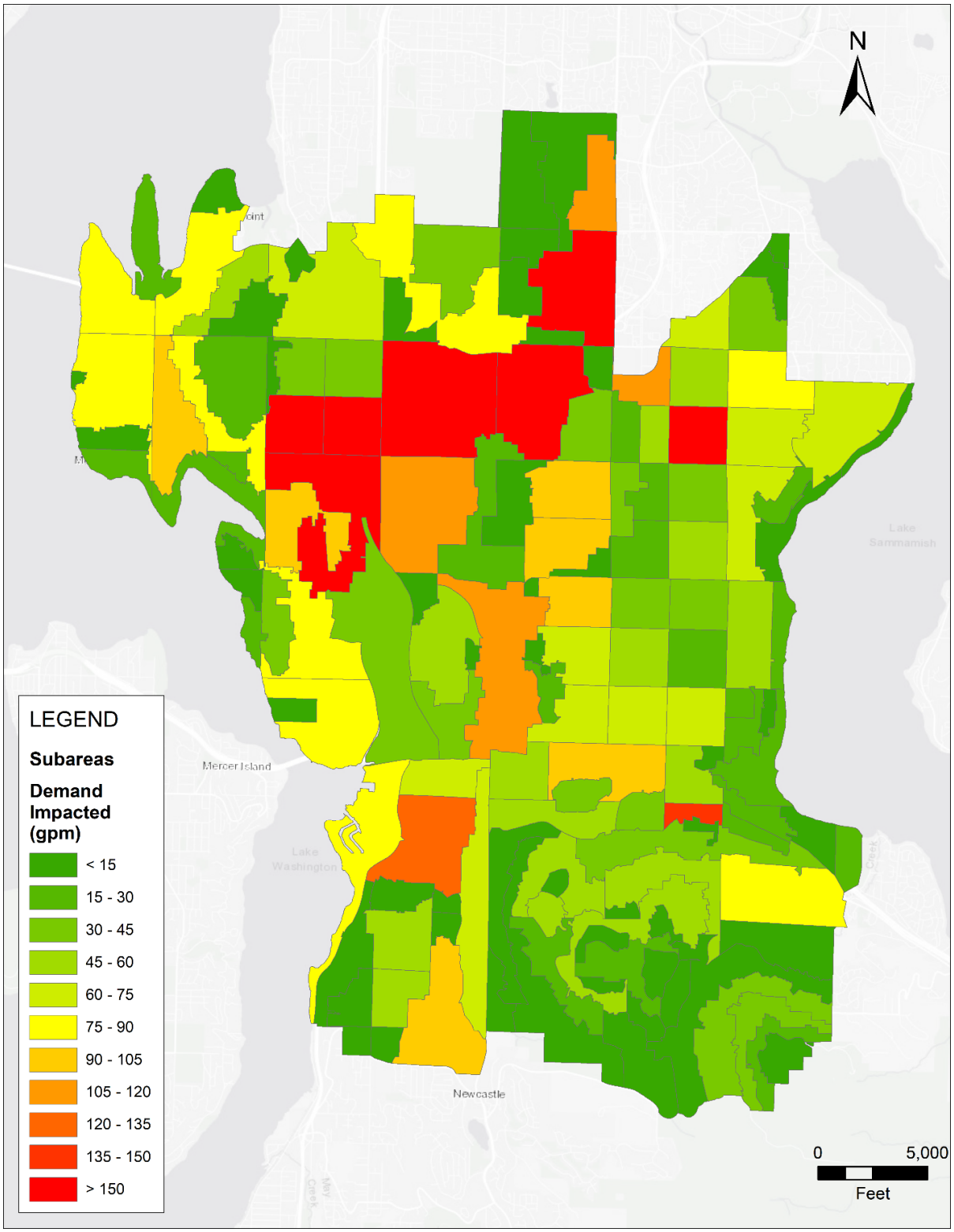


Figure 12. Predicted Demand Impacts in gpm by Subarea immediately following SFZE

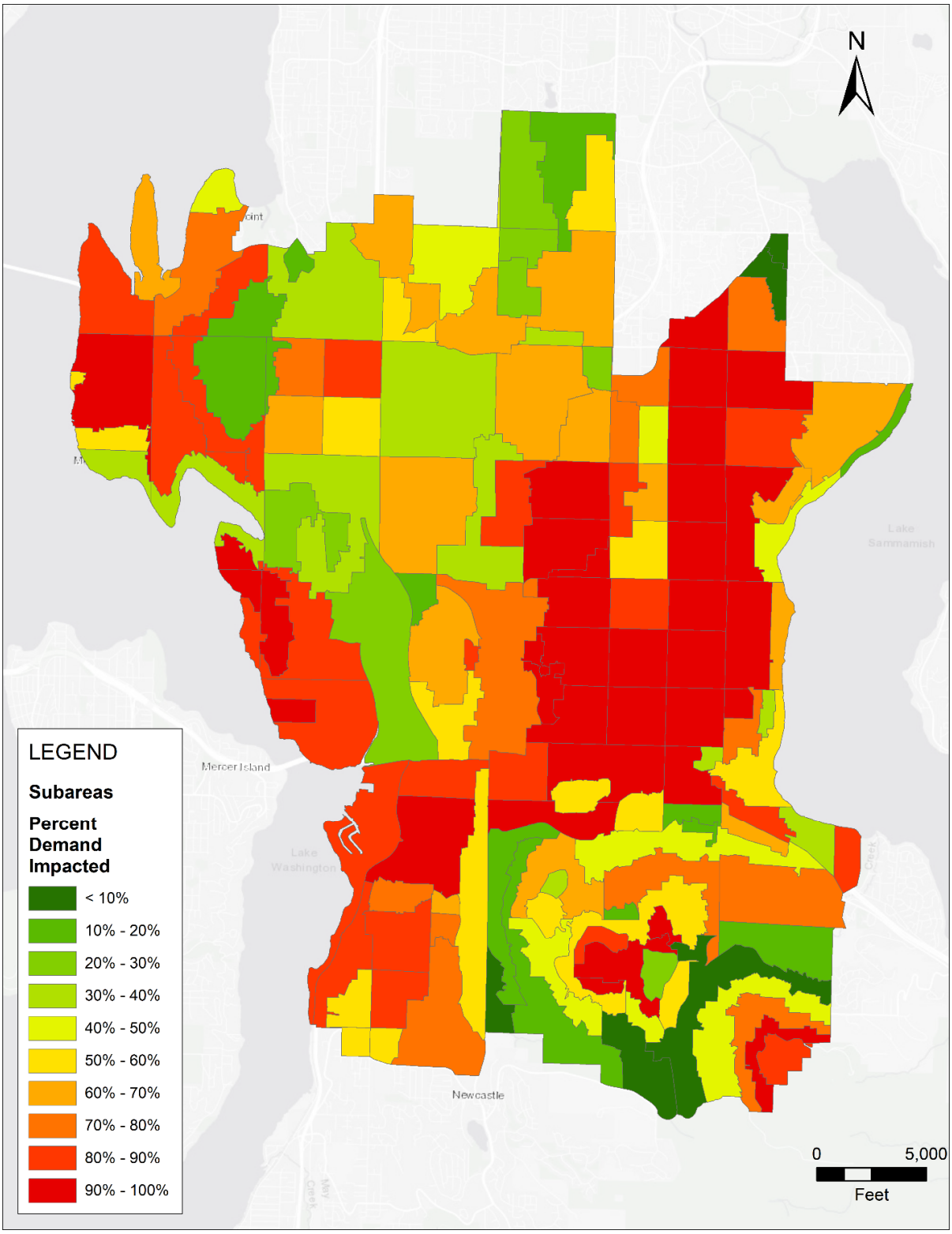


Figure 13. Predicted Demand Impacts by Percent of Subarea Demand immediately following SFZE

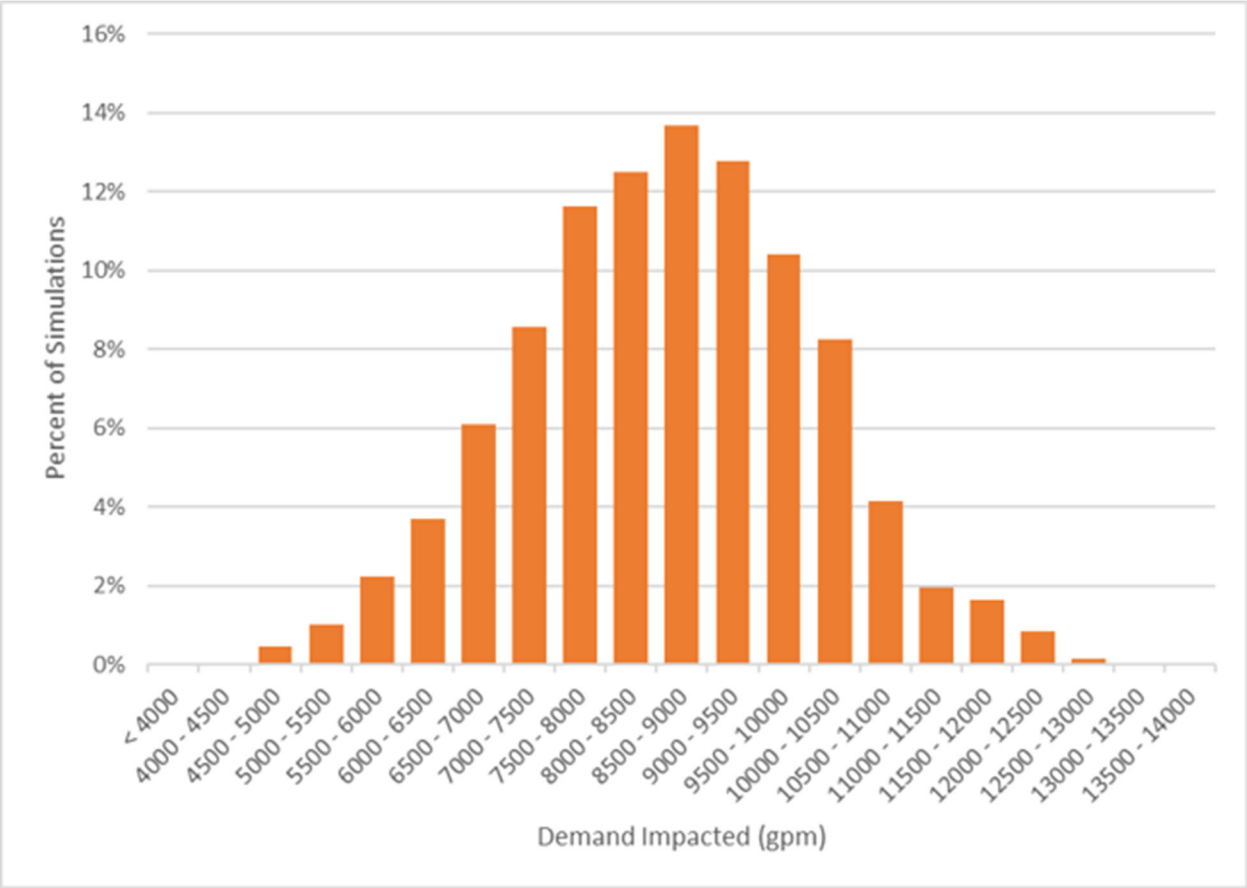


Figure 14. Distribution of System-wide Demand Impacts for all SFZE Multi-Break Monte Carlo Simulations

5.2 Cascadia Subduction Zone Multi-Break Results

The approach applied for the SFZE simulations was also applied for the CSZ simulations to quantify the demand impacts by subarea. Figure 15 and Figure 16 show the quantity and percent of demand by subarea that cannot be met with pressures above 30 psi for the CSZ. As noted previously, the SFZE is likely to be a more significant and impactful event given the more intense localized shaking expected, and the magnitude and extent of demand impacts is much greater than shown for the CSZ event. For example, there is a much lower percentage of the system that cannot meet 60% of the demand in a subarea for the CSZ event (Figure 16) as compared to the SFZE event (Figure 13).

For the CSZ, Figure 16 shows the distribution of demand impacts for all of the CSZ simulations. The SFZE event (Figure 14) showed a normal distribution with a median of approximately 8,750 gpm (12.6 mgd). For the CSZ event, the distribution of the demand impacts shows two “peaks”. The two peaks are due to the conditions when a specific supply is likely to be out of service due to damage. The median demand impact of the first peak is around 1,500 gpm (2.2 mgd), and the median demand impact of the second peak is around 3,250 gpm (4.7 mgd).

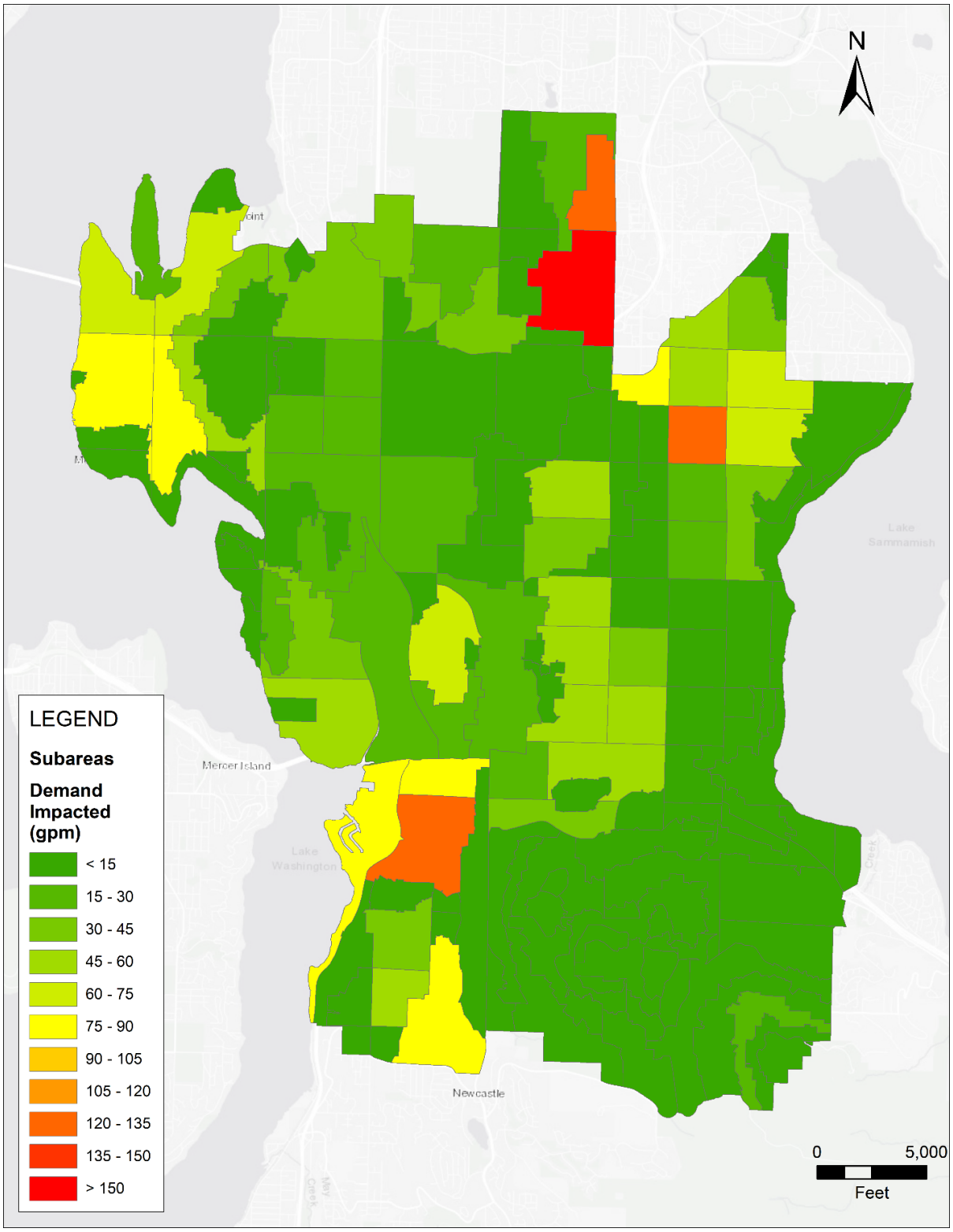


Figure 15. Summary of Predicted Demand Impacts in gpm by Subarea for CSZ

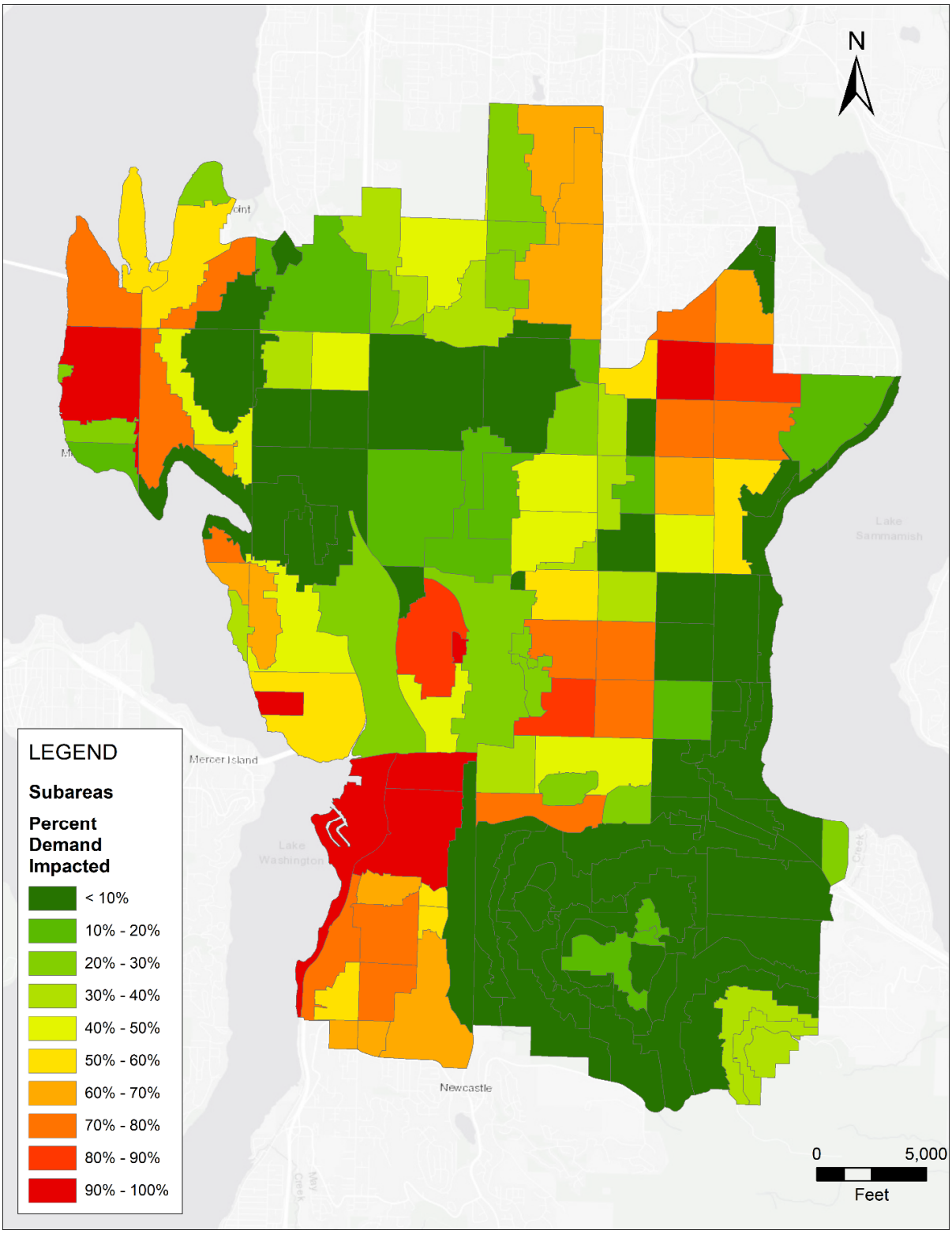


Figure 16. Summary of Predicted Demand Impacts by Percent of Subarea Demand for CSZ

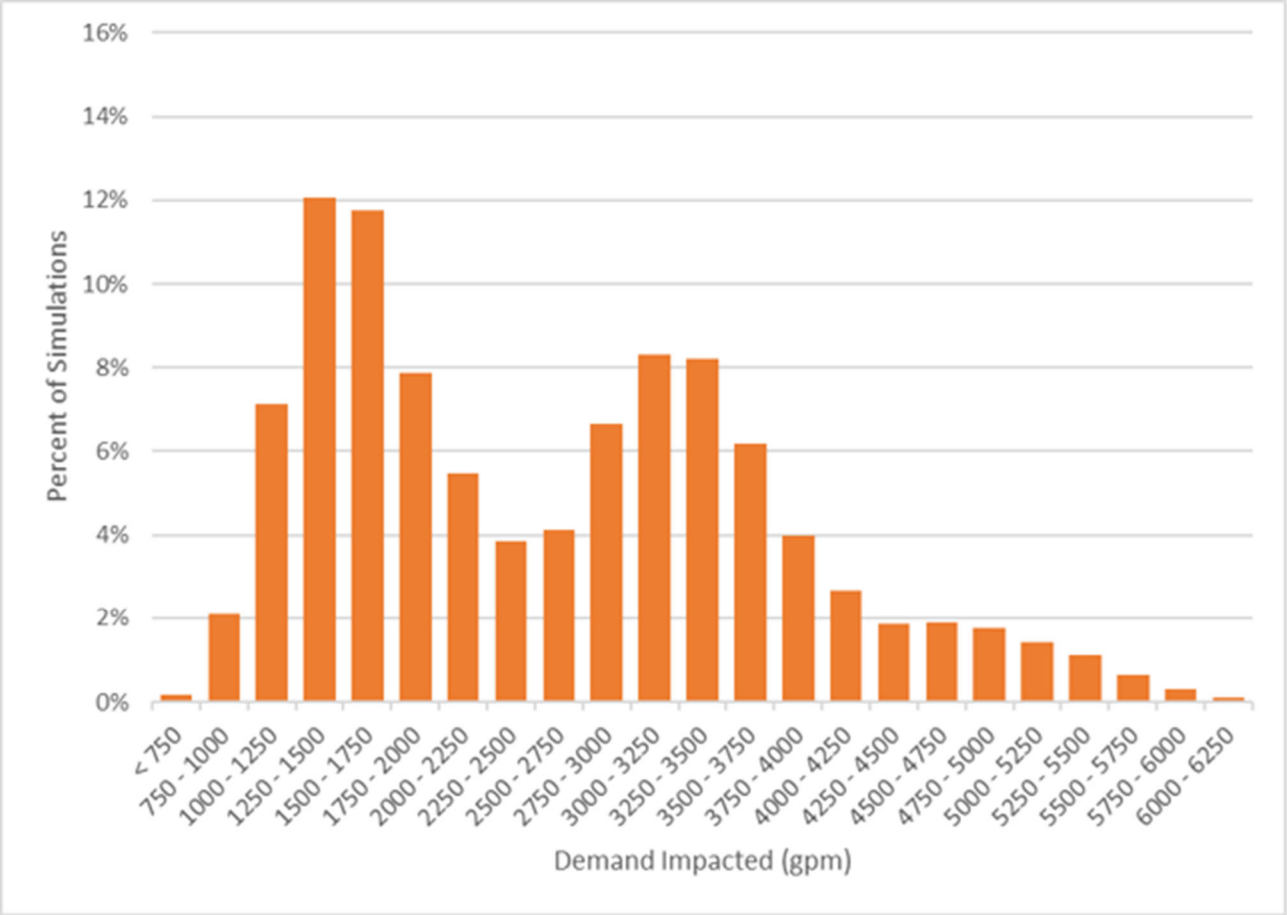


Figure 17. Distribution of System-wide Demand Impacts for all CSZ Multi-Break Simulations

5.3 Critical Customer Outage Probabilities

In addition to looking at overall impacts to the ability of the water system to maintain supply to customers in specific subareas, the multi-break results were also analyzed to determine the impact on individual Category 1 Critical Customers as described in TM 2: Seismic Analysis Methodology for Pipeline and Facilities Assessment. Table 2 shows the Category 1 Critical Customers as well as the probability that they are expected to have water above 30 psi following each of the two earthquake events.

Table 2. Category 1 Critical Customer Water Service Probabilities

Critical Customer	Junction ID	SFZE Service Probability	CSZ Service Probability
Overlake Hospital	COB1027757		
	COB1004597		
	COB1004596		
	COB1027172		
	COB1026642		
Kaiser Permanente Bellevue Medical Center	COB1026457		
Seattle Children's Bellevue Clinic and Surgery Center	COB1028033		
Bellevue High School	COB1102138		
Interlake High School	COB1026027		
Newport High School	COB1026048		
Sammamish High School	COB1023715		
	COB1110362		
	COB2010386		
City Hall	COB1025906		
North Bellevue Community Center	COB1012549		
South Bellevue Community Center	COB1024791		
Crossroads Community Center			
Washington State DOT EOC and Road Maintenance Facility	COB1003963		

5.4 Multi-Break Analysis Results Summary

The multi-break analysis shows that the majority of the Bellevue water system is not likely to have water immediately following a Seattle Fault Zone East (SFZE) event and that situation will only worsen as water drains out of system water storage tanks as a result of leaks and breaks distributed across the system. The most frequent water outages are predicted for areas near water bodies where significant liquefaction potential exists, as well as in a wide area of the Lake Hills 520 zone. For the Cascadia Subduction Zone event the outages are less widespread and much less likely. The primary areas with high probabilities of outages are the areas near water bodies where there is higher liquefaction expected.

The information presented above as determined by this analysis provides a picture of the likely state of the water system following an earthquake and identifies the magnitude of the problem.

The results of this analysis will be used moving forward in the project, with 3 individual simulations for each earthquake event being selected to determine the amount of time it will take to restore water service following the earthquakes as well as to develop and evaluate mitigation alternatives that could reduce the amount of time that water outages may extend after a major earthquake.

Appendix E. Economic Impacts Characterization

E.1 TM5: Economic Impact Parameters

Jacobs

Technical Memorandum

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Subject	**FINAL DRAFT – TM5: Economic Impact Parameters**
Project Name	Bellevue Water System Seismic Vulnerability Assessment
Attention	Doug Lane, City of Bellevue
From	Jacobs
Date	December 29, 2021

1. Background

The City of Bellevue Water System Seismic Vulnerability Assessment (SVA) includes detailed assessment of potential impacts to the Bellevue water system, and system customers, as a result of a major earthquake. In order to provide a basis to compare the cost of water system improvements targeted at improving system seismic resiliency against the benefits and value such increased system resiliency may provide, the SVA seeks to assess and estimate the economic impacts that could result from loss of service to Bellevue water system customers as a result of major seismic events.

This technical memorandum summarizes the methodologies used and resulting economic impact parameters assessed as part of the SVA. The economic impact parameters considered evaluate four components that are combined to represent potential overall impacts to the local economy resulting from potential loss of water service following a major seismic event:

1) Impacts to residential water customers resulting from loss of water service

2) Decrease in economic activity resulting from business disruption resulting from loss of water service

3) Economic impacts from loss of life resulting from an inability to effectively operate hospitals and major healthcare facilities if water service is unavailable

4) Economic impacts resulting from loss of water required to support fire suppression.

For each of these economic components, the impacts stemming from loss of water service cannot be isolated from other factors that may adversely impact economic activity such as loss of electricity, impact to transportation infrastructure, employees lost to injury or death, or direct earthquake damage to buildings or homes. Because this evaluation is focused only on benefits stemming from increased water system seismic resiliency, the water service impacts are evaluated independent of these other factors. The primary goal is to improve water system seismic resiliency and reduce the likelihood that water system failures are the cause of in significant impacts to customers and economics.

This analysis does not include economic impacts of collateral infrastructure damage such as damage to streets and public/private property resulting from system water main breaks, failures, and related flooding, the cost of repairing the water system related to seismic damage, or injuries/loss of life due that could result directly from water system infrastructure or facility failures.

2. Economic Impact Parameter Methodology and Results

The methodology and results for evaluating the potential economic impacts relating to a loss of water supply after an earthquake for each of the four categories identified above are described in the following sections.

2.1 Impacts to residential customers resulting from loss of water service

The dollar impacts to residential customers are estimated based on an estimated loss of service cost per household, the number of households without water after an earthquake, and the duration of water service outages. In equation form, this calculation is:

$$Loss\ of\ service\ cost = \frac{\$231}{household\ x\ day} * Number\ of\ households\ without\ water * days\ without\ water$$

The loss of service cost per household was estimated in 2018 to be $231 per household per day based on consumer surplus calculations completed previously for the City of Bellevue (BIS Engineering, 2018). This analysis represents a higher cost of living in the City of Bellevue compared to the Impact on Residential Customers of $60.00 per capita per day (2010 dollars) (Federal, 2011),

The number of households was estimated for each Bellevue SVA (SVA) subarea using the following steps:

1. Spatial Join population GIS data provided by the City (parcels_2018_0313_ORandPPH_yrbuilt.lyr[1]) with SVA Subareas.

2. Aggregate number of households per parcel within each SVA

2.2 Decrease in economic activity resulting from business disruption resulting from loss of water service

To determine the economic impact of loss of water service to businesses, a complex and spatially distributed analysis of business activity, value added effect, and potential impact from loss of water service was conducted.

The foundation for the business economic impact is Value Added as provided by IMPLAN (www.implan.com), which is a software and data package frequently used by economists to conduct input-output (I-O) analysis that quantifies the economic value or impact of changes to industry sectors within a local economy. From their website “IMPLAN is a platform that combines a set of extensive databases, economic factors, multipliers, and demographic statistics with a highly refined modeling system that is fully customizable.” The SVA uses the term Value Added Effect (VAE) to refer to impacts specifically related to a loss of water service, more specifically, the VAE is an estimate of what the impact to the local economy would be if a particular proportion of the revenue from a given economic sector were lost because of a loss of water service.

According to IMPLAN, Value Added is defined as follows:

> “Value Added represents the difference between Output and the cost of Intermediate Inputs within a region in a given period of time. It equals Gross Output (sales or receipts and other operating income, plus inventory change) minus intermediate inputs (consumption of goods and services purchased from other

[1] Calculations based on King County Assessor (March 2018) and U.S. Census Bureau’s 2012-2016 American Community Survey (ACS) data.

industries or imported). Value Added is equivalent to the industry's contribution to GDP.".

Value Added is calculated using SAM multipliers which represent the change in total gross domestic product resulting from a change in business activity within a particular sector of the economy. SAM multipliers account for both the indirect and induced effects of a change in demand from an economic sector, which are defined as follows.

- Indirect Effects. If a business ceases operation because of a water outage, the indirect multipliers account for losses for businesses in Bellevue that supply goods or services to that business, i.e. in addition to the business affected by the water outage, its local suppliers also lose sales for supplying them with goods or services.

- Induced Effects. Induced effects account for lost household income from employees at affected businesses that is no longer spent on goods and services such as food, beverages, and clothing purchased from businesses in Bellevue.

It should be noted that using I-O multipliers to calculate VAE may somewhat overstate the immediate economic impacts from the early stages of water outage because the methodology assumes annual effects can be divided by 365 to calculate daily effects and the multiplier effects do not take place instantaneously. I-O models are typically silent about how long that process takes, but full multiplier effects will take more than a matter of days to be realized. The time lag of multiplier effects should be considered when evaluating the estimates provided in the SVA.

VAE is then tailored to specific industry sectors using water resiliency factors that estimate the proportion of that business's economic impact that would likely be lost during a water service interruption. For example, some businesses like restaurants and food processing are highly dependent on water service, and an extended disruption in water service can be expected to result in a significant reduction in production from the business. However, real estate and construction have only minor dependency on water supply, so the proportion of the VAE lost due to lack of water service from construction or real estate is much lower than the proportion for manufacturing or food processing.

In order to use the VAE for the geospatial modeling being completed as part of the SVA, the following process was used.

1. As summarized in Table 1, delineate North American Industry Classification System (NAICS) sectors for use in the SVA by using the first 2 digits of the NAICS code, except Sector 51-Information which uses the first 4 digits of the NAICS code to separate dissimilar industries that are included within Sector 51. Sector 51 represents 46% of the total VAE for the City of Bellevue, with 44% of total VAE coming from two of the 9 subsectors included in Sector 51.

2. Calculate total annual VAE for the City of Bellevue by NAICS Sector using economic data purchased from IMPLAN. Total annual VAE is calculated by multiplying IMPLAN value added for each sector times that sector's Value Added "SAM Multiplier".

3. Obtain Bellevue B&O Tax Data by business. Tax data was provided by the City of Bellevue for each individual business. Data included business name, NAICS code, physical address, 2018 Gross Receipts (Net, Gross and Tax Due), 2018 Utility Revenue (Net, Gross and Tax Due), 2018 Other Revenue (Net, Gross and Tax Due), and 2018 Taxable Square Footage and Square Footage Tax Due.

4. Map physical business addresses geospatially and then join them with the SVA subareas to allow for spatial distribution during the subsequent vulnerability analysis modeling (see step 10).

Table 1. NAICS Codes and Sector Description for SVA Business Economic Impact Analysis

NAICS Code (First 2 or 4 digits)	Sector Description
11	Agriculture, Forestry, Fishing and Hunting
22	Utilities
23	Construction
31	Manufacturing
32	Manufacturing
33	Manufacturing
42	Wholesale Trade
44	Retail Trade
45	Retail Trade
48	Transportation and Warehousing
49	Transportation and Warehousing
51	Information ***(Not Used, See Breakout Below)***
5111	All Publishers Except Software
5112	Software Publishers
5121	Motion Picture and Video Industry
5122	Sound Recording Industry
5151	Radio and Television Broadcasting
5173	Wired and Wireless Telecommunications Carriers
5174	Satellite and Other Telecommunications
5182	Data Processing, Hosting and Related Services
5191	Other Information Services
52	Finance and Insurance
53	Real Estate and Rental and Leasing
54	Professional, Scientific, and Technical Services
55	Management of Companies and Enterprises
56	Administrative and Support and Waste Management and Remediation Services
61	Educational Services
62	Health Care and Social Assistance
71	Arts, Entertainment, and Recreation
72	Accommodation and Food Services
81	Other Services (except Public Administration)
92	Public Administration

5. Calculate the Total "Effective Tax Due" for each business by adding Gross Receipts and Square Footage "Actual Tax Due" to ([Utility Tax "Net Revenue"] + [Other "Net Revenue"]) x 2018 Gross Receipts Tax Rate (0.001496). This method of estimating utility tax and other tax moderates observed extreme variations in tax rate for the Utility Tax and Other categories resulting in taxable revenue from those categories that is consistent with Gross Receipts. Table 2 below includes a hypothetical example of how this calculation would work for a business that reported revenue in all three categories, as well as taxable square footage. Note, that this example is not representative of any actual business. The example in Table 2 shows how this method "smoothed" the estimated taxes for a business that has unusually high reported Actual Utility Tax and Other Tax Due. The actual Utility Tax Due and Other Tax Due is $600,000 and $300,000, respectively. The Effective Utility Tax Due and Effective Other Tax Due, used in this methodology is $14,960 for each of the two tax categories, and the Total Effective Tax Due is $435,082.

Table 2. Example calculations of effective tax due for a hypothetical business

Category	Gross Revenue[1]	Net Revenue[2]	Taxable Square Footage	Actual Tax Due[3]	Effective Tax Rate	Effective Tax Due[4]
Gross Receipts	$150,000,000	$100,000,000		$149,600	0.001496[5]	$149,600
Square Footage			1,000,000	$255,562	0.2555618[5]	$255,562
Utility Tax	$25,000,000	$10,000,000		$600,000	0.001496[6]	$14,960
Other	$25,000,000	$10,000,000		$300,000	0.001496[6]	$14,960
Total	$200,000,000	$120,000,000	1,000,000	$1,305,162		$435,082

Notes;

[1] Gross Revenue represents Gross Gross Receipts, and Gross Revenue in Utility Tax and Other categories

[2] Net Revenue represents Net (Taxable) Gross Receipts, and Net (Taxable) Revenue in Utility Tax and Other categories

[3] Actual Tax Due is the actual tax paid by the business. For Gross Receipts, this is the Net Gross Receipts x 0.001496, for the Utility Tax and Other categories, the rate varies depending on the type of revenue generated, and for the Square Footage Tax, the rate is $0.2555618/taxable square foot.

[4] Effective Tax Due is equal to Actual Tax Due for Gross Receipts and Square Footage categories. For Utility Tax and Other categories, Effective Tax Due is the Net Revenue for the category multiplied by the gross receipts tax rate of 0.001496

[5] Effective Tax Rate is the same as actual tax rate

[6] Effective Tax Rate is lower than actual tax rate

6. For each SVA NAICS Sector, proportion the total VAE for the sector to businesses based on each businesses' Effective Total Tax Due. The Equation below shows how each sector's VAE is proportioned to individual businesses based on effective tax due.

$$Business\ A's\ VAE = \frac{Business\ A's\ Effective\ Tax\ Due}{\sum Effective\ Tax\ Due\ for\ Business\ A's\ Sector} \times \sum VAE\ for\ Business\ A's\ Sector$$

7. Compare the VAE in each SVA NAICS Sector to the businesses revenue to identify any potential disproportional attribution of VAE.

   Two sectors, Sector 11 (Agriculture) and Sector 31 (Manufacturing) both had significant and apparently unrealistic discrepancies between effective total tax due and revenue, primarily due to a small number of large businesses that pay little or no tax. For these two sectors, VAE was proportioned based on the total reported revenue of the businesses, instead of effective tax due. Note that this method does not account for businesses that report and are taxed on square

footage in lieu of revenue, but in these two sectors, square footage was minimal and can be considered negligible as it would not significantly alter the distribution of VAE.

The Equation below shows how the VAE for Sector 11 and 31 is proportioned to individual businesses.

$$Business\ A's\ VAE = \frac{Business\ A's\ Total\ Gross\ Revenue}{\sum Total\ Gross\ Revue\ for\ Business\ A's\ Sector} \times \sum VAE\ for\ Business\ A's\ Sector$$

8. Review the top 25 business by VAE (representing almost half of the total VAE in the water service area) to verify that their locations correspond to the location where they conduct the majority of their business. In one case, the Subarea assigned to the business was manually adjusted to correct for a discrepancy between locations where the business conducts the majority of their business and where their revenue was reported.

9. Apply water resiliency factors to each SVA NAICS Sector based on values developed by Chang, et al. Calculated Economic Loss Factor (ELF) = (1 – Water Resiliency Factor). Water Resiliency Factors account for the relative ability of a business to keep operating during a water outage[2] (Chang et al. 2002).

   Table 3 shows how the NAICS codes used in the SVA have been aligned to the corresponding Standard Industrial Classification (SIC)[3] Divisions and Sectors from Chang, et al., as well as the resiliency factors which were used to calculate the economic loss factor for each sector as described above.

10. Calculate Daily Economic Loss for each business by dividing Annual VAE from # 6 or 7 above by 365 days per year, and then multiplying by the business' sector's ELF.

$$Business\ A\ daily\ VAE\ lost\ from\ water\ outage = \frac{Business\ A\ Annual\ VAE}{365\frac{days}{year}} \times Business\ A's\ Sector's\ ELF$$

11. Calculate the total Daily Economic Loss for each SVA subarea to be used in modeling by summing the individual daily economic loss for each business in a subarea to obtain the total economic loss due to water outage for that subarea.

    Note: Because the tax data for many businesses with multiple locations are reported at only one location, it is not appropriate or accurate to distribute potential economic loss on a business by business basis. In order to distribute Daily Economic Loss spatially, it is recommended that Daily Economic Loss for a SVA subarea be proportioned based on water demand by subarea.

[2] Note that the recent Bellevue Water System Emergency Supply study used an unpublished value for outages between 0 and 3 days. However, for this analysis the published resiliency factors were used without modification.

[3] SIC Codes are part of the old U.S. business sector classification system that was replaced by NAICS in 1997.

Table 3. NAICS Sector to SIC Division Reference and Water Resiliency Factors

NAICS Code for SVA	NAICS Sector Description	SIC Division	SIC Economic Sector	Chang, Et, al. Resiliency Factor		
				Less than 1 Week	1 to 2 Weeks	Greater than 2 Weeks
11	Agriculture, Forestry, Fishing and Hunting	A	Agriculture	0.53	0.35	0.3
22	Utilities	E (46, 48, 49)	Communications/Utilities	0.65	0.49	0.43
23	Construction	C	Construction	0.68	0.47	0.43
31	Manufacturing	D	Nondurable and Durable Manufacturing	0.42	0.34	0.28
32	Manufacturing	D	Nondurable and Durable Manufacturing	0.42	0.34	0.28
33	Manufacturing	D	Nondurable and Durable Manufacturing	0.42	0.34	0.28
42	Wholesale Trade	F	Wholesale Trade	0.51	0.36	0.3
44	Retail Trade	G	Retail Trade	0.46	0.32	0.28
45	Retail Trade	G	Retail Trade	0.46	0.32	0.28
48	Transportation and Warehousing	E (40-45)	Transportation	0.65	0.49	0.43
49	Transportation and Warehousing	E (40-45)	Transportation	0.65	0.49	0.43
51	Information					
5111	All Publishers Except Software	D	Nondurable and Durable Manufacturing	0.42	0.34	0.28
5112	Software Publishers	I	All Services Except Health	0.45	0.33	0.27
5121	Motion Picture and Video Industry	I	All Services Except Health	0.45	0.33	0.27
5122	Sound Recording Industry	I	All Services Except Health	0.45	0.33	0.27
5151	Radio and Television Broadcasting	E (46, 48, 49)	Communications/Utilities	0.65	0.49	0.43

Table 3. NAICS Sector to SIC Division Reference and Water Resiliency Factors

NAICS Code for SVA	NAICS Sector Description	SIC Division	SIC Economic Sector	Chang, Et, al. Resiliency Factor		
				Less than 1 Week	1 to 2 Weeks	Greater than 2 Weeks
5173	Wired and Wireless Telecommunications Carriers	E (46, 48, 49)	Communications/Utilities	0.65	0.49	0.43
5174	Satellite and Other Telecommunications	E	Communications/Utilities	0.65	0.49	0.43
5182	Data Processing, Hosting and Related Services	I	All Services Except Health	0.45	0.33	0.27
5191	Other Information Services	I	All Services Except Health	0.45	0.33	0.27
52	Finance and Insurance	H	Finance, Insurance, and Real Estate	0.44	0.27	0.24
53	Real Estate and Rental and Leasing	H	Finance, Insurance, and Real Estate	0.44	0.27	0.24
54	Professional, Scientific, and Technical Services	I	All Services Except Health	0.45	0.33	0.27
55	Management of Companies and Enterprises	H	Finance, Insurance, and Real Estate	0.44	0.27	0.24
56	Administrative and Support and Waste Management and Remediation Services	I	All Services Except Health	0.45	0.33	0.27
61	Educational Services	I	All Services Except Health	0.45	0.33	0.27
62	Health Care and Social Assistance	I (80)	Health Services	0.27	0.21	0.19
71	Arts, Entertainment, and Recreation	I	All Services Except Health	0.45	0.33	0.27
72	Accommodation and Food Services	I	All Services Except Health	0.45	0.33	0.27
81	Other Services (except Public Administration)	I	All Services Except Health	0.45	0.33	0.27
92	Public Administration	I	All Services Except Health	0.45	0.33	0.27

2.3 Economic impacts from loss of life resulting from an inability to effectively operate hospitals and major healthcare facilities if water service is unavailable

Water is an essential resource for hospitals and major healthcare facilities. In the event of a major earthquake, a sharp increase in life-threatening injuries and high demand for treatment can be anticipated. This increases the importance of maintaining an adequate water supply to hospitals as it can become the difference between losing or saving lives. To estimate the economic impact of water outage in these scenarios, the value of a statistical life (VSL) and estimated number of deaths due to water service loss are used to quantify the total impact.

The environmental protection agency (EPA) defines the VSL as "a summary for the dollar value of small changes in mortality risk experienced by a large number of people" and recommends a default VSL of $7.9 million in 2008 dollars (EPA 2014). The default VSL is $9.4 million in 2019 dollars using a 19.3% cumulative increase in inflation between 2008 and 2019 based on the October 2019 Consumer Price Index (CPI-U). This is the value of reducing mortality by one statistical death based on what people are willing to pay to reduce the risk.

There are three major medical facilities within the Bellevue WSA: Seattle Children's, Overlake Hospital, and Kaiser Permanente. Staff from each hospital were interviewed to understand the potential impact of not having water service after an earthquake, and the status of their onsite emergency water supply reserves. Following any major seismic event, Children's and Kaiser currently plan to triage and treat simple, urgent cases while sending complicated cases to Overlake Hospital. Both facilities have emergency water, but noted that they would likely not remain open, and are not required to, if adequate water could not be available.

Overlake Hospital is the designated Disaster Medical Coordination Center back up for King County, with Harborview in Seattle serving as the primary facility for both the County and Washington State. If either the Cascadia Subduction Zone (CSZ) or Seattle Fault Zone Event (SZFE) earthquakes occurred, overland and roadway routes to Harborview and other facilities could likely be cut off based on fault lines and known liquefaction hazard areas. Therefore, Overlake is likely to see a significant number of cases after an event. The hospital has 340 beds and could see up to 10,000 people seeking treatment after an earthquake occurs. In terms of emergency water supply, Overlake is required by the Joint Hospital Association to have enough resources to operate for ninety-six hours (four days). Hospital staff have estimated they currently have approximately three days' worth of bottled/stored water on hand (Axtell, pers. Comm. 2019). Following a major seismic event, water supply service to Overlake Hospital is likely to quickly become a critical issue.

Based on this information, the economic analysis uses the following assumptions to estimate loss of life due to loss of water service to the hospital:

- 5% of the 10,000 cases seen are considered life-threatening (500 cases)
- Of the life-threatening cases, a portion will result in death even with water service.[4] An additional 5% of the life-threatening cases will result in loss of life without access to a hospital as a result of loss of water (25 cases)
- 5% of the 340 occupied beds would be life-threatening cases that will result in loss of life without water (17 cases). This assumes the worst case scenario that the hospital is operating at capacity before the event occurs.

[4] The 1989 Loma Prieta earthquake in the Bay Area, California resulted in 63 deaths out of 3,757 injuries. The 1994 Northridge earthquake in Los Angeles, California resulted in 72 deaths out of 9,000 injuries.

- Emergency onsite reserves of potable water and non-potable water for sanitation are exhausted by the end of day three after a significant event, causing the hospital to shut down and begin relocating patients

- Lives lost without water would occur between days four and seven after an initial seismic event

These assumptions estimate 42 deaths due to water outage (25 + 17 = 42). If these deaths were prevented, it would equate to $394.8 million (42 * $9.4 million VSL).

Note that it is assumed that there would be significant loss of life resulting from either of the major earthquakes considered in the SVA. The deaths and economic impacts described above are only those that would be directly attributed to loss of hospital service due to loss of water service at Overlake Hospital.

2.4 Economic impacts resulting from loss of water required to support fire suppression

Fires after an earthquake can result in tremendous damage which can be exacerbated without a functioning water system to support fire suppression. John M Eidinger developed a model to study these impacts by iterating scenarios based on historic data, fire spread physics, and water system damage (Eidinger 2004). This analysis uses the general principals presented in Eidinger's paper using simplifying assumptions suited to the Bellevue WSA.

Three variables are important for estimating the extent of fire damage: number of ignitions, fire spread, and fire suppression.

1. Number of ignitions is calculated using an ignition rate (IR) and total building floor area. Based on historic data, IR can be calculated using the following equation $IR = -0.025 + (0.59 * PGA) - (0.29 * PGA^2)$ where the IR is per 1,000,000 sf of building floor area and PGA stands for peak ground acceleration of an earthquake. Table 4 summarizes the number of ignitions estimated for each earthquake scenario.

Table 4. Total Number of Ignitions After Earthquake

Earthquake Scenario	Average Peak Ground Acceleration	Ignition Rate (IR/1,000,000 sf)	Total building floor area in Service Area (sf)	Number of Ignitions
Cascadia Subduction Zone Event[1]	0.145	0.055	381,870,000	21
Seattle Fault Zone East Event[2]	0.547	0.211	381,870,000	81

[1]Aligns with estimated 155 ignitions in the Lower Mainland, British Columbia for the CSZ scenario if scaled proportionately to a city the size of Bellevue (Scawthorn and Waisman 2001).

[2] The 1989 Loma Prieta Earthquake (7.1 magnitude event comparable to SFZE scenario) recorded 67 ignitions (Eichman 2004).

sf = square feet

2. The Hamada and TOSHO models have historically been used to simulate fire spread within community blocks. Both models assume that fires do not spread across firebreaks such as streets while additional modeling suggests that the probability of fire spreading across firebreaks depends heavily on wind (Eichman 2004). Bellevue typically has low wind conditions ranging from two to four miles per hour on average (CLV 2019) therefore, if an ignition is not extinguished, it is assumed to burn all of the buildings within one side of the street on a single block but does not cross the street or cross to another block.

3. Fire suppression depends on the condition of the water system after an event and the planned emergency response by the fire department and other emergency responders. Complex models such as the HAZUS model (developed by the National Institute for Building Sciences), System Earthquake Risk Assessment (SERA) and RiskLink simulate fire ignitions, spread and suppression to estimate the damage caused by fires following earthquakes. Case studies with hundreds of simulations suggest that the most sensitive parameters for estimating damage include the number of ignitions, wind conditions, and location of fires (Eichman 2004). The Bellevue fire department has 9 fire stations staffed 24 hours per day with at least 48 fire suppression personnel on hand at all times within the Bellevue WSA. Based on conversations with the fire department, emergency response after an earthquake will be focused primarily on saving lives and assessing damage for prioritization. Therefore, this analysis assumes that fire department response could contain about 10 ignitions with a fully functioning water system and about 5 ignitions absent water service availability to fire hydrants and building sprinkler and fire suppression systems.

Based on historical data, most ignitions occur in residential areas because of their prevalence of ignitable building materials (such as wood) and vulnerable natural gas service lines. For example, in the 1994 California Northridge earthquake, more than 70% of earthquake related ignitions occurred in residential areas (Eidinger, 2004). Additionally, historic ignition data suggests that 75% of ignitions occur in wood structures (more typical for residential areas) and mobile homes (Elhami et. Al. 2017). Therefore, the probability of a fire occurring in a particular block in a particular SVA subarea, was estimate separately for both residential and non-residential areas according to the following equation:

$$Probability\ of\ residential\ fire\ loss = total\ ignitions * probability\ of\ ignition\ being\ extinguished * \frac{number\ of\ residential\ blocks\ in\ BSVA\ subarea}{Total\ number\ of\ blocks\ in\ WSA}$$

This equation assumes that each ignition that is not extinguished results in one block of loss. It also assumes that the probability of fire loss is proportional to the number of blocks in each SVA subarea.

Fire loss (economic impact due to fire damage) includes both direct loss (structures burned) and indirect loss (revenue loss due to burned business being closed). This analysis assumes

1. Direct loss based on 2018 King County Assessor data for improvements. Values are averaged across the Bellevue WSA on a per house basis for single family residential to provide the same direct loss value for each home; regardless of location, size, or appraised value.
2. Indirect loss using the same methodology described in the section 2, and assuming that the total indirect loss is the annual VAE multiplied by the number of years required to rebuild commercial structures (estimated at two years).

Direct loss is applied to both burned residential buildings and burned non-residential buildings, but indirect loss is only applied to non-residential buildings. In order to isolate the economic impact of water outages, the fire loss for each SVA subarea is calculated as the delta between the estimated fire loss with water and the estimated fire loss without water. The delta depends on the estimated number of contained ignitions with water service active (10) versus without water service (5). In equation form,

$$\begin{aligned} &Fire\ loss\ due\ to\ water\ outage \\ &\quad = [(direct\ residential\ loss) \\ &\quad * (probability\ of\ residential\ fire\ loss\ with\ water \\ &\quad - probability\ of\ residential\ fire\ loss\ without\ water)] \\ &\quad + [(direct + indirect\ nonresidential\ loss) \\ &\quad * (probability\ of\ nonresidential\ fire\ loss\ with\ water \\ &\quad - probability\ of\ nonresidential\ fire\ loss\ without\ water)] \end{aligned}$$

Based on case studies simulating number of fires burning over time, the majority of ignitions are anticipated to be contained, or run out of fuel or self-extinguish within the first 24 hours following a major seismic event (Eidinger 2004). Therefore, this analysis assumes that 70% of the economic loss related to fires can be attributed to day 1 after an earthquake event, followed by 20% for day 2 and 10% on day 3.

3. Summary of results

The following observations are made based on the results of this analysis;

- Of the four economic parameters, Loss of Value Added Effect due to potential loss of business activity is the primary driver for post seismic event economic impact related to potential loss of water service. For example, if water service were interrupted across the entire Bellevue WSA and not restored after fourteen days, business loss could likely account for 75% of the $3.76 billion cumulative economic impact.

- Economic impact due to loss of life and fire loss are likely to be realized within the first seven days following a major seismic event.

- There is no significant difference in economic impact between the CSZ and SFZE events. The only difference is a minor difference in fire loss.

Figures 1 through 5 illustrate the cumulative economic impact to each SVA Subarea of having no water at 3, 7, 14, 30 and 60 days following the CSZ event. These figures are also representative of the SFZE event, which has only inconsequential differences due to the variation in impact on fire suppression.

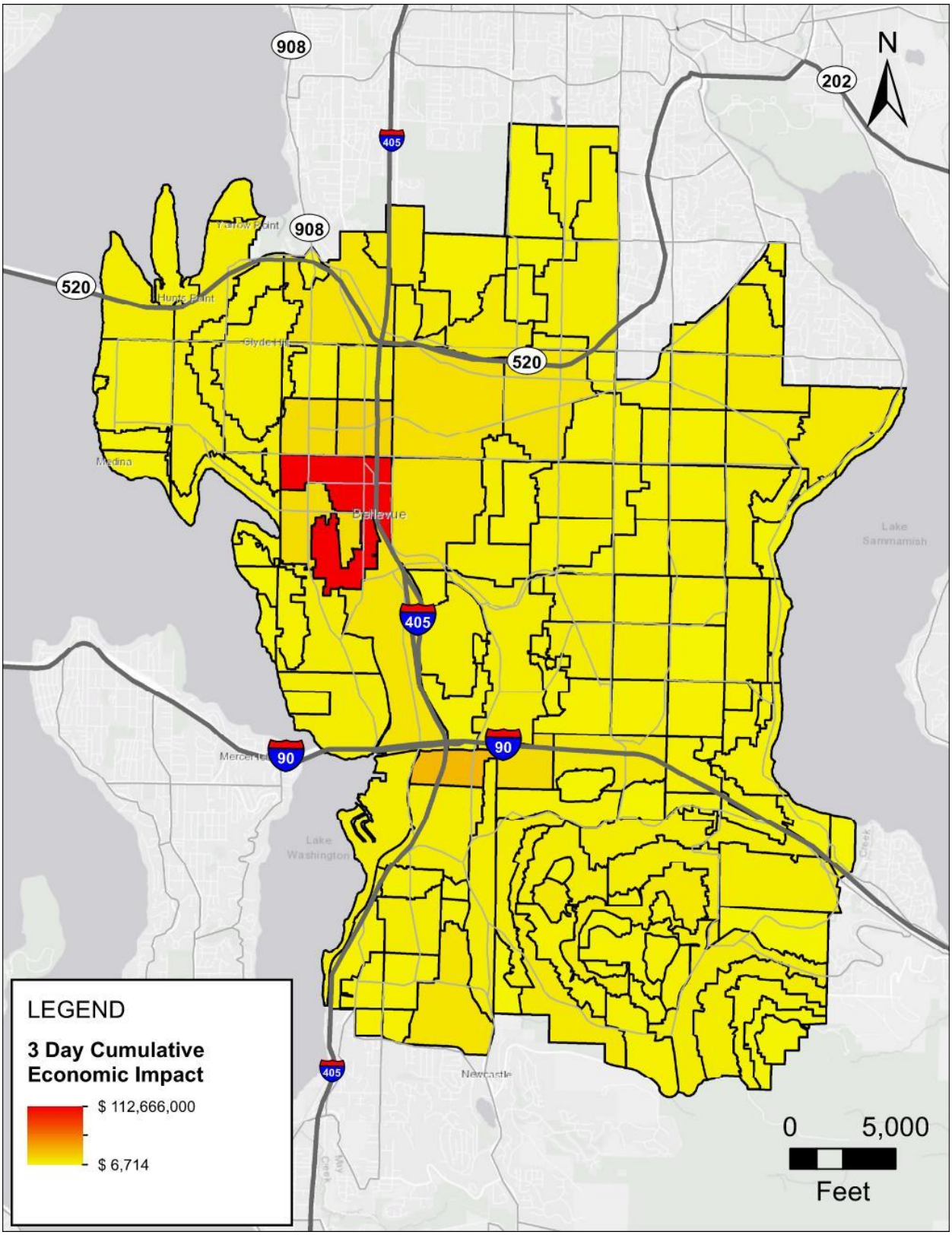

Figure 1. 3 Day Cumulative Economic Impact

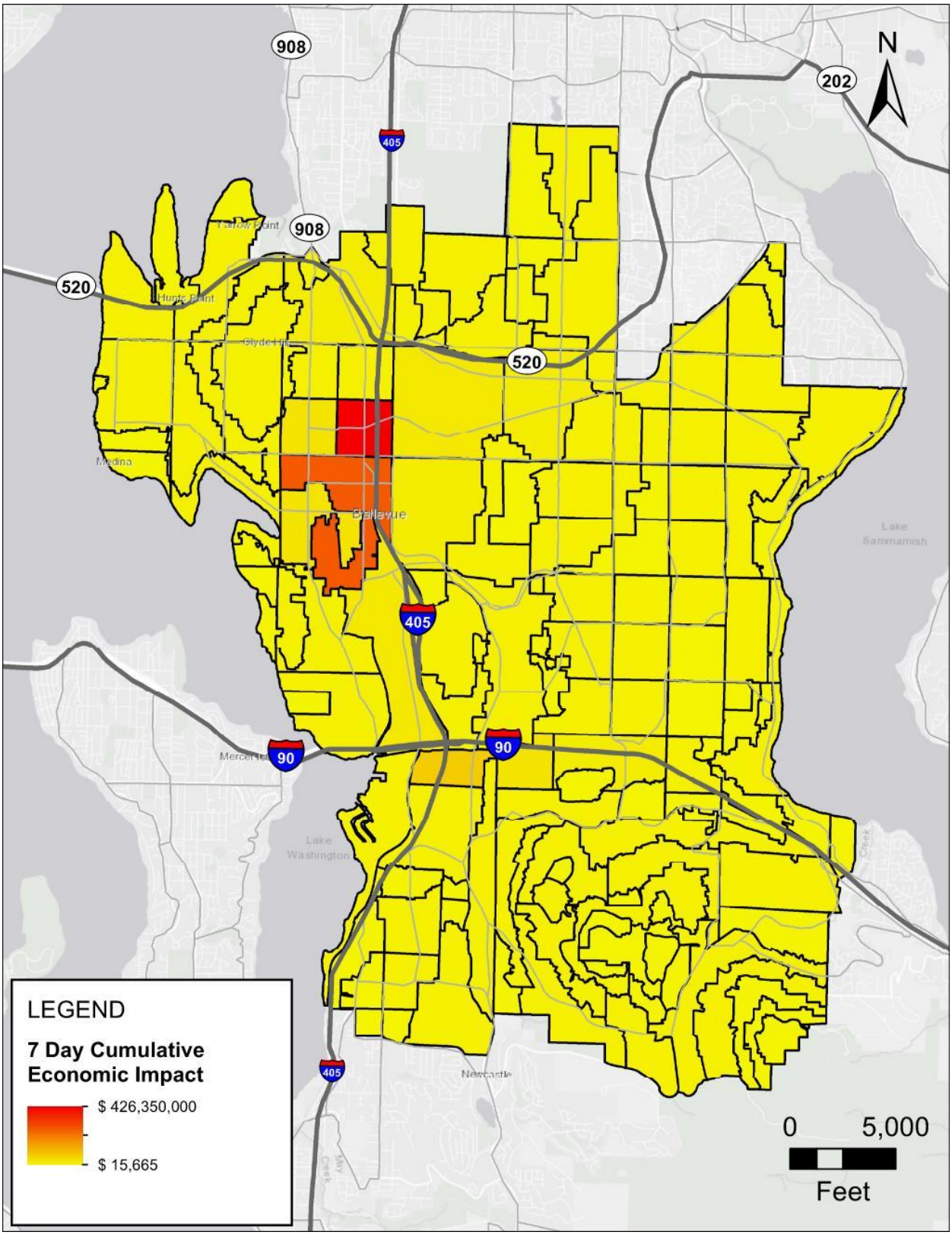

Figure 2. 7 Day Cumulative Economic Impact

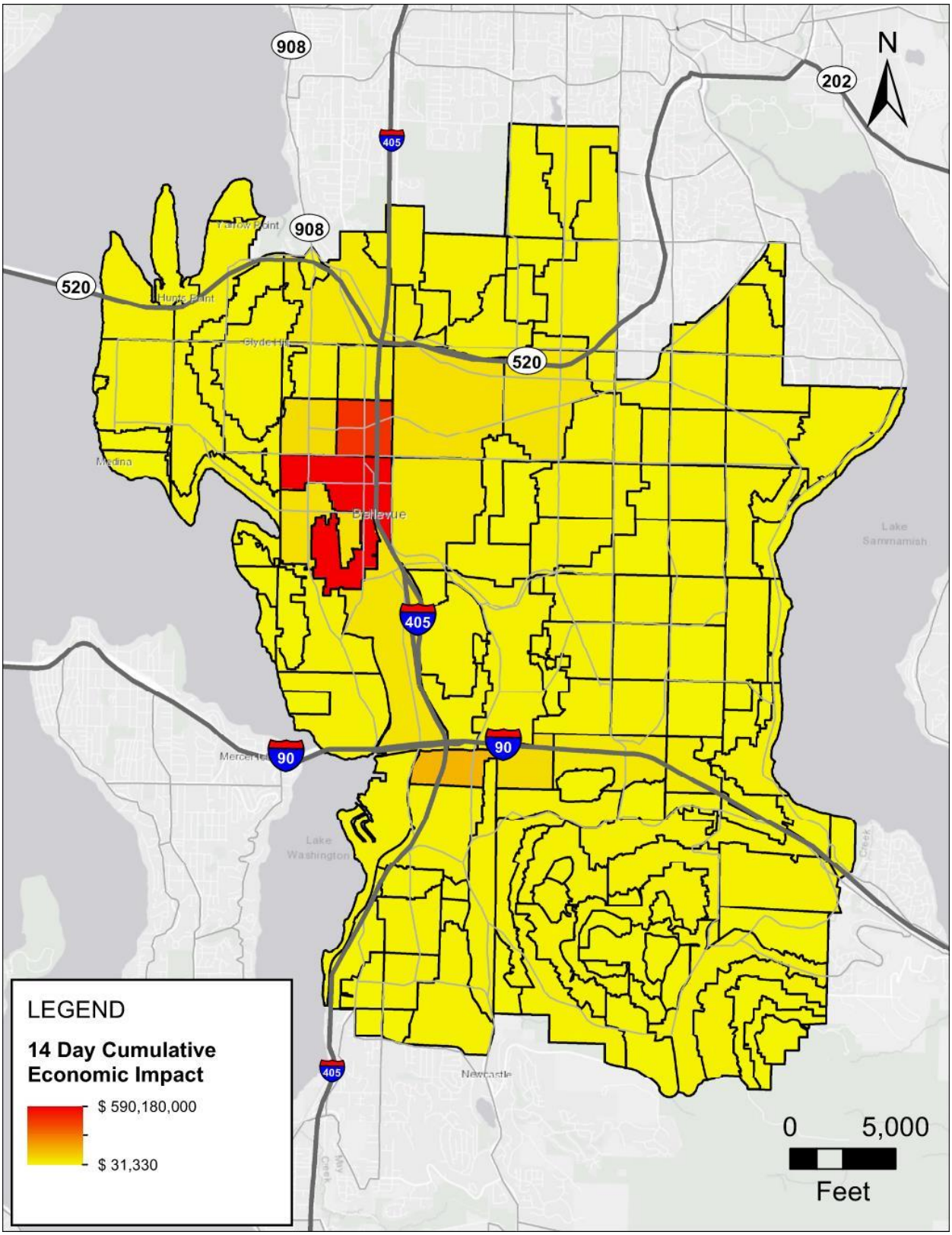

Figure 3. 14 Day Cumulative Economic Impact

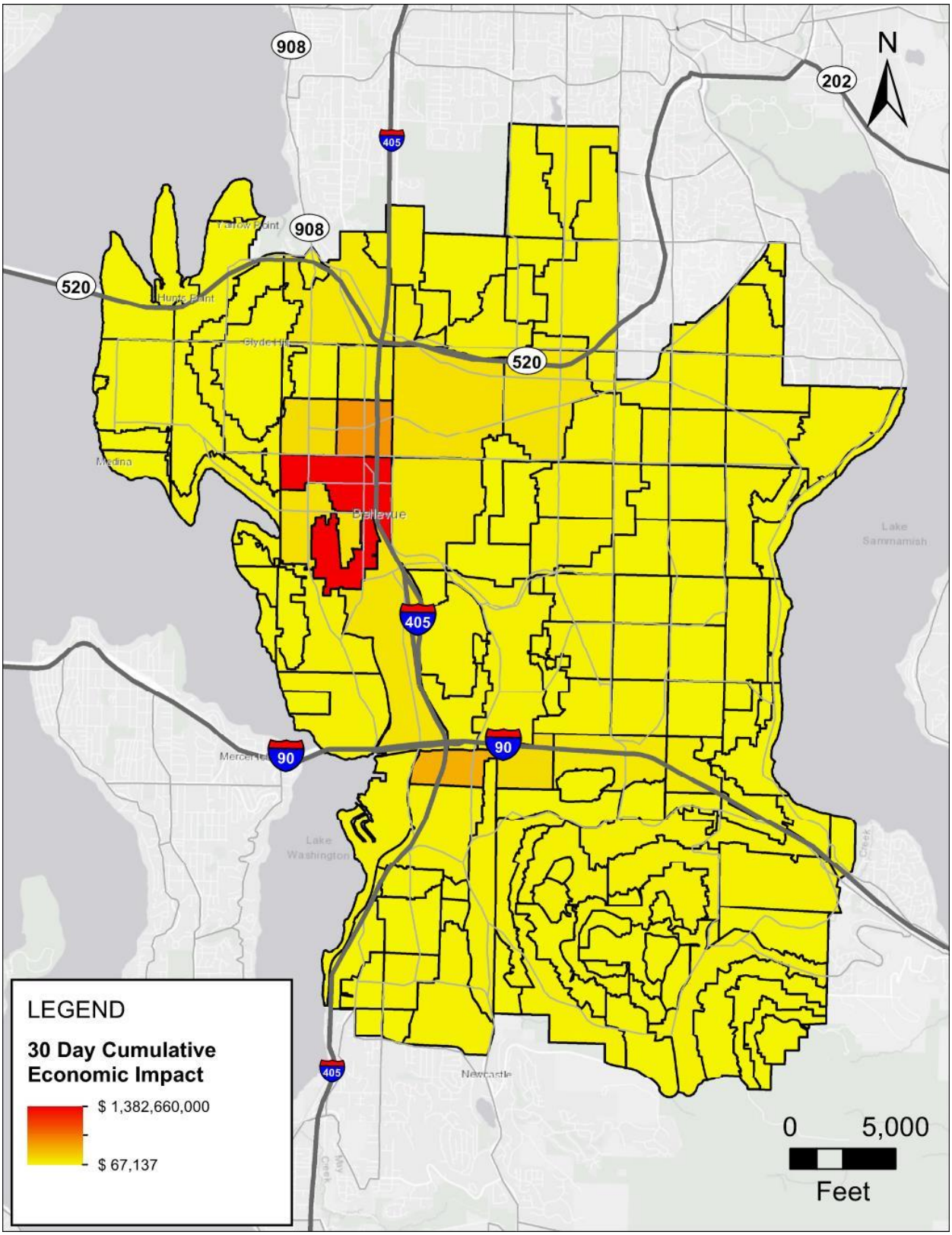

Figure 4. 30 Day Cumulative Economic Impact

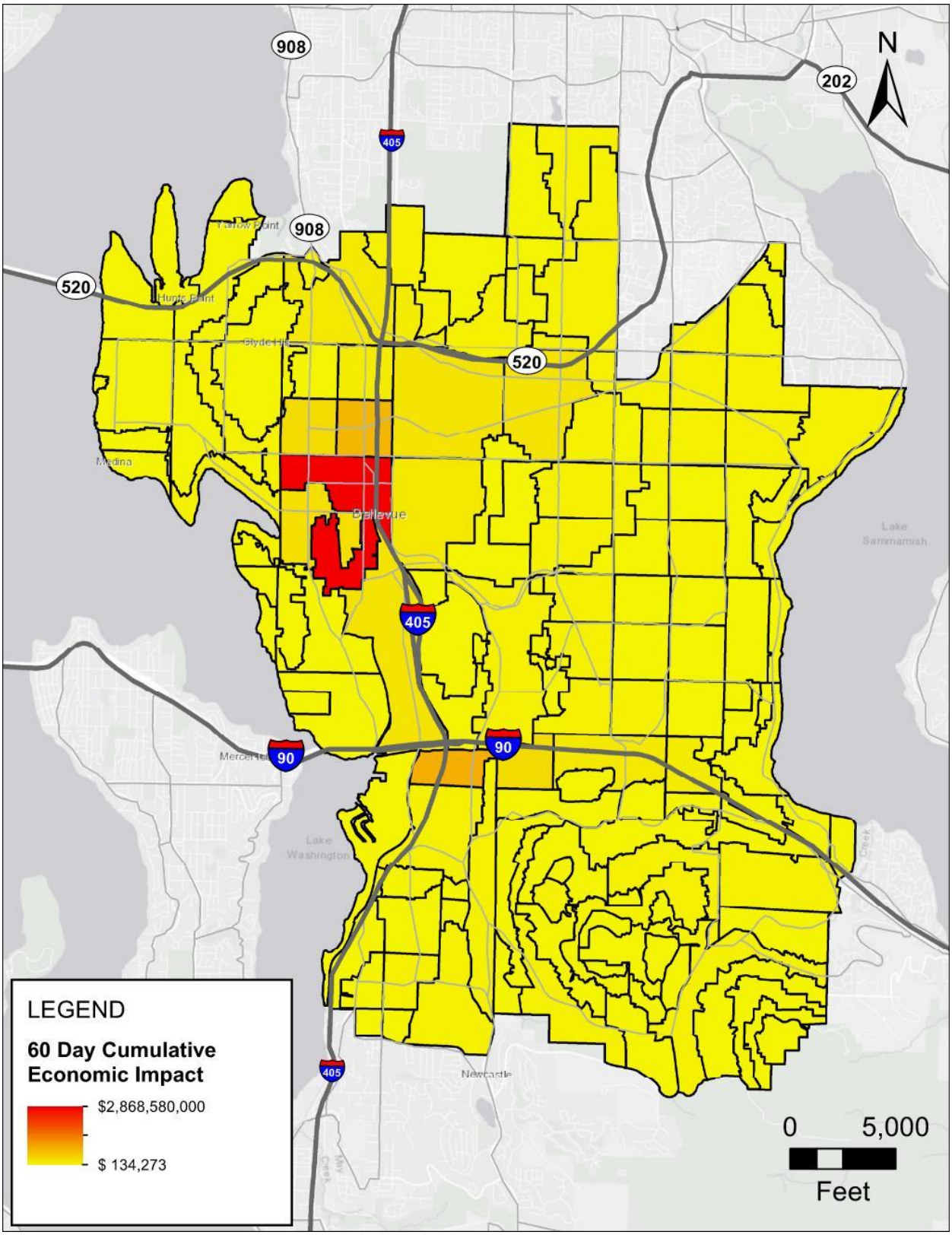

Figure 5. 60 Day Cumulative Economic Impact

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Appendix F. Existing System Seismic Vulnerability and Potential Service Outage Severity

F.1 TM6: As-Is Service Outage, Restoration Times, and Economic Impacts

Jacobs

Technical Memorandum

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Subject	**DRAFT FINAL - TM6: As-Is Service Outage, Restoration Times, and Customer Impacts**
Project Name	Bellevue Water System Seismic Vulnerability Assessment
From	Jacobs
Date	December 29th, 2021

1. Background

The City of Bellevue Water System Seismic Vulnerability Assessment (SVA) includes identification of the as-is service outage for different seismic scenarios, developing an approach for returning service to customers to identify restoration times for customers for the as-is condition, and then identifying the economic impacts of post-earthquake water outage for the as-is condition. This as-is condition provides the baseline for comparing the benefit that system improvements provide by reducing the restoration time and the overall economic impact in the City.

The development of the methodology used and the determination of the vulnerability of existing system components can be found in TM 2[1] and TM 3[2], and the modeling results for customer outage probability in TM4[3]. The restoration assumptions were developed jointly with the City during the Outage and Restoration Assumptions workshop, and the economic assumptions applied to develop the economic impact curves is summarized in TM 5: Economic Impact Parameters.

This document describes the results of the restoration scenario modeling described in TM 3, and then uses the modeling results to identify customer and economic impacts. The results presented in this document include the following items:

- Restoration Methodology: Summary of methodology for restoration scenario development.
- Restoration Assumptions: Identification of the assumptions for repair times, resource availability, available materials, and availability of mutual aid
- Damage Scenarios and Restoration Curves: Identification of the restoration time for each seismic scenario by applying the restoration assumptions to the simulated system restoration.
- Potential Economic Impact: Identification of the potential economic impact by applying the economic assumptions to the simulated system restoration.

[1] TM2: Seismic Vulnerability Assessment for Pipelines and Facilities
[2] TM3: Modeling Methodology
[3] TM4: Existing System Vulnerability and Customer Outage Probability

2. Methodology

As outlined in TM 3: Modeling Methodology, modeling was performed to estimate the potential damage to the system, customer service impacts, and the probable restoration times following a seismic scenario event. The modeling that was completed for the restoration evaluation was completed using Optimizer by Optimatics on each of four selected multi-break scenarios. As described in TM 3, an objective function was developed to identify the preferred order of system improvements that would return service most efficiently to the City's system. The objective function applied in Optimizer combined meeting minimum pressure criteria with a pressure penalty that was a function of the economic impact for each subarea as defined in TM 5. This approach to the restoration simulations focused efforts on the areas for initial improvements that had the most benefit both for large population groups and for critical economic centers.

Once the order of improvements was defined, the assumptions for restoration resources and repair durations was assigned to formulate the timeline for repairs. The tiered structure of the City's system was also considered, and water supply to receiving pressure zones could not be provided until the supplying pressure zone was repaired. For some zones, this meant that up to 5 pressure zones must be repaired and returned to service before water supply could be restored.

3. Restoration Assumptions

A summary of the restoration assumptions developed with the City to repair facility and asset damage after an earthquake is provided in Table 1. These are shown separately for the Cascadia Subduction Zone event (CSZ) and the Seattle Fault Zone East (SFZE) event. The primary difference in the CSZ and SFZE restoration assumptions is in the number of crews available to support repairs over time. This difference in crew availability is due to the difference of the extent and anticipated damage between the CSZ and SFZE events on a regional basis, in considering the likely availability of mutual aid. For the CSZ event, less damage is anticipated, but the damage is anticipated to be more widespread, causing more nearby utilities to be unable to provide mutual aid as well as requesting mutual aid from more distance water systems. As a result, the rate of additional crews to support repairs is less than the projected number of crews available for the SFZE event. The restoration assumptions for the repair to the SPU system is based upon information provided in the SPU seismic system assessment public report and discussions with SPU staff.

Table 1: Restoration Assumption Summary

	SFZE	CSZ
Pipe Repair Crews		
Time from Seismic Event	Crews Available	
0-3 days	2	2
4-7 days	5	2
8-14 days	10	5
14-21 days	20	10
21+ days	20	20
Pipe Repair Rate		
Time from Seismic Event	Repair Rate (number of repairs per crew day)	
AC and DI Pipe Break	1	1
All other Pipe Break	1.5	1.5
AC Pipe Leak	1	1
All other Pipe Leak	2	3
Facility Repair Rate		
Pump Stations and Reservoirs	Number of Facilities Repaired per Week	
First 30 days	0	0
After 30 days	2	1
Inlet Stations	Use pipe repair crews and repair rates for AC pipe	
PRVs	Use pipe repair crews and repair rates for AC pipe, these should already be coded as pipes with leaks and breaks.	
SPU Repair Time		
CESSL and TESSL (if offline)	21 days	21 days

4. Results

A summary of the selected damage scenarios and the restoration curves and economic impacts are summarized in the following sections.

4.1 Damage Scenarios

Seismic damage scenarios for restoration analysis were selected from the multi-break Monte Carlo analysis. The seismic scenarios selected for restoration analysis included the following scenarios:

- CSZ: 50% Scenario, Simulation C2213
- SFZE: 25% Scenario, Simulation S9496
- SFZE: 50% Scenario, Simulation S8938
- SFZE: 75% Scenario, Simulation S2301

The percentage values shown to describe the scenarios (e.g., 25%, 50%, or 75%) are indications of the relative probability of each occurring. These scenarios were selected from a set that was narrowed by looking for scenarios in which the number of facilities offline and the number of pipes offline represented approximately the 25th, 50th, or 75th percentile of values from all 10,000 multibreak scenario iterations for each of the two events (CSZ and SFZE). These scenarios were selected to cover the range of scenarios in the multi-break analysis. Table 2 summarizes the number of pipe repairs (leaks+breaks), and facility outages for each selected damage scenario. As described in the methodology section, each as-is damage scenario was modeled and evaluated to determine the preferred order or repairs to return service to the distribution system customers most efficiently.

Table 2: Restoration Scenario Summary

Item	C2213 (CSZ 50%)	S9496 (SFZE 25%)	S8938 (SFZE 50%)	S2301 (SFZE 75%)
SPU Supplies Online[1]	1	1	1	0
Number of Inlets Online	13	9	10	9
Pump Stations Online	22	11	12	15
Reservoirs Online	31	27	26	21
Total Pipe Repairs	220	523	537	552
[1]CESSL is offline in all selected scenarios				

4.2 Restoration Curves

Using the selected order of repairs identified in the restoration modeling and the restoration assumptions presented above, system outage times were calculated and restoration curves that present the customer impact over time were developed for each of the selected seismic scenarios.

System outage times were also calculated for each pressure zone and sub area for each scenario. The outage times were based on the expected damage, and the estimated restoration times of critical components required to restore service. Table 3 summarizes the benchmark restoration times for each seismic scenario, and Figure 1 shows the entire restoration period for each seismic scenario by percent of customers with water, and Figure 2 summarizes the restoration time by number of customers without water for each seismic scenario.

Table 3: Restoration Time Summary by Earthquake Scenario

	Days after Earthquake Event			
Percent of Customers Restored with Service	C2213 (CSZ 50%)	S9496 (SFZE 25%)	S8938 (SFZE 50%)	S2301 (SFZE 75%)
50%	38	59	65	60
75%	47	74	77	72
90%	58	83	85	83
99%	70	90	96	94

Figure 1: Restoration Time Summary by Earthquake Scenario

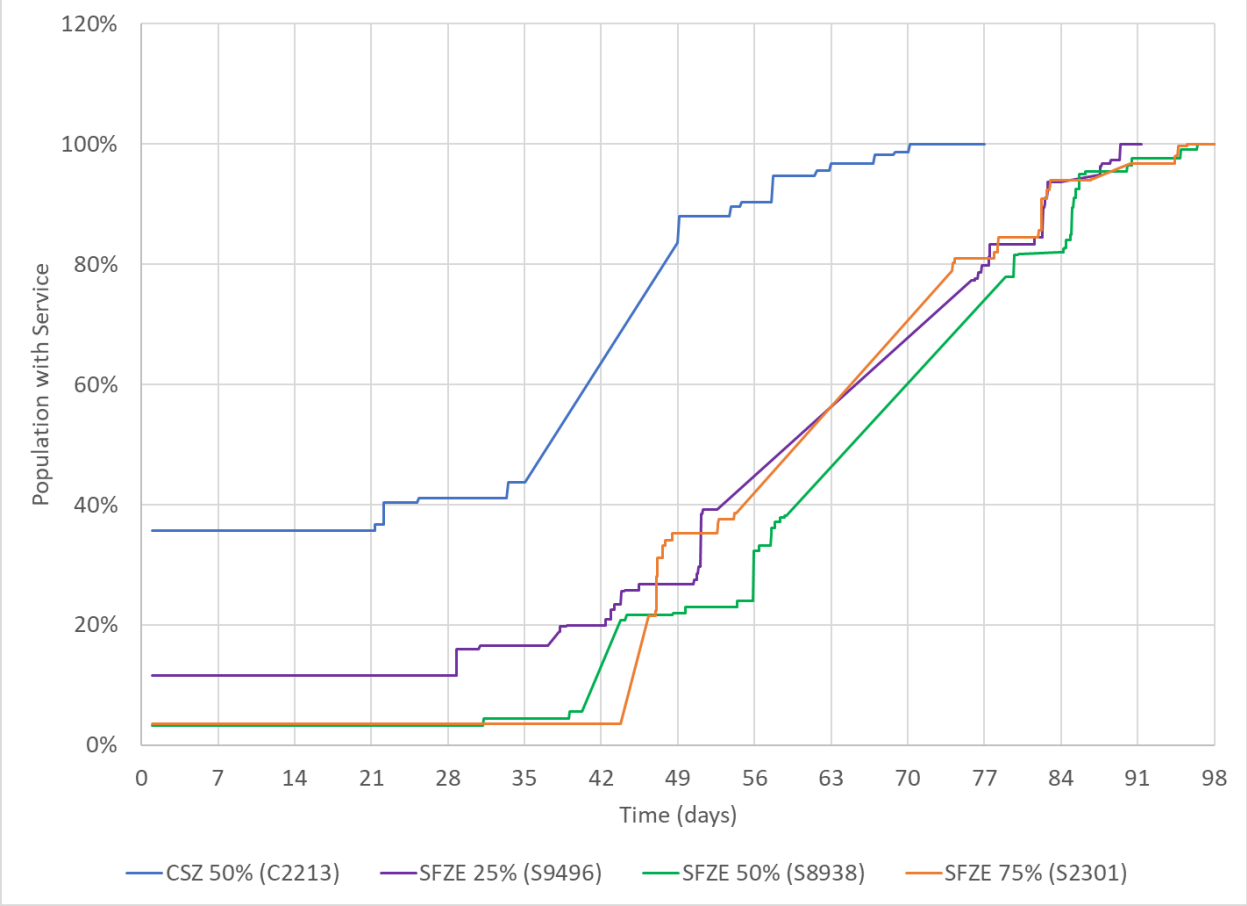
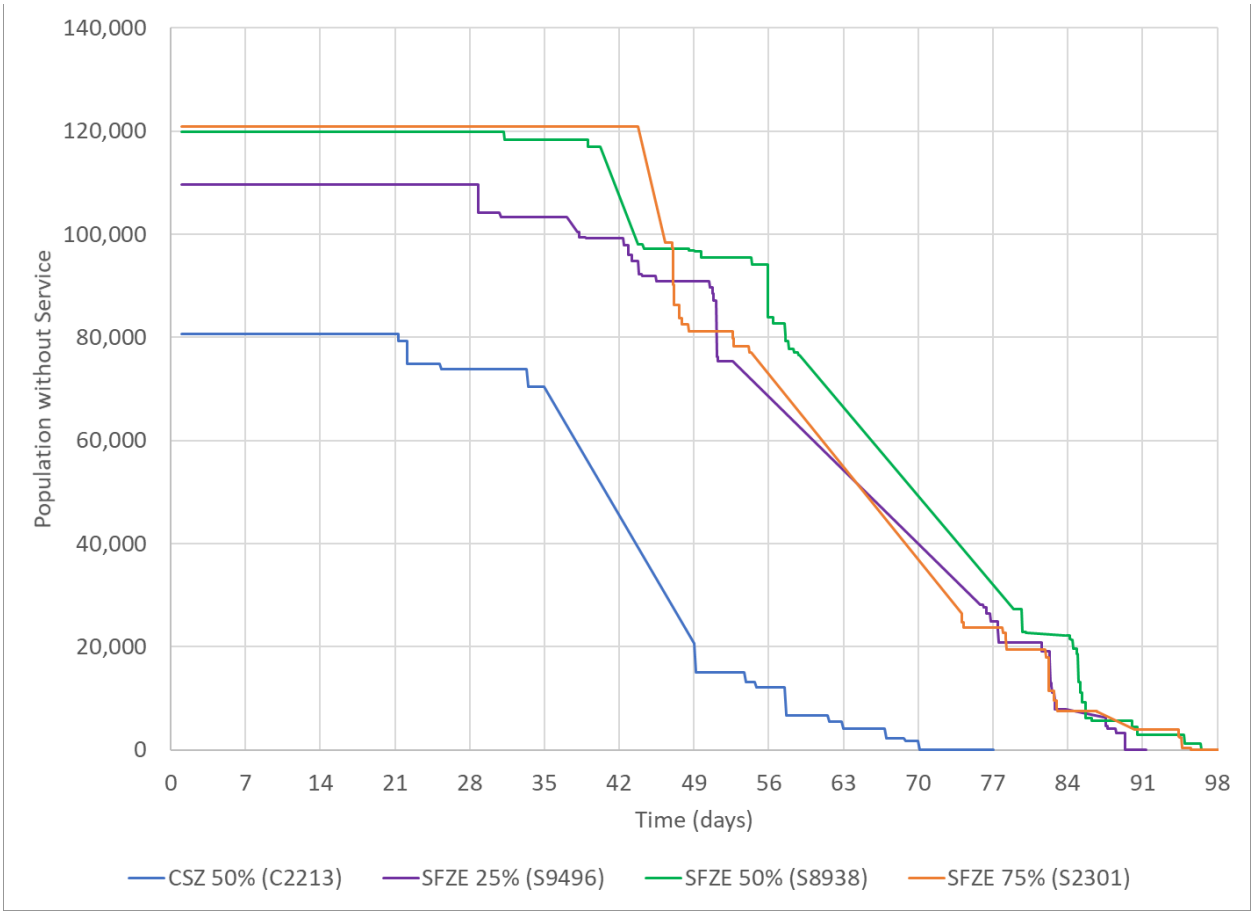


Figure 2: Customer Outage Summary by Earthquake Scenario



In addition to the system-wide assessment of outages, geographic assessment of restoration was also completed. Due to the tiered nature of the City's distribution system, supply is introduced in pressure zones that are in the middle of the HGL range of the system. Therefore, pressure zones that are higher in the system or served from PRVs from the City's primary supply zones (BV0400 and LH0520) continue to be out of water service until water supply is returned to each subsequent supply zone. The areas of the system that show the most potential for damage from an earthquake are also located in the lower pressure zones based upon the geology. Once repairs in the supplying pressure zones are made, supply can be returned to the receiving pressure zones and reservoirs to sustain water pressure.

Figure 3 through Figure 6 show the geographic restoration times for the four selected seismic scenarios. Table 5 summarizes the restoration times for critical facilities and essential facilities/distribution centers within the system, and Figure 7 shows the time series distribution of the restoration time for critical facilities. Figure 8 shows the time series distribution of the restoration time essential businesses. The information for the critical facilities will provide the baseline for assessing improvements and supporting LOS goals.

For the purposes of this analysis, critical facilities are those defined as "Category 1 Critical Customers" in TM 2: Seismic Analysis Methodology for Pipeline and Facilities Assessment. These include Hospitals, High Schools, Community Centers, and Washington State DOT facilities and Bellevue City Hall. Essential businesses for this analysis have been defined as based on the following NAICS codes shown in Table 4, which were informed by the official Washington State essential business declarations made during the COVID-19 emergency.

Table 4: Essential Business NAICS categories

NAICS Code	NCAIS Description
4441	**Building Material and Supplies Dealers**
444110	Home Centers
444120	Paint and Wallpaper Stores
444130	Hardware Stores
444190	Other Building Material Dealers
4442	**Lawn and Garden Equipment and Supplies Stores**
444210	Outdoor Power Equipment Stores
444220	Nursery, Garden Center, and Farm Supply Stores
4451	**Grocery Stores**
445110	Supermarkets and Other Grocery (except Convenience) Stores
445120	Convenience Stores
4452	**Specialty Food Stores**
445210	Meat Markets
445220	Fish and Seafood Markets
445230	Fruit and Vegetable Markets
445291	Baked Goods Stores
445292	Confectionery and Nut Stores
445299	All Other Specialty Food Stores
4453	**Beer, Wine, and Liquor Stores**
445310	Beer, Wine, and Liquor Stores
4461	**Health and Personal Care Stores**
446110	Pharmacies and Drug Stores

Table 5: Restoration Time Summary for Key Restoration Percentages of Critical Facilities and Essential Businesses for Earthquake Scenarios

	Days after Earthquake Event		
Earthquake Scenario	**25% Restoration**	**50% Restoration**	**90% Restoration**
Critical Facilities			
CSZ 50% (C2213)	21%	49%	68%
SFZE 25% (S9496)	45%	77%	84%
SFZE 50% (S8938)	48%	80%	86%
SFZE 75% (S2301)	48%	75%	95%
Essential Facilities			
CSZ 50% (C2213)	23%	49%	68%
SFZE 25% (S9496)	44%	77%	85%
SFZE 50% (S8938)	57%	80%	86%
SFZE 75% (S2301)	48%	75%	91%

Figure 3: Subarea Restoration for C2213 (CSZ 50%) Earthquake Scenario

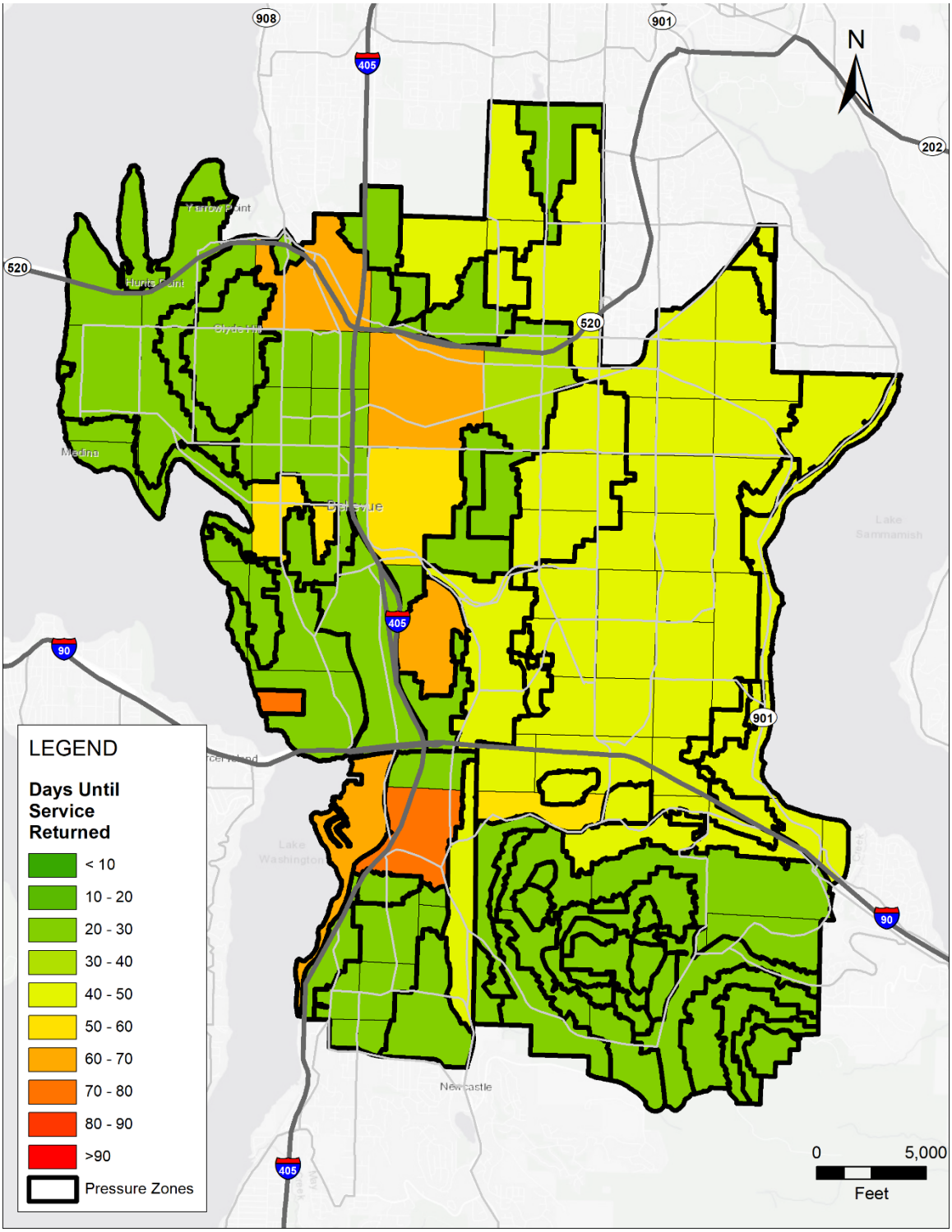


Figure 4: Subarea Restoration for S9496 (SFZE 25%) Earthquake Scenario

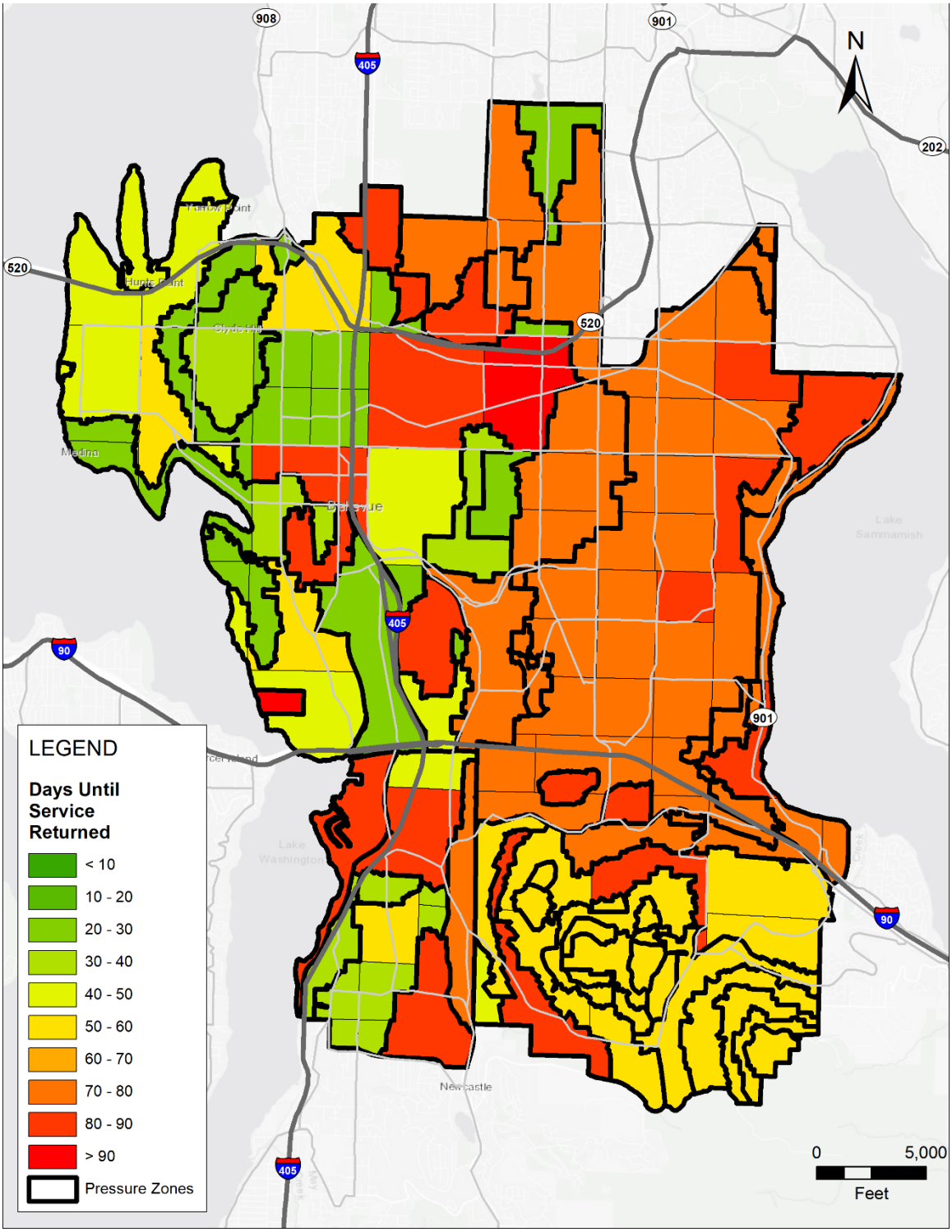


Figure 5: Subarea Restoration for S8938 (SFZE 50%) Earthquake Scenario

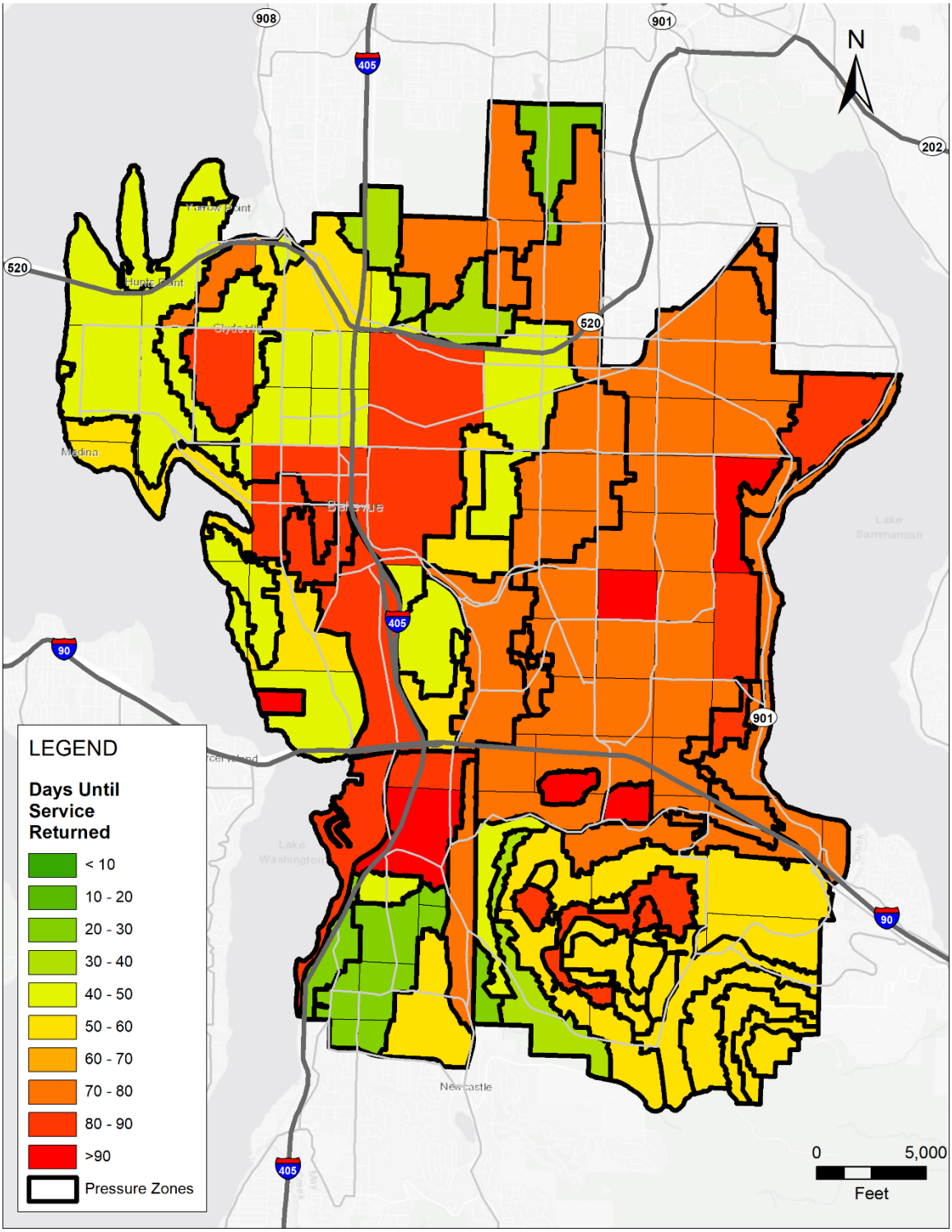


Figure 6: Subarea Restoration for S2301 (SFZE 75%) Earthquake Scenario

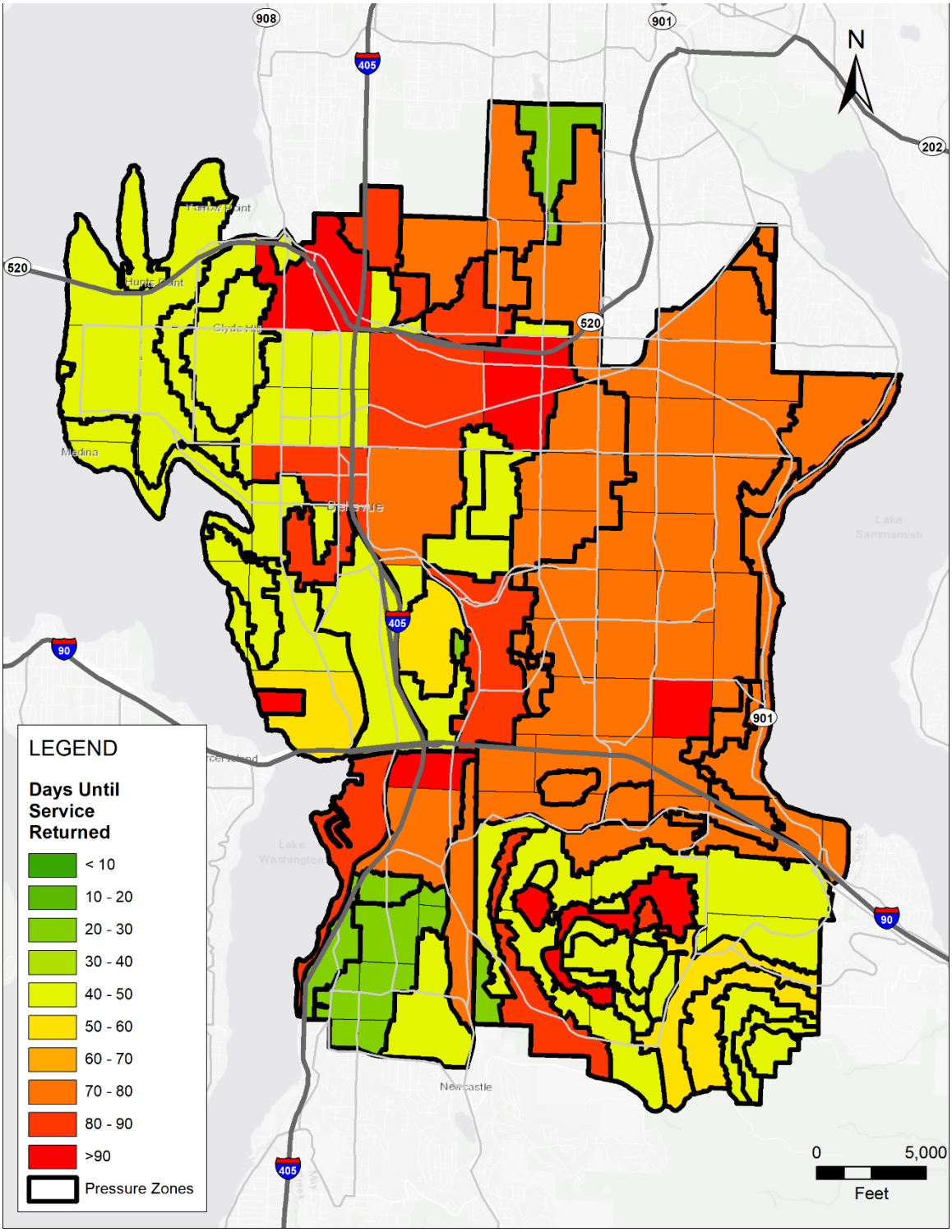


Figure 7: Critical Facilities Restoration Times for Earthquake Scenarios

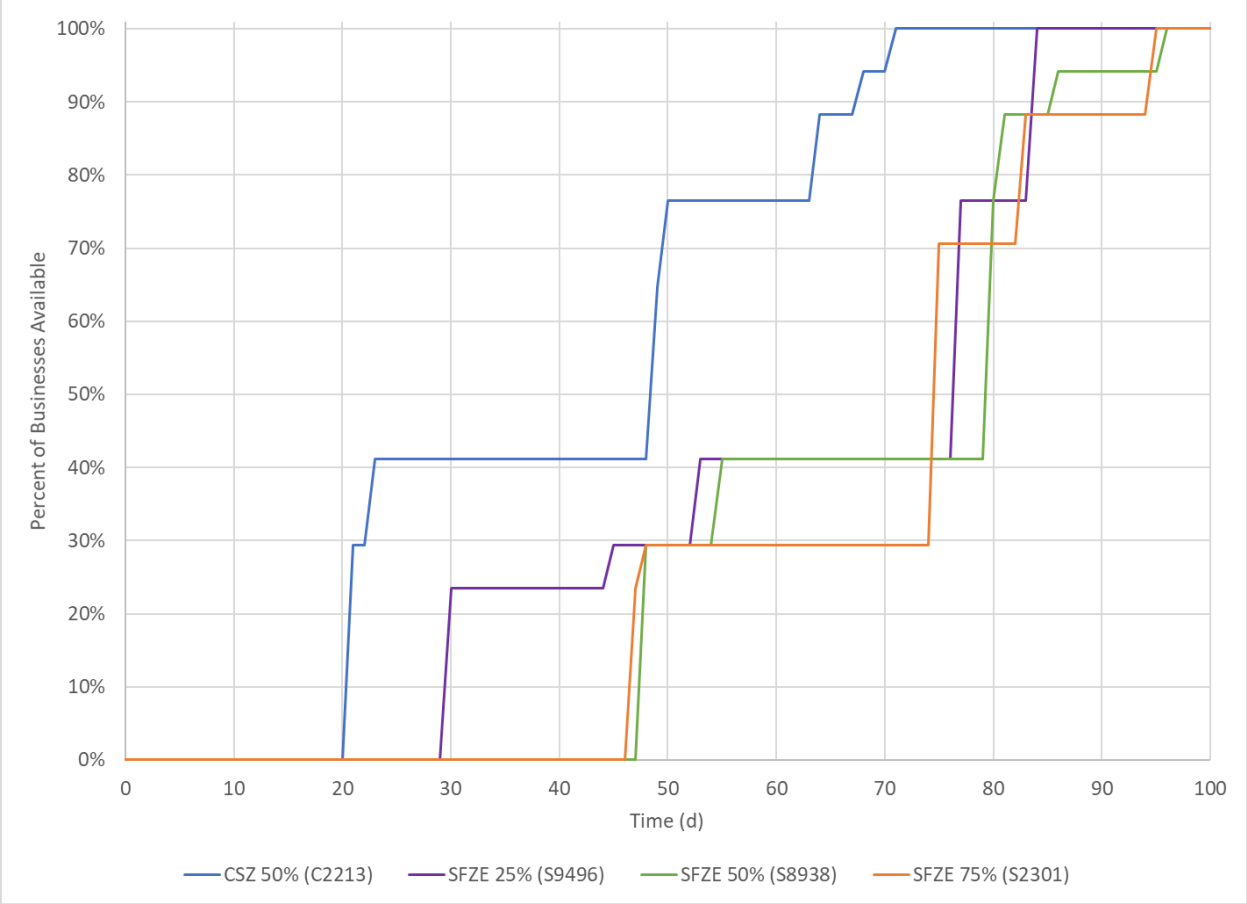
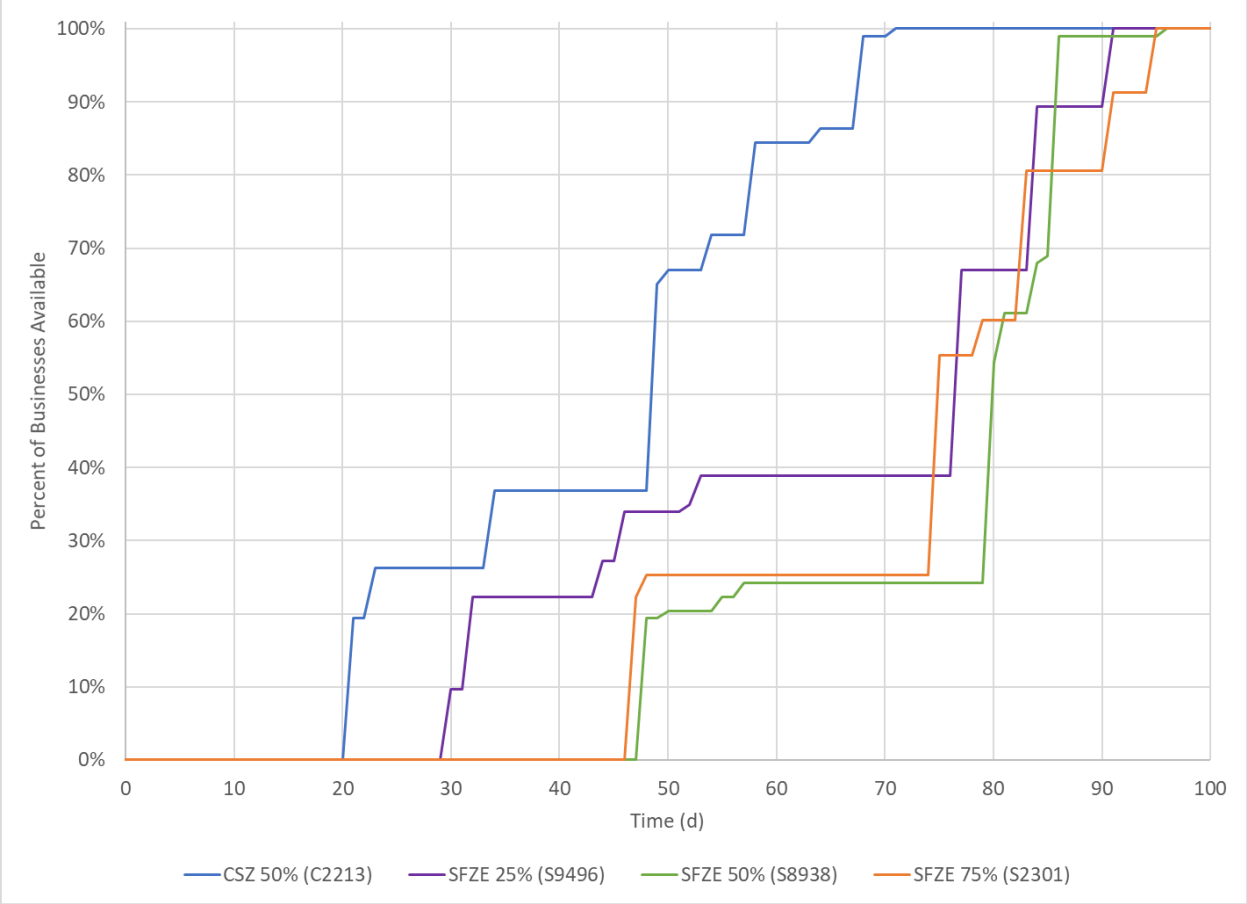


Figure 8: Essential Business Restoration Times for Earthquake Scenarios



5. Potential Economic Impact

Using the restoration results presented above and the economic assumptions presented in TM 5, economic impact curves were developed for each selected seismic scenario. Table 6 summarizes the total economic impact due to water outage as well as the annual risk for each seismic event. The annual risk for the CSZ event was calculated based upon a 500-year return period (0.2% probability of occurrence each year), and the annual risk for the SFZE event was calculated based upon an 800-year return frequency with a 50% probability of occurrence (0.0625% probability of occurrence per year).

Figure 9: Water Outage Economic Impact for As-Is Restoration for Selected Earthquake Scenarios

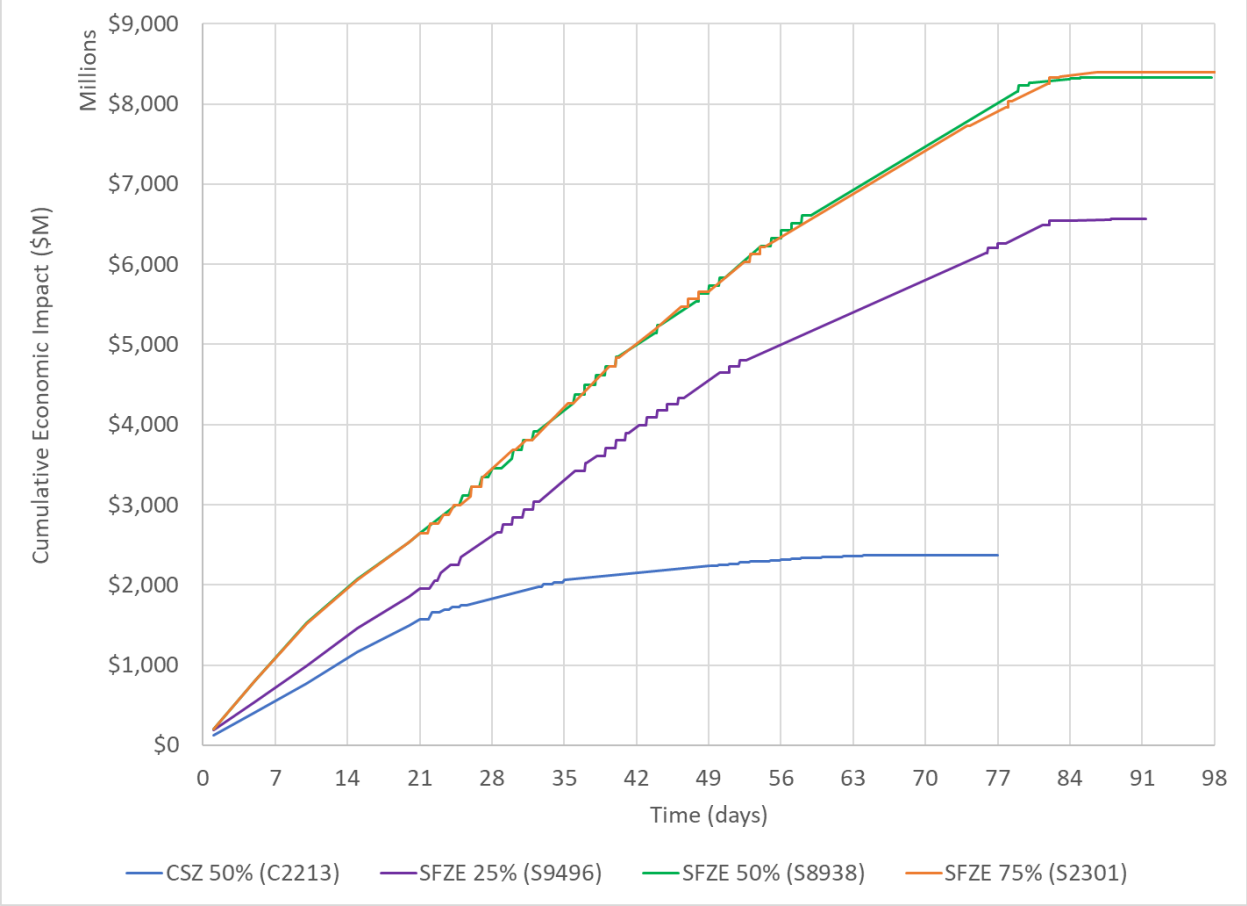


Table 6: Total Economic Impact of Water Outage by Earthquake Scenario

	Total Economic Impact ($M)	Annual Risk ($M/Year)
CSZ 50% (C2213)	2,375	4.7
SFZE 25% (S9496)	6,564	4.1
SFZE 50% (S8938)	8,326	5.2
SFZE 75% (S2301)	8,398	5.2

6. Summary

The restoration analysis of the as-is system shows that the restoration times for residential service range from 55 to 75 days across the selected scenarios. Based upon the order of preference for restoration activities, the most beneficial system repairs that improved system performance were to pipe in the primary supply zones of BV0400 and LH0520 and repairs to facilities.

The restoration analysis showed that due to the geographical diversity of the Critical facilities and essential businesses, the restoration of these facilities is similar to the restoration of residential service.

Based upon the results of the As-Is Restoration analysis, improvements will be developed and evaluated to assess their benefit in reducing the number of days that service is returned to customers and essential facilities are able to operate. The initial restoration analysis provides the benchmark by which to assess the benefits of improvements implemented in the City's system. Table 7 and Table 8 show the current state of the Bellevue Water System based on the categories and timeframes developed for the City of Bellevue water system post-earthquake level of service goals. Note that the goals for each of these categories will be developed as part of the next steps of the seismic vulnerability analysis.

Table 7: As-Is Water System Post-Earthquake Performance for CSZ 50% Earthquake Scenario

	Event	1-Day	3-Days	7-Days	14-Days	21-Days	1-Month	2-Month	3-Months	6-Months
Emergency Room Hospitals						🟢				
Hydrants at Designated Resilient Supply Points[1]										
Community Recovery Facilities[2]						🔴		🟠	🟢	
Essential Businesses[3]						🔴		🟠	🟢	
Basic Domestic Service to All Customers			🔴				🟠		🟢	
Existing Service Restored to All Hydrants[4]										

🔴 = 20%-30% Operational 🟠 = 50%-60% Operational 🟢 = 80%-90% Operational

Notes:
[1]Designated Resilient Supply Points have not yet been defined.
[2]Community Recovery Facilities are Critical Facilities, excluding Hospitals as defined in Section 4.2
[3]Essential Businesses are as defined in Section 4.2
[4]Analysis does not include evaluation of fire flow conditions.

Table 8: As-Is Water System Post-Earthquake Performance for SFZE 50% Earthquake Scenario

	Event	1-Day	3-Days	7-Days	14-Days	21-Days	1-Month	2-Months	3-Months	6-Months
Emergency Room Hospitals								🟢		
Hydrants at Designated Resilient Supply Points[1]										
Community Recovery Facilities[2]								🔴	🟢	
Essential Businesses[3]								🔴	🟢	
Basic Domestic Service to All Customers								🟠	🟢	
Existing Service Restored to All Hydrants[4]										

🔴 = 20%-30% Operational 🟠 = 50%-60% Operational 🟢 = 80%-90% Operational

Notes:
[1]Designated Resilient Supply Points have not yet been defined.
[2]Community Recovery Facilities are Critical Facilities, excluding Hospitals as defined in Section 4.2
[3]Essential Businesses are as defined in Section 4.2
[4]Analysis does not include evaluation of fire flow conditions.

Appendix G. Post-Earthquake Level of Service Goals

G.1 TM7: PE-LOS Goals

Jacobs

Technical Memorandum

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Subject	**DRAFT FINAL - TM7: PE-LOS Goals**
Project Name	Bellevue Water System Seismic Vulnerability Assessment
From	Jacobs
Date	December 29th, 2021

1. Background

This document describes the development of target Post-Earthquake (PE) Level of Service (LOS) Goals used to identify potential performance measures for water system seismic resilience improvements alternatives evaluated as part of the SVA.

Anticipated "as-is" performance of the existing system and subsequent water service outage duration restoration times were estimated for the Seattle Fault Zone East (SFZE) and Cascadia Subduction Zone (CSZ) seismic event scenarios. The as-is performance was then compared to target PE-LOS goals to identify upgrades that will improve system seismic performance to levels that are acceptable to the City. The estimated as-is system restoration durations and economic impacts to the City due to damage from both events are described in TM 6: Restoration and Economic Impacts (TM6).

2. PE-LOS Goal Framework

As awareness of the magnitude of seismic risks to water systems has become more widely recognized, utilities and local governments have begun implementing a practice of creating Post-Earthquake/Event Level of Service (PE-LOS) goals. PE-LOS goals start with the assumption that having a water system that can supply water to all customers immediately after a major seismic event is either impossible or impractical. As such, the PE-LOS goals focus on which parts of the system should be upgraded to provide the necessary water to people in reasonable durations and additionally focus on where restoration efforts and system improvements should be prioritized to most effectively reduce and mitigate adverse impacts following a major seismic event.

When creating PE-LOS goals, there are four key components to consider:

1. Water quantity (flow rates and volumes available)
2. Water quality (suitability for use)
3. Duration to restore service (time involved in recovering system water supply and returning to "normal")
4. Priority locations for service restoration

Each of the above components forms the basis of the PE-LOS goals presented in the following sections.

3. PE-LOS Goal Regulations and Standards

There are no regulations or fully adopted industry standards that govern or define the establishment of specific PE-LOS goals for water supply and utility systems. However, there are several references that are helpful to use as a comparison while developing PE-LOS goals for the City. The following outlines the approaches to developing or recommending PE-LOS goals taken by other utilities and states, as well as the differentiation between building codes and PE-LOS goals.

3.1 State and Other Utility PE-LOS Goals

The Washington State Seismic Safety Committee's Emergency Management Council (WSSC) published *Resilient Washington State* in 2012. *Resilient Washington State* provides some guidance for PE-LOS goals for water systems, but the guidance is high level and does not take into account the severity of the earthquake or account for the different types of customers served by a typical water system. It also does not account for locational specific seismic hazards such as those evaluated for Bellevue, and as a result the requirements are not consistent with other guidelines from neighboring states or other utilities in Washington and is not directly applicable to the City of Bellevue.

The Oregon Seismic Policy Advisory Committee (OSSPAC) published the *Oregon Resilience Plan* (ORP) in 2013. As the ORP was developed with significantly more detail than *Resilient Washington State*, the ORP will be used as a reference for the remainder of this TM. Both the Oregon and Washington resiliency guidance documents were prepared with broad involvement from the respective states' community stakeholders, and both developed earthquake performance goals after an evaluation of their respective existing infrastructure systems.

A key feature of the ORP is developing phased PE-LOS goals that align water system restoration priorities for different types and groups of customers. The ORP's main objective when developing the phased PE-LOS goals was to generally meet a two-week recovery period and return to a resilient level of service after a 500-year Cascadia Subduction Zone (CSZ) event. The timeline of the phased approach was based off general recommendations created by the OSSPAC.

The PE-LOS goals that the ORP proposes include target percentages for the operational level for various functions of the water system on a timeline. The operational level percentages are suggested to meet average winter demands with potable water that has been disinfected and tested. The PE-LOS goals developed by the ORP for a 500-year event are shown in Table 1.

Various local utilities have also developed their own PE-LOS goals, while others have seismic projects in the works, with the intent of developing their own LOS goals. They are listed below by geographic location from north to south. In all of these cases, the goals are generally in alignment with the basic concepts of the ORP, with minor variations in the way levels of service are defined and whether water must be potable or not. However, given that the ORP is the most comprehensive set of goals that is applicable to a wide range of utilities, the framework from the ORP has been used as a basis for establishing goals for the City of Bellevue.

- City of Everett, Washington – From the *City of Everett Water Supply Risk Assessment Study* (Carollo, 2012), PE-LOS goals were proposed for a Probable Event (a 500-year event) and a Maximum Earthquake Event (a 2,500-year event). These goals are different that most in the industry, as they were developed before the ORP and other commonly used frameworks were established.
- Seattle Public Utilities (SPU), Washington – The *Seismic Study Summary* (SPU, 2019) investigated seismic hazards in the central Seattle district and holistically assessed existing system vulnerabilities. Findings were used to develop both short-term goals (within the next 15-20 years) and long-term goals (within the next 50+ years). SPU's PE-LOS goals were developed specifically for the SPU system, with goals associated with specific assets.
- Water Supply Forum, Washington – While not a utility, the Forum is a group of agencies that serve the Snohomish, King, and Pierce Counties with a utility perspective on current and future regional water supply and related water resources issues. The Forum began the Regional Water Supply Resiliency project in 2015 to identify key risks to water supply and to strategize how best to address and recover from them. See Table 2 below for the PE-LOS goals developed via the Forum. Note that these goals focus on only supply to water distribution systems and do not address restoration of/within the

distribution systems themselves. Water Supply Forum PE-LOS goals were developed based on the ORP. City of Bellevue staff represented Cascade Water Alliance as part of the Water Supply Forum.

- Tacoma Water – Tacoma Water developed PE-LOS goals as part of the *2015 All Hazards Vulnerability Assessment*, (CH2M HILL (now Jacobs), 2016). Tacoma Water's PE-LOS goals were developed based on the ORP.

Table 1: 500-Year Return Earthquake LOS Goals (ORP, OSSPAC, 2013)

System Function	Event	0-24 Hours	1-3 Days	3-7 Days	1-2 Weeks	2-4 Weeks
Potable water available at supply source		🔴	🟠		🟢	
Main transmission facilities, pipes, pump stations, and reservoirs operational		🟢				
Water supply to critical facilities available		🟠	🟢			
Water for fire suppression at key supply points		🟢				
Water for fire suppression at fire hydrants				🔴	🟠	🟢
Water available at community distribution centers/points			🟠	🟢		
Distribution system operational			🔴	🟠	🟢	

🔴 = Desired time to restore component to 20%-30% Operational

🟠 = Desired time to restore component to 50%-60% Operational

🟢 = Desired time to restore component to 80%-90% Operational

3.2 PE-LOS Goals compared to Building Codes

It is critical to understand that PE-LOS goals are different from building codes, and the two may not necessarily align. For water systems, building codes focus on the importance of the water system facility and do not govern the resiliency of buried piping. Buildings are categorized into one of four categories, ranging from Category I to Category IV. Category IV buildings are considered "essential" as those that need to have immediate occupancy after a major 2,475-year seismic event. For water systems, the code only requires this highest level of performance for facilities that are required to maintain and provide fire

suppression. This fire suppression condition usually only applies to some reservoirs and to pump stations serving dead-end zones.

PE-LOS goals will often result in the determination that designs for water system facilities that are critical to the operation of the system need to be upgraded or replaced with facilities that are designed with higher levels of seismic resiliency than the code might require for a new facility. While there is an added cost to be paid for this additional seismic strengthening when incorporated as part of the initial construction, the added cost is usually relatively small in comparison to the total cost of a replacement facility. Seismic retrofits of facilities already constructed, however, can be significantly more costly, and may not be as effective, often making the added cost of seismic retrofit options less appealing.

Finally, it is necessary to make a distinction between classification of a facility as essential (Category IV according to the building code) and designing to the equivalent classification level. Designating a facility as a Category IV (essential) facility results in additional stringent requirements for all components of the facility. For facilities that are not designated as Category IV (essential) according to the building code, achieving the same level of resiliency design for the facility can be achieved by increasing the importance factor for the facility without designating the facility as a Category IV (essential) facility.

The result is that the PE-LOS goals that are established for the City of Bellevue water system will result in most water system facilities being designed to seismic standards that are greater than what is required by code.

4. PE-LOS Goal Customer Category Development

As noted above, identifying which locations in the water system to restore first is a primary component for developing PE-LOS goals. Determining the categories for which customers would be grouped was generally based off of the concepts presented in the ORP. To be more applicable to the needs of the City, the seven groupings from the ORP were adjusted to the six categories detailed below. The categories were primarily developed by City staff with input from Jacobs.

Emergency Room Hospitals: Hospitals are critical to the emergency response and support after a seismic event. The Joint Commission, a primary accreditation body for hospitals and health care organizations within the United States, requires accredited hospitals to maintain a minimum of 72 hours of emergency potable water supplies. Water is essential for the operation of a hospital and loss of water beyond this timeframe typically results in the hospital being required to close and evacuate.

Designated Resilient Supply Points: The City will be establishing designated resilient supply points throughout the water system that will provide access for water bottle filling stations and water for fire suppression. These locations have not been identified as the location is dependent upon ability to provide traffic management, expected availability of water, and community need. In general, these locations will include emergency well sites, water reservoirs with seismic valves (that automatically close to prevent loss of stored water to system leakage and pipe breaks as a result of a major seismic event), and locations along resilient piping routes that are expected to be able to sustain active water supply service after a seismic event.

Community Recovery Facilities: Community recovery facilities include water-sensitive customers that are critical to short-term emergency response and recovery, including emergency shelter sites, emergency operations centers, and key agencies such as WSDOT maintenance facilities. For evaluation purposes, these include Category 1 Critical Customers as defined in TM 2: Seismic Analysis Methodology for Pipeline and Facilities Assessment. While additional critical customers may be considered during implementation of the proposed improvements, the Category 2 Critical Customers from TM 2 are not included because

while they are important, water supply is not critical to their operation or they are not well suited as emergency shelters.

Essential Businesses: Essential businesses include grocery stores, pharmacies, medical clinics, first-aid facilities, and other locations essential for non-emergency health, safety, and well-being. This category was developed based on observation of designated essential businesses as part of the COVID-19 pandemic.

Basic Domestic Service: Basic domestic service is water service that is not up to normal standards for pressure and capacity (may be reduced pressure or curtailed supply availability) supplied from residential services and taps.

Existing Service Restored: Restoration to existing service is the eventual goal after a seismic event and is full restoration of the level of service, with no restrictions in water availability or use.

Table 2: Water Supply Forum, PE-LOS Goals for a CSZ Earthquake Scenario (2018)

System Component	Service Provided		Immediately After	24 Hours	3 Days	7 Days	14 Days	1 Month
Water Supply	Supply transmission system, provide local distribution source (wells), fill tank trucks.	Quantity	Storage	Storage	50% AWD[1]	50% AWD[1]	50% AWD[1]	AAD
		Quality	Non-Potable[2]	Non-Potable[2]	Non-Potable[3]	Non-Potable[3]	Potable	Potable
Transmission to End Points[4]	Supply terminal reservoir, wholesale meters along transmission line, provide fire suppression along transmission lines. Includes critical facilities (pump stations, treatment etc.)		50% AWD[1]	50% AWD[1]	50% AWD[1]	50% AWD[1]	AWD	AAD
Transmission/Supply to Major Regional Essential Services[5]	Serve essential customers (e.g., hospitals).		50% AWD[1]	50% AWD[1]	50% AWD[1]	50% AWD[1]	50% AWD[1]	AWD
Backbone	Supply special seismic resistant lines to essential customers, service to community distribution points, provide fire suppression along backbone.		Individual utility decision					
System Storage	Support backbone and local distribution		Limited water from storage for fire, drinking			Individual utility decision		
Distribution	Service to individual customers - residential, business, industrial. Water to fire hydrants for fire suppression.		Individual utility decision					

(AWD = Average Winter Demand; AAD = Average Annual Demand)

Notes:

[1]Percentages represent the estimated percent of total delivery. Not all areas will be feasible to serve within the first month.

[2]Water supply and water held in terminal reservoir are expected to be potable immediately after the event. However, there could be short-term disruptions/damage to water treatment plants and/or transmission pipelines that could compromise potability of water in the terminal reservoir within 24 hours following the event.

[3]Disruptions/damage to the transmission pipelines could result in contamination of water coming from treatment plants or into terminal reservoirs until repairs can be made and normal operations are resumed.

[4]Transmission to End Points includes one or more transmission pipelines providing the noted level of service connecting the supplies to and including the first terminal reservoirs downstream from each supply. At the utility's discretion, additional transmission pipeline segments and reservoirs can be included in this criterion.

[5]Transmission/Supply to Major Regional Essential Services includes a supply, and transmission line supplying water to hospitals designated as essential by the utility. The supply and transmission may be dedicated to supply to essential services and be different than the supply and transmission system serving the overall utility service area. Additional facilities in addition to hospitals such as nursing homes, may be designated by the utility.

Potable water at the supply source/treatment source and at the transmission system were not included as categories as City of Bellevue water supply and transmission is provided, owned, and managed by SPU under contract with the Cascade Water Alliance, of which Bellevue is a member utility. Careful coordination with the Cascade Water Alliance to influence SPU investment in regional water supply and transmission system seismic resiliency should be a priority for the City.

5. PE-LOS Goal Implementation Timeframe and Adoption

Most PE-LOS goals are established with a target implementation timeframe of approximately 50 years. These goals are typically adopted by the water utilities governing body as an established benchmark towards which the utility is committed to working. Some utilities have established additional, less challenging targets and shorter-term goals to work towards in the near-term with the long-term goals as the ultimate milestone.

To get stakeholder and governing body buy-in to adoption of PE-LOS goals, it is critical to have a clear understand of the costs and water rate impacts for achieving these goals. The Bellevue SVA project took the cost and rate impacts into consideration by establishing target PE-LOS goals, identifying improvements needed to achieve those goals, and determining the cost associated with those improvements. Once the suite of improvements needed to achieve the goals is defined, the cost and rate-payer impacts can be more clearly understood and communicated to stakeholders to help facilitate the adoption and implementation process.

To aid the development of a clear roadmap to achieving seismic resiliency, the SVA PE-LOS goals were developed for Short-, Mid-, and Long-Term planning horizons. The duration of these planning horizons have not yet been finalized, as the timeline will be dependent on stakeholder feedback regarding the willingness to pay for the various improved levels of service.

6. Bellevue Water System PE-LOS Goal Targets

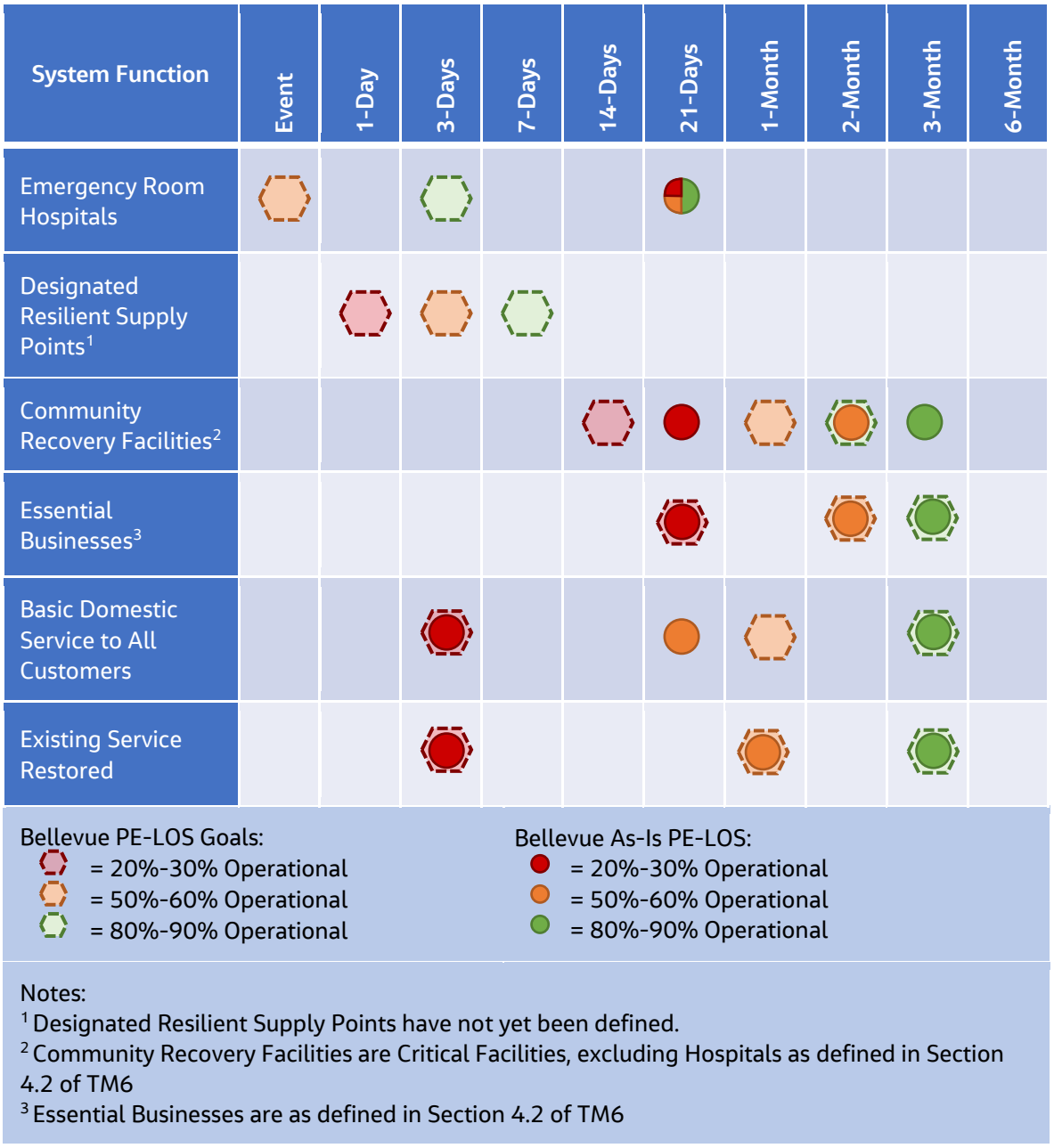
The following section defines the target PE-LOS goals developed as part of the SVA to aid in identifying the potential improvement alternatives available to achieve seismic resiliency. Once these PE-LOS goals were established, improvements relative to these target goals could be evaluated, and benefit-cost analysis applied to determine the optimal prioritization and grouping of improvement alternatives appropriate to realizing PE-LOS goals. Once the cost of improvements associated with achieving these goals is better understood, the PE-LOS goals will be formalized along with target implementation timeframes for each time period.

The framework for the PE-LOS goals is described in Section 2 and includes target timelines for each customer/supply category to return to service. The figures below that depict the PE-LOS framework show the duration that has elapsed after the seismic event across the top row and the customer/supply category down the left column. The hexagons show the target goals for the system restoration and the circles show the as-is state of the system. The colors (red, orange, and green) represent the percentage of the customer class connections/locations that are expected to be restored by the time shown.

For example, the orange hexagon in the Community Recovery Facilities category represents the timeframe for which 50 to 60 percent of the community recovery facilities would be expected to have water once improvements to reach that PE-LOS goal have been implemented.

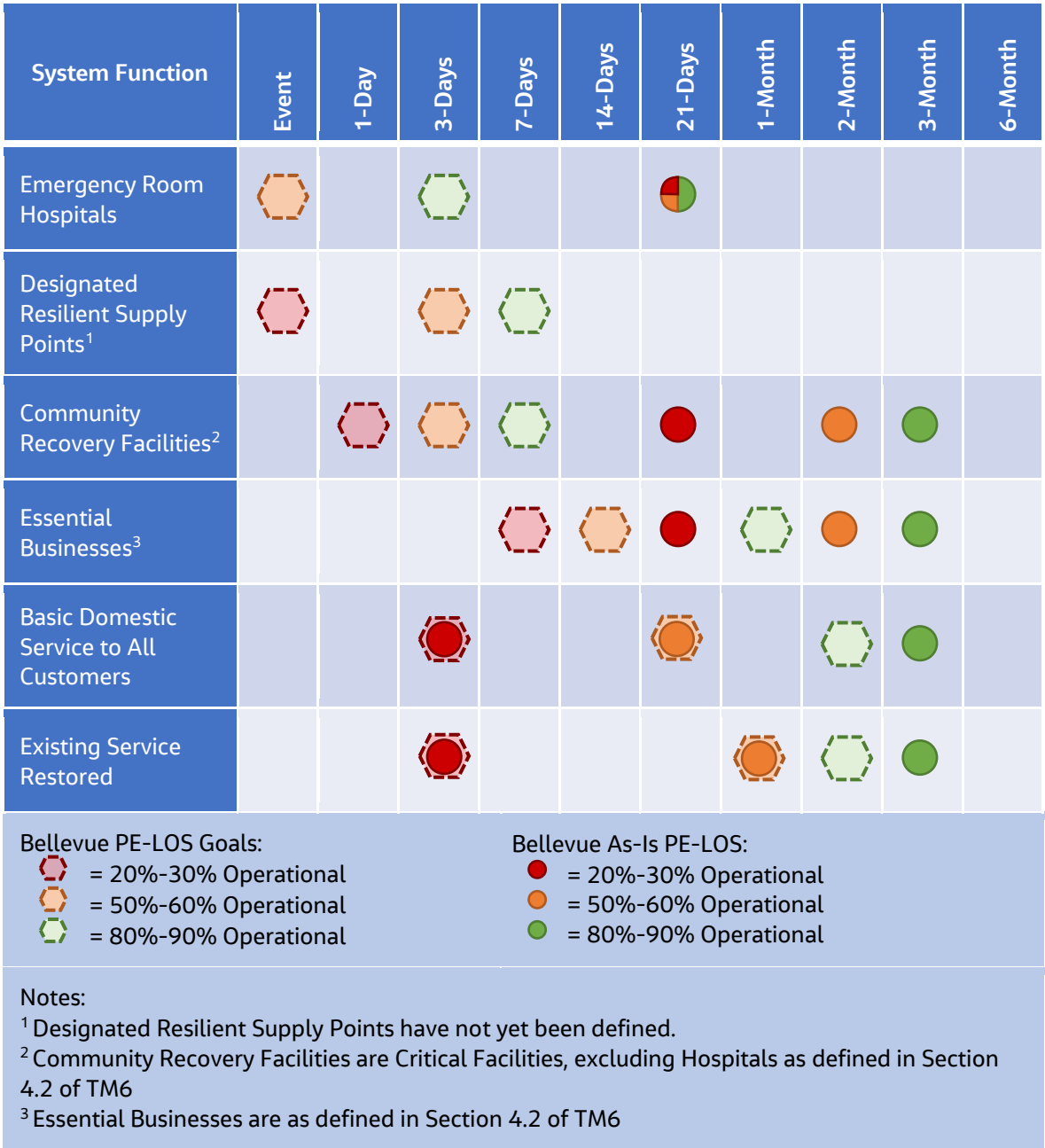
Two sets of short-, mid-, and long-term “target” PE-LOS goals were developed for the SVA, one for the CSZ and one for the SFZE, as presented below in Figure 1 through Figure 6. A comparison of the six sets of target PE-LOS goals is provided at the end of this section.

Figure 1: SVA Target Short-Term PE-LOS for CSZ



Notes:
[1] Designated Resilient Supply Points have not yet been defined.
[2] Community Recovery Facilities are Critical Facilities, excluding Hospitals as defined in Section 4.2 of TM6
[3] Essential Businesses are as defined in Section 4.2 of TM6

Figure 2: SVA Target Mid-Term PE-LOS for CSZ



Notes:
[1] Designated Resilient Supply Points have not yet been defined.
[2] Community Recovery Facilities are Critical Facilities, excluding Hospitals as defined in Section 4.2 of TM6
[3] Essential Businesses are as defined in Section 4.2 of TM6

Figure 3: SVA Target Long-Term PE-LOS for CSZ

System Function	Event	1-Day	3-Days	7-Days	14-Days	21-Days	1-Month	2-Month	3-Month	6-Month
Emergency Room Hospitals	⬡		⬡			◔				
Designated Resilient Supply Points[1]	⬡	⬡								
Community Recovery Facilities[2]	⬡	⬡				●		●	●	
Essential Businesses[3]		⬡	⬡		⬡	●		●	●	
Basic Domestic Service to All Customers			⬡	⬡	⬡	●			●	
Existing Service Restored			⬡		⬡		⬡		●	

Bellevue PE-LOS Goals:
- ⬡ = 20%-30% Operational
- ⬡ = 50%-60% Operational
- ⬡ = 80%-90% Operational

Bellevue As-Is PE-LOS:
- ● = 20%-30% Operational
- ● = 50%-60% Operational
- ● = 80%-90% Operational

Notes:
[1] Designated Resilient Supply Points have not yet been defined.
[2] Community Recovery Facilities are Critical Facilities, excluding Hospitals as defined in Section 4.2 of TM6
[3] Essential Businesses are as defined in Section 4.2 of TM6

Figure 4: SVA Target Short-Term PE-LOS for SFZE

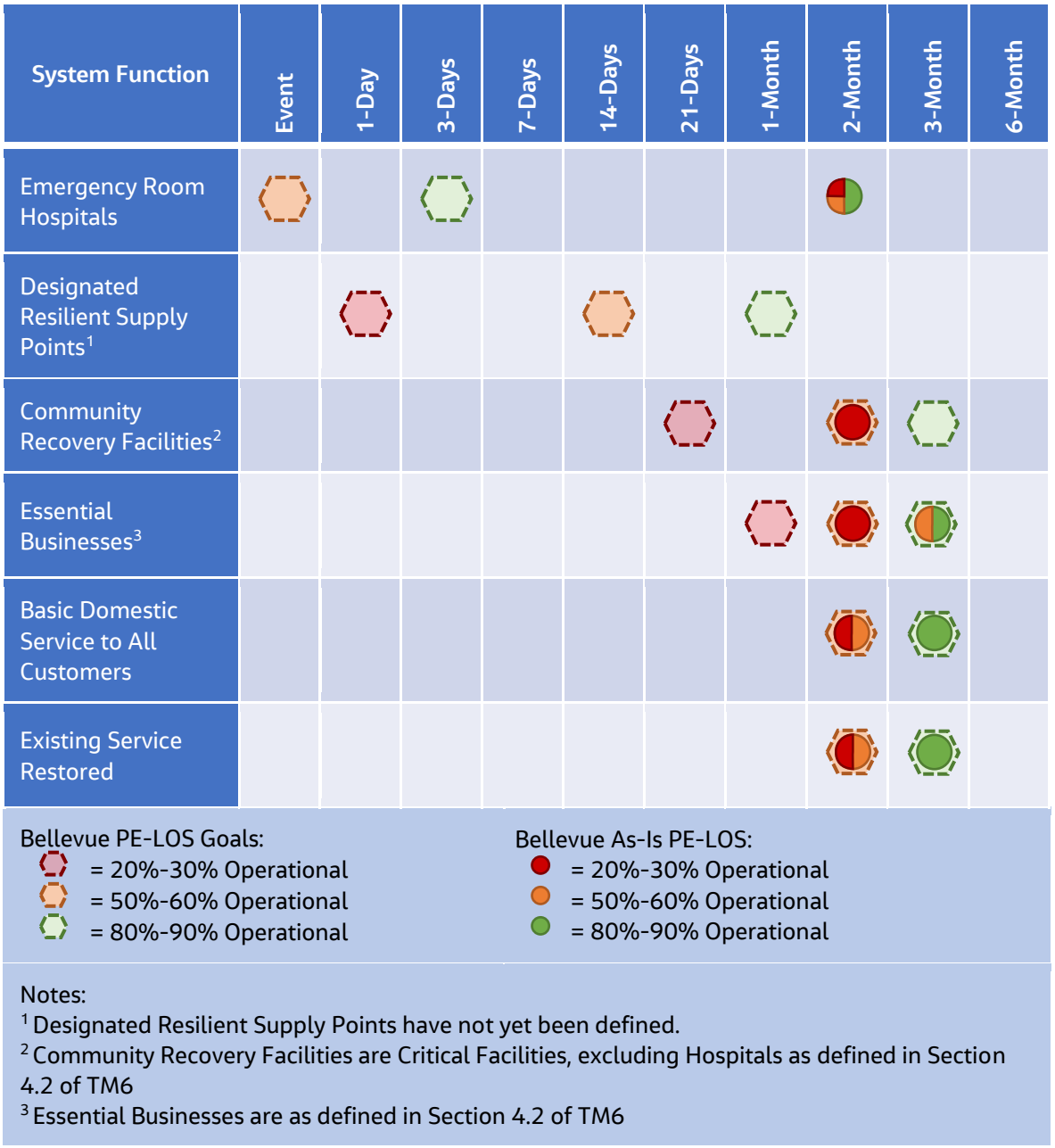
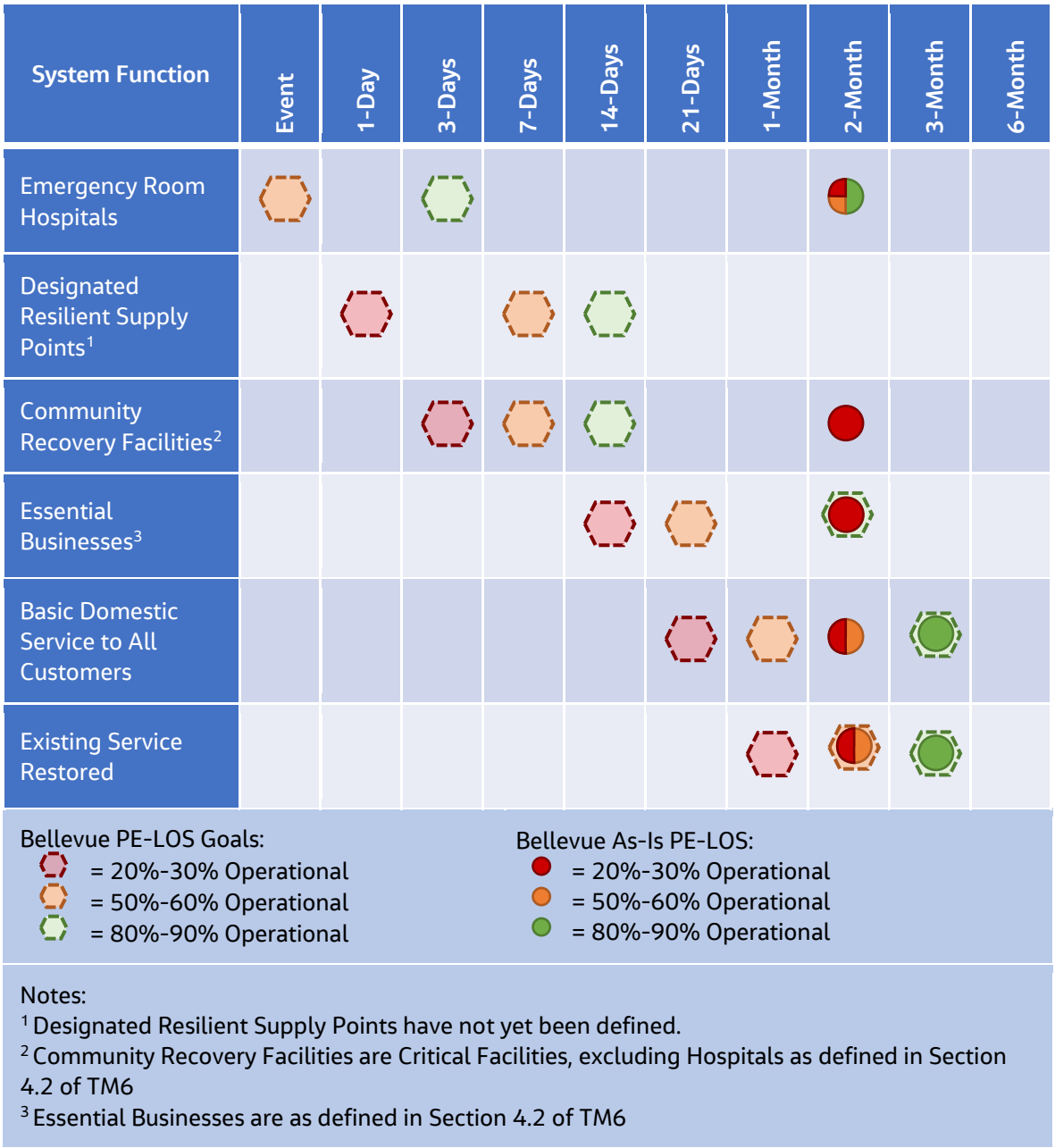
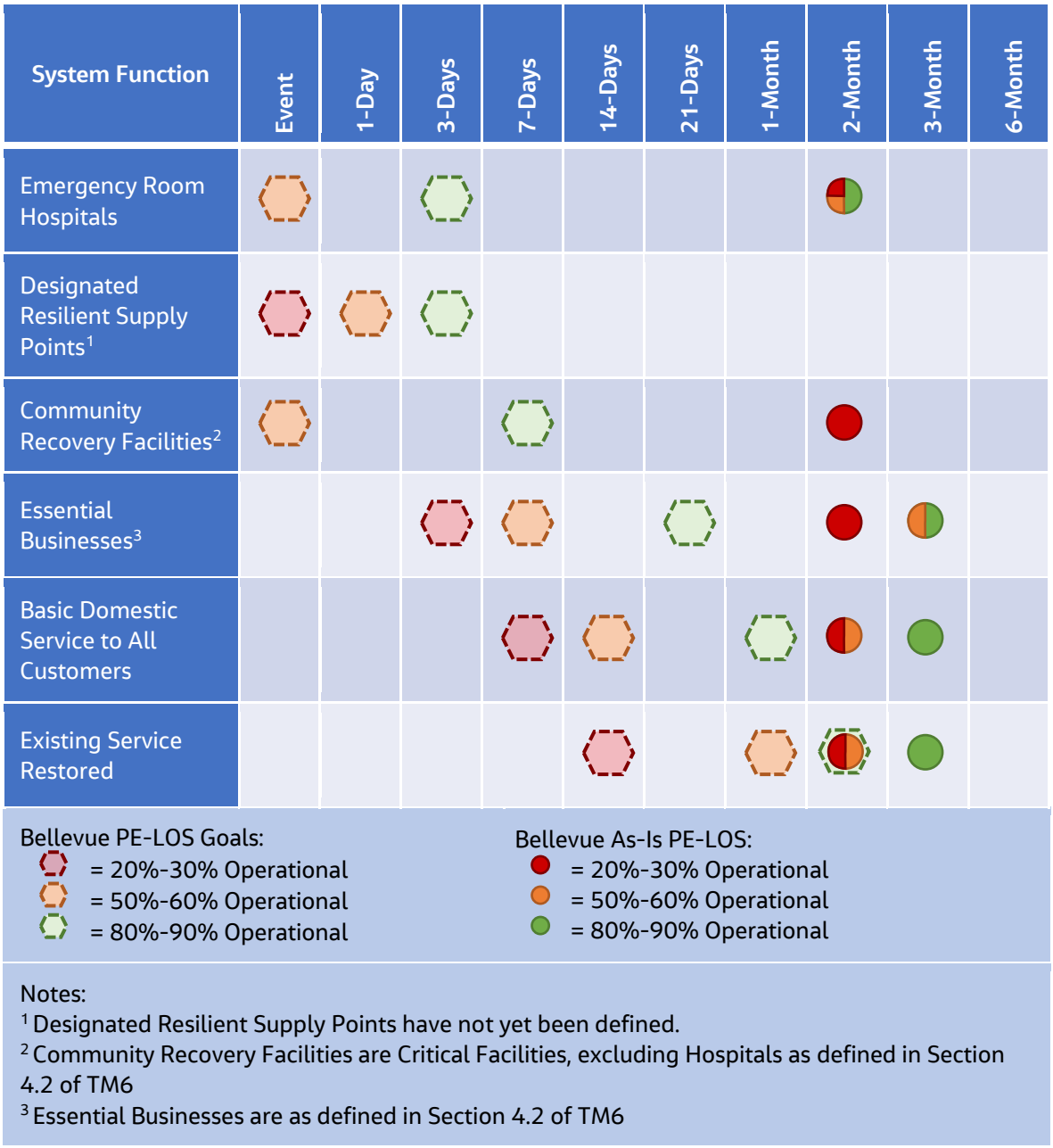


Figure 5: SVA Target Mid-Term PE-LOS for SFZE



Notes:
[1] Designated Resilient Supply Points have not yet been defined.
[2] Community Recovery Facilities are Critical Facilities, excluding Hospitals as defined in Section 4.2 of TM6
[3] Essential Businesses are as defined in Section 4.2 of TM6

Figure 6: SVA Target Long-Term PE-LOS for SFZE



In general, the Long-Term goals were developed based on comparison with other utilities goals and the ORP. These represent the ultimate destination that would signify what a seismically resilient water system earthquake response should look like. The short-term goals are based on readily available improvements and critical needs, such as the need to improve water availability to emergency room hospitals. The mid-term goals serve as an intermediate guidepost between the long and short-term goals that helps to prioritize what should be improved after the initial improvements while the utility is along the path to the long-term PE-LOS goals.

When looking at the differences between the CSZ and SFZE goals, it is important to keep in mind the severity of the two earthquake events. As the SFZE fault is both shallow and the epicenter is estimated to

be very near or even under the City, the impacts to water service (water system damage) will be much more severe. The PE-LOS goals reflect this difference by allowing for additional time to restore water service. This can be most easily noticed in the differences between the two's short-term goals: recovery efforts at the emergency room hospitals and designated resilient supply points are much more focused on for the SFZE event.

7. Summary

The target PE-LOS goals presented in this TM were developed in collaboration between City staff and Jacobs. The goals are based on and are comparable to goals developed by state committees and peer utilities and were modified to specifically meet the needs of the City. These goals will be used for the remainder of the SVA as a benchmark to compare and evaluate improvement alternatives with the intent that once the improvements required to achieve these goals are defined, the City will formally adopt them and implement improvements as required to meet the goals in a specified timeframe.

8. References

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Appendix H. Improvements Alternatives

H.1 TM8: Improvement Alternatives

Jacobs

Technical Memorandum

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Subject	**DRAFT FINAL - TM8: Improvement Alternatives**
Project Name	Bellevue Water System Seismic Vulnerability Assessment
From	Jacobs
Date	December 29th, 2021

1. Background

Potential improvement alternatives to increase the seismic resilience of the City of Bellevue (City) Water System have been developed as part of the City's Water Distribution System Seismic Vulnerability Assessment (SVA). These alternatives are based on the as-is restoration durations for water service after an earthquake, the economic impacts to the community, and the target Post-Earthquake Level of Service (PE-LOS) goals developed previously as part of the SVA.

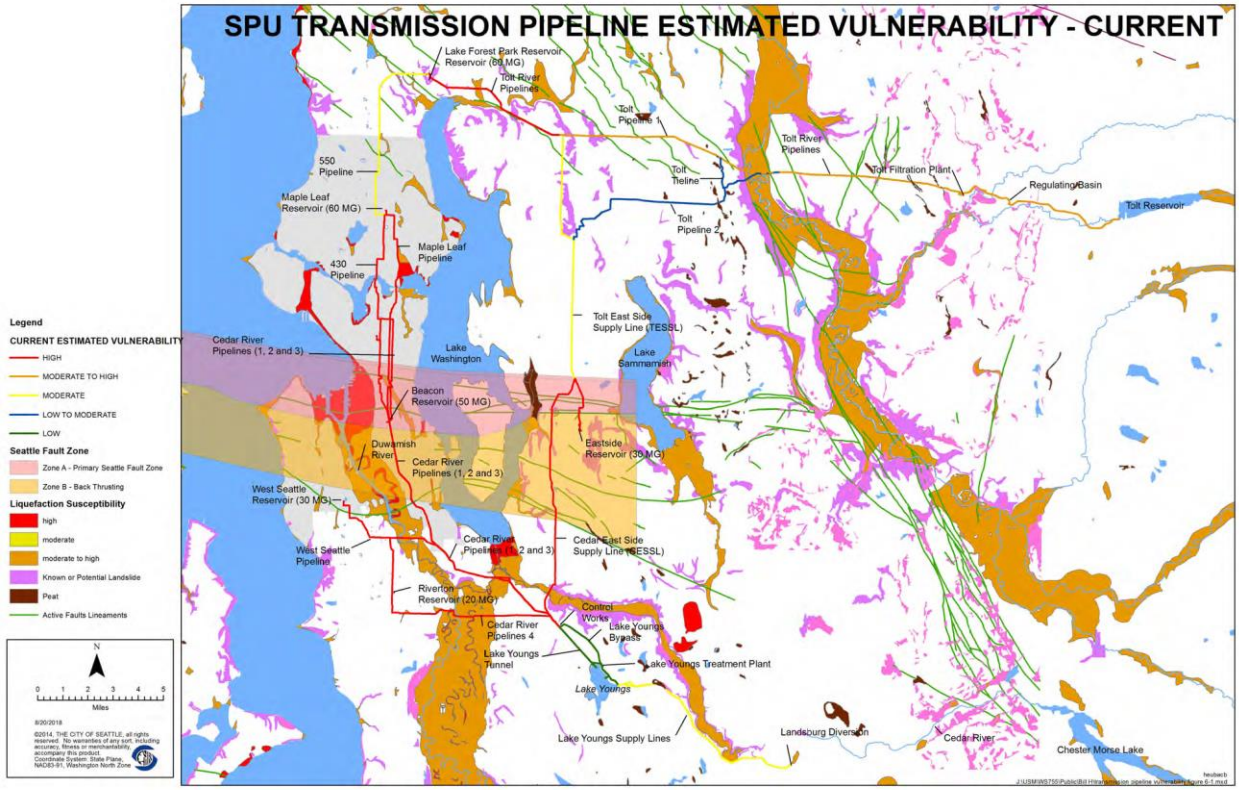
This document characterizes and describes the range of improvement alternatives developed to improve the City's water system seismic resilience and reduce the customer outage durations and economic impacts to the region resulting from loss of water service after a major earthquake. The improvement alternatives presented in this document are developed under the following five categories:

- Water Supply Improvements
- Resilient System Backbone Improvements
- Facility (Pump Station and Reservoir) Improvements
- Widespread Pipe Replacement
- Operational Improvements

2. Water Supply

The City of Bellevue purchases water from Seattle Public Utilities (SPU) as part of the Cascade Water Alliance (Cascade), of which Bellevue is a member utility. Water supply for Bellevue is supplied into the City water system from the Tolt Supply Line (TSL) from the north via the Tolt Eastside Supply Line (TESSL) and from the Cedar Supply Line (CSL) from the south via the Cedar Eastside Supply Line (CESSL). While the SPU 2018 Water System Seismic Study did not include analysis of the TESSL, CESSL or TSL, the overall estimates included detailing likely water service restoration timelines for the SPU direct water service area customers is informative. The study reports that expected service restoration time for direct service customers is up to 3 weeks, and it is further assumed that this would occur before restoration of water service via the CESSL and TESSL. Based on this, the SVA assumes 21 days as a minimum likely water service outage duration relative to SPU regional system water supply into the City of Bellevue following a major seismic event, consistent with the current state of the SPU system. A schematic of the SPU Supply System is provided in Figure 1.

Figure 1: SPU Supply System Schematic and Current Estimated Vulnerability
From 2018 Seattle Public Utilities Water System Seismic Study Summary Report



Alternatives to improve the seismic resilience of water supply delivery into Bellevue were evaluated and are described below.

2.1 Improve Resiliency of SPU Supply

The City of Bellevue does not have direct control over SPU regional water supply and transmission system operations, resilience, improvements, or capital investment, and this system is essential to the current and likely future operation of the Bellevue water system. Because the evaluation of the SPU transmission system is outside of the scope of the SVA, the improvement alternatives considered for this analysis are based on general knowledge of the SPU transmission system and limited published data available from the SPU 2018 Seismic Study.

Ultimately, it will be up to the City to work with Cascade and SPU to evaluate the SPU regional water supply system and identify improvements and opportunities that can allow the City to reduce water service outage risks, mitigate water supply outage impacts, and meet its own target PE-LOS goals.

Improvements to the SPU system were defined based on those that are likely needed to get the SPU system functional in just one day following a major seismic event, and those that could be necessary to restore SPU supply functionality for Bellevue within 7-days following a major earthquake. Table 1 shows these two categories of improvements as well as the assumed cost impact to City of Bellevue ratepayers, along with notes about the assumed improvements that would be required within the SPU system to achieve the indicated levels of performance. These alternatives and values serve only as placeholders until an in-depth analysis of the SPU system and necessary improvements is completed. The improvements are

focused on the Tolt Supply and TESSL because this a more direct route to get SPU water supply into Bellevue following a major seismic event, and also because this supply routing is likely to be less vulnerable to SFZE impacts. Note that SPU's stated approach has been to focus improvement on the Cedar Supply system since it is capable of serving more of the SPU supply area than the Tolt. It is expected that the cost to reach the same level of service from the Cedar Supply would be higher than from the Tolt Supply; however, other factors may require that additional cost to be justified after more in-depth evaluation is completed.

Table 1: SPU Supply System Improvement Alternatives

Improvement Alternative	Rough-Order-of-Magnitude Cost Assumption (Bellevue Ratepayer Impact)	Notes
SPU Supply to Bellevue Available in 1 Day	$45M	Assumes nearly complete replacement of Tolt Supply Line (upstream of TESSL) and TESSL with seismically resilient steel or ductile iron pipe, of which approximately 25% would be indirectly paid by City of Bellevue ratepayers.
SPU Supply to Bellevue Available in 7 Days	$15M	Assumes targeted replacement of critical vulnerable (landslide and liquefaction prone) areas along Tolt Supply Line (upstream of TESSL) and TESSL with seismically resilient steel or ductile iron pipe, of which approximately 50% would be paid by City of Bellevue ratepayers.
Note: The values in the table above are placeholder values based on budgetary costs for similar types of projects at other utilities. These values were assumed in order to identify the relative potential cost of different alternatives for consideration during evaluation as part of the SVA. Actual budgetary costs cannot be determined until a more thorough evaluation of the TSL and TESSL is completed and required improvements are identified. Costs shown reflect assumed total project cost.		

2.2 Groundwater Supply in Bellevue

2.2.1 Preexisting Groundwater Wells for Emergency System Supply

In 2019, the City of Bellevue completed a planning study for emergency water supply which is summarized in the *Bellevue Emergency Water Supply Planning Report* (HDR & Stantec, 2020). This report identifies several different options and goals that could be addressed to provide emergency water supply to Bellevue. The City holds water rights for existing groundwater supply wells that are not currently equipped to supply potable water into the City's distribution system. Primary conclusions of the emergency supply report that are relevant to the improvement alternatives considered for the SVA are summarized below:

1) The City's current water rights may not be sufficient relative to the full water system demand following an earthquake.

2) The City could develop emergency groundwater supplies that would provide a baseline volume of supplemental water supply for use following a major seismic event, and it is likely feasible that emergency water rights could be legally secured to support such supply.

3) The City's four existing water supply wells and sites could be reconstructed and configured with community water distribution capability to support drive-up water bottle filling stations.

The *Emergency Water Supply Planning Report* recommends a minimum emergency water supply of 9 MGD, which is less than the average Bellevue winter water demand of 12 MGD. Most utilities plan for post-earthquake demands to be similar to average winter demands, given that there are some water demand savings and reductions that can be accomplished due to curtailment and conservation. However, a significant portion of the water supply after a major earthquake will likely be required for firefighting and water system restoration and repair, in addition to a significant amount of water loss due to pipe leaks and breaks, and other system seismic damage.

Permanent, full-time operational groundwater supply to the Bellevue water system at capacities that could meet the post-earthquake demands are not realistic or feasible in the planning horizon for this project, so the permanent groundwater supply option has been eliminated from consideration.

The *Emergency Water Supply Planning Report* identified a target alternative to develop up to 3.8 MGD of emergency well capacity that is connected to the system only during an earthquake. The estimated capital cost for this alternative was $7.5 million. In order to have a representative total project budget for 9 MGD of emergency water supply the groundwater supply alternative assumes a total project cost of $20 million for potential emergency well supplies.

If this alternative is implemented, the City will require additional operations staff to test, exercise, and maintain these wells so that they are available in the event of an emergency. For planning purposes, the City should assume that a two-person crew will spend 2 days per month at each well site. For example, if the emergency groundwater system includes 5 wells, the City should assume a two-person crew will spend 10 days per month on the wells, which is equivalent to 1 FTE. This assumption is based on approximately one day for pump, treatment system, and generator testing. The other day would be allotted for maintenance activities, which might require 1 day each at multiple wells or several days at one well in any given month.

2.2.2 Groundwater Wells for Emergency Local Water Distribution and Supply

In addition to the use of the preexisting wells for emergency system supply and/or as community distribution points, the *Emergency Water Supply Planning Report* identified the potential to develop other lower capacity emergency wells to be used as emergency neighborhood water distribution points. While this is alternative would provide significant value in making water available via fill stations while service from the water distribution system is being restored, it does not allow for the City to supply water to critical customers and have water available to begin locating and repairing water main breaks immediately after an event even if the SPU supply is not available.

Given the substantial benefits and relative ease of implementation, it is recommended that the City develop neighborhood distribution emergency wells as described in the *Emergency Water Supply Planning Report*.

2.3 Connection to Neighboring Groundwater Supplies

Three utilities (Issaquah, Redmond, and Sammamish Plateau Water) on the eastside of Lake Washington and adjacent to Bellevue own and operate permanent groundwater supplies. Of these, Redmond and Issaquah are already connected directly to the Bellevue Water System via interties between the two systems. Sammamish Plateau Water is not currently connected directly to the Bellevue Water System.

For the purposes of supply augmentation during a major seismic event such as the two considered as part of the SVA, none of these utilities have adequate groundwater supply to provide all of their normal demands from groundwater alone. Sammamish Plateau Water is the closest with 80% of their supply supported from their groundwater sources. Since none of these neighboring utilities have excess groundwater supply available, and because any such available supplies would be likely be dependent on additional pumping in order to supply the Bellevue system, the option of including emergency water supply from a neighboring utility was eliminated from the analysis as not feasible/desirable relative to other water supply and resilience options.

3. Resilient System Backbone Routes

Water from the SPU regional supply system feeds primarily into the Bellevue 400 and Lake Hills 520 zones. These two zones are the largest zones in the Bellevue water system, and along with having the most pipe in the system, they also are expected to experience the most pipe damage during a major seismic event. After reviewing the as-is damage and restoration durations, it was apparent that resilient backbones to feed key parts of the system, connecting water supply to the customers in less vulnerable zones, had the potential to provide significant value with reduced cost compared to widespread pipe replacement in these large distribution zones.

The evaluation did not incorporate any additional resilience features for backbone piping compared to normal distribution system piping. See Section 5 for the evaluation and assumptions associated with pipe replacement alternatives. The evaluation showed that improvement to these levels provides a significant reduction in the number of pipe repairs required for these routes following a major earthquake, which would be adequate to allow the city to achieve the target level of service goals. This is true as long as the backbones themselves can be isolated in a timely manner, the details of which was outside of the scope of the study.

The City and Jacobs worked together to develop a collection of resilient backbone routes for consideration as part of the improvement prioritization evaluation. The backbones developed are shown in Table 2 and Figure 2. The table shows the primary function that each of the backbone routes serve, the length of the backbone segment, and a cost for replacing the pipe within the backbone. Note that cost assumptions for distribution pipe replacement are presented in Section 6. Critical customer categories 1, 2, and 3 are defined in TM 2: Seismic Analysis Methodology for Pipeline and Facilities Assessment. The functions of the backbone routes are defined as follows:

Community Recovery: These system backbones provide water to community recovery facilities such as community centers and high schools, emergency operations centers, and maintenance facilities. They also serve as critical transmission corridors to move water throughout the water system.

Supply to South Bellevue from TESSL/Wells: These system backbones convey water from the TESSL water supply inlet stations and emergency wells in the Crossroads area to the Eastgate and Factoria areas to provide water to customers in South Bellevue.

Serves Isolated Zone: These system backbones provide connections to zones that are isolated on the edges of the distribution system.

Critical Customer: These system backbones primarily function to serve critical customers.

Economic Impact: These system backbones serve the economic centers of the city as a means to maintain water supply in support of economic activity and post event recovery.

Supplies Southeast Hills: These system backbones are parallel pipes that serve the higher residential zones on Sunset hill, Somerset hill, and Cougar Mountain.

Connection to CESSL: These system backbones provide connections from the CESSL water supply inlet stations to other major supply corridors.

Connection to TESSL: These system backbones provide connections from the TESSL water supply inlet stations to other major supply corridors.

Figure 2: SVA Resilient System Backbone Routes

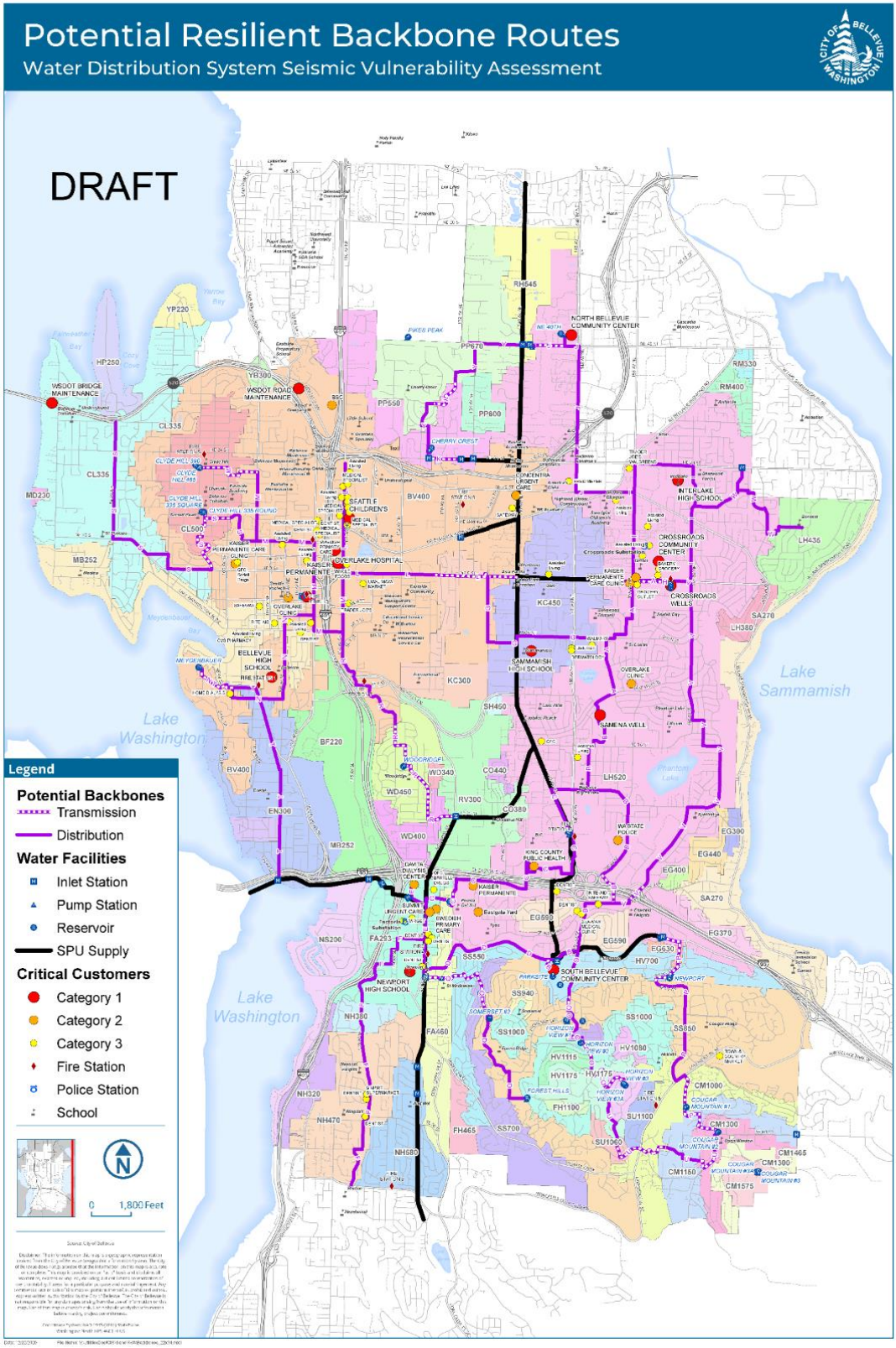


Table 2: SVA Resilient System Backbone Alternatives

ID	Route	Primary Function	Pipe Replaced in Improvement Alternative (ft)	Replacement Cost (2021 $)
A	Crossroads to Samena Well	Community Recovery	8,736	$4.3 M
B	Samena Well to Parksite/SBCC	Supplies South Bellevue from TESSL/Wells	13,659	$6.0 M
C	Lake Hills to Factoria	Supplies South Bellevue from TESSL/Wells	6,721	$5.2 M
D	Parksite to Factoria	Supplies South Bellevue from TESSL/Wells	5,315	$2.5 M
E	Inlet #11 to dialysis center & Factoria Blvd / Inlet #11	Community Recovery	2,292	$1.9 M
F	Newport Hills to Factoria	Serves Isolated Zone	10,280	$4.4 M
G	LH520 to BV400	Community Recovery	7,526	$4.1 M
H	NE 8th Inlet to Crossroads	Community Recovery	1,525	$1.5 M
I	Crossroads to Interlake HS	Community Recovery	13,674	$5.9 M
J	NE 40th Inlet to Bel-Red*	Community Recovery	8,082	$4.3 M
K	Cherry Crest Inlet and Pump Station	Community Recovery	1,070	$0.6 M
L	136th Ave Inlet to Hospitals	Critical Customers	10,338	$5.6 M
M	Bel-Red/Downtown/Clyde Hill	Economic Impact	13,421	$7.2 M
N	Downtown to Meydenbauer	Serves Isolated Zone	7,689	$3.7 M
O	Horizon View Pump Supply	Supplies Southeast Hills	8,801	$4.8 M
P	Cougar Mountain Pump Supply	Supplies Southeast Hills	97	<$0.1 M
Q	Somerset/Forest Hills Pump Supply	Connection to CESSL	4,848	$2.6 M
R	Richards/Woodridge to Downtown	Connection to CESSL	9,459	$4.6 M
S	Clyde Hill to Medina	Serves Isolated Zone	20,700	$11.1 M
T	Enatai to Meydenbauer	Connection to CESSL	12,501	$5.9 M
U	Horizon View to Cougar Mountain	Supplies Southeast Hills	40	<$0.1 M
V	Crossroads to Eastgate	Supplies South Bellevue from TESSL/Emergency Wells	14,158	$6.7 M
W	Lake Hills Spur	Community Recovery	7,354	$3.3 M
Y	NE 40th to Cherry Crest	Connection to TESSL	9,254	$4.1 M

4. Facility Improvements

Facility Improvements focus on improving the seismic resiliency of pump stations, reservoirs, pressure reducing valve (PRV) stations, and water supply inlet stations from SPU supply corridors. Because most PRVs and inlets are in buried vaults and structures, they tend to have reasonable inherent seismically resiliency and did not receive significant focus in this analysis. Reservoirs are helpful for pressure equalization and redundancy for short-term localized emergencies or planned pipeline shutdowns, but cannot feasibly store enough water to mitigate or maintain service through a regional supply outage. The City's operators have confirmed that almost all pressure zones can be operated (some at reduced pressure) without a reservoir online in an emergency scenario. As such, the majority of the focus for the SVA is on the seismic resilience of pump stations, as they are critical to moving water from the lower supply fed zones up to customers located at higher elevations.

The facility improvements are divided into categories as follows:

- **Required for backbone routes:** Facilities located at the start or end of resilient backbone routes or are integral to the backbone routes
- **Required to supply zones not on backbone routes:** Facilities that are the primary or only source of supply to zones, but are not a part of a backbone route
- **Backup or redundant facilities:** Facilities that are not the primary or most direct feed to a zone and can easily be bypassed and still provide water to customers

Ultimately, facilities are the hardest element of the system to bring back online after an earthquake due to the potential for damage to the structure and the interior components, long lead times to replace equipment, resource limitations for repair, and need to get red-tags removed prior to re-entry. Given this, the City should develop a plan to eventually upgrade all pump stations to be seismically resilient in order to allow for full system restoration in the target timeframes described by the target PE-LOS goals.

Costs for improvement or replacement of each pump station were developed to be incorporated into the improvement prioritization analysis. The costs shown are based on data extracted from the City of Bellevue Water System Capital Project Planning Budget Tool, which uses a unit cost value of $900,000 per MGD of pump station capacity (as 2021 dollars). This unit cost value of $900M/MGD was used for all pump station replacement cost calculations except for Forest Hills because Forest Hills has significant geotechnical concerns that may require significant additional work or relocation to include construction of a new pump station and reservoir.

Figure 3 and Figure 4 show City water system facilities and their expected probability of failure for the CSZ and SFZE events overlayed on the water system hydraulic profile (taken from the *2016 City of Bellevue Water System Plan*). Probability of failure is defined as the estimated likelihood of extensive or complete damage (resulting in the facility being offline) following the seismic event, as defined in TM 2: Seismic Analysis Methodology for Pipeline and Facilities Assessment. The areas of the system that are served by the highest risk facilities can be observed from the information shown in Figure 3 and Figure 4. The capacity, anticipated replacement cost, associated system backbone route (if applicable) and probability of failure in each of the considered earthquake events is shown in Table 3 for each of the pump stations.

Table 3: Pump Station Improvements Summary

Pump Station	Capacity (MGD)	Assumed Replacement Cost (2021 $)	Backbone Route	SFZE Failure Prob.	CSZ Failure Prob.	Notes	Risk Category (See Table 4)
Cherry Crest	New PS, Not Evaluated					2	
Clyde Hill	3.1	$2,800,000		76%	24%	1	
Cougar Mountain 1	3.1	$2,800,000	P	62%	4%		IV
Cougar Mountain 2	2.9	$2,600,000	P	62%	3%	1	IV
Cougar Mountain 3	3.6	$3,200,000		62%	3%		
Forest Hills	3.9	$10,000,000		61%	7%	3	
Horizon View 1	5.2	$4,700,000	O	25%	1%	2	IV
Horizon View 2	3.2	$2,900,000	O	83%	20%	1	IV
Horizon View 3	3.8	$3,400,000		20%	<1%		
Lake Hills (Crossroads)	5.1	$4,600,000		56%	6%	4	
Meydenbauer	1.2	$1,100,000		26%	1%		
NE 8th Inlet 1	13.6	$12,200,000		15%	<1%		IV
NE 40th Reservoir	14.4	$13,000,000		38%	6%	4	
Newport	3.7	$3,300,000	P	62%	4%		IV
Parksite	5.7	$5,100,000	O	86%	22%	1	IV
Pikes Peak	Decommissioned and Incorporated into new Cherry Crest PS					1	
SE 28th Inlet	11.6	$10,400,000		33%	<1%		
Somerset Inlet	5.2	$4,700,000	Q	26%	<1%		
Somerset 2	4.1	$3,700,000	Q	22%	<1%		
Woodridge	9.8	$8,800,000		68%	7%	5	
161st Ave Inlet	10.1	$9,100,000		25%	<1%		
670	6.9	$6,200,000		67%	23%		IV
CCD 475/580	7.8	$7,000,000		No Structural Data			

Notes:

1- Already Programmed or Budgeted for Replacement
2- Recently Replaced or Upgraded
3- Requires significant geotechnical improvements or relocation
4- Repumps into storage facility, emergency bypass possible
5- Pumps to zone also fed by PRV from above

Figure 3: CSZ Facility Outage Probability

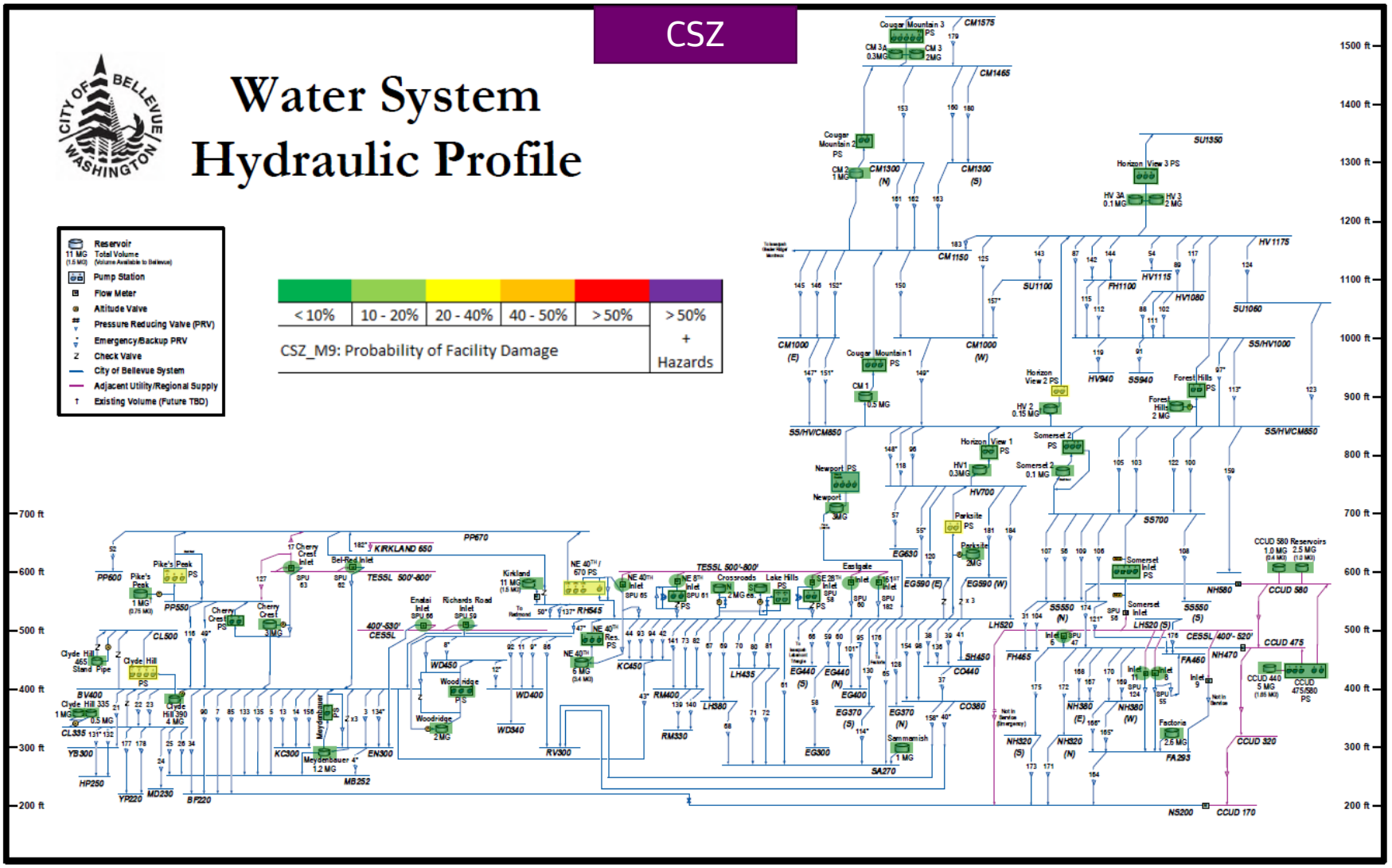
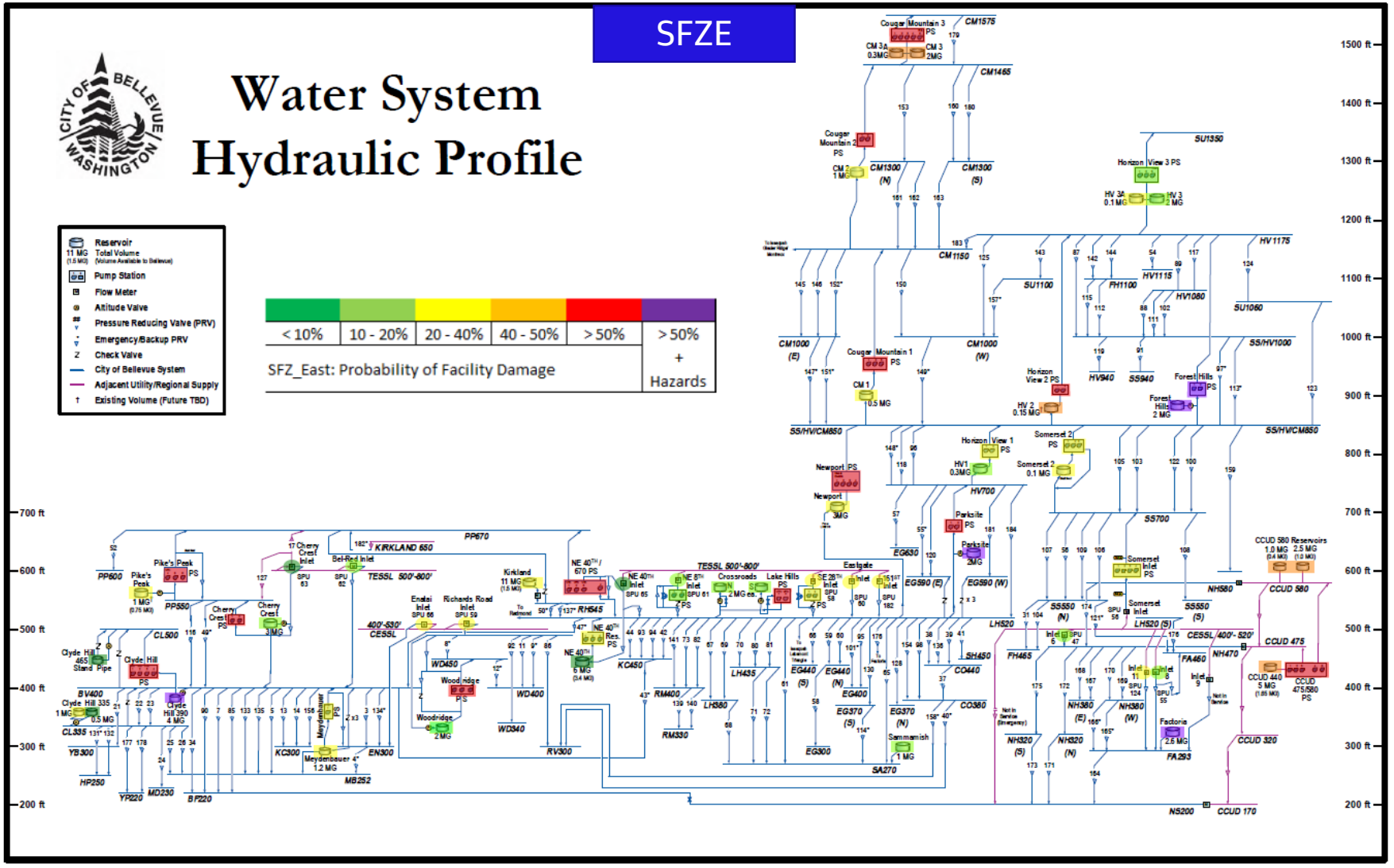


Figure 4: SFZE Facility Outage Probability



4.1 Facility Improvement Design Criteria Recommendations

As explained in Section 3.2 of TM 7: PE-LOS Goals, designing facilities (primarily pump stations) according to the International Building Code is likely not adequate to meet the Post-Earthquake Level of Service Goals targeted as part of a broader seismic resilience program. As such, the improvements assumed as part of the evaluation incorporate a higher level of seismic evaluation and design than would be required by code for most facilities.

Table 4 provides proposed enhanced performance criteria that should be adopted by the City to bring the pump stations up to a level that is consistent with the seismic events considered as part of the seismic vulnerability assessment. Following these criteria will be critical to allowing the City to improve the system to the point that the post-earthquake level of service goals developed as part of the SVA are achievable. This table should supplement other code based seismic design criteria during the evaluation and design of pump station improvements or replacement projects. Anytime that the code requires a higher performance level than this table, the code should take precedence. The Table is organized and formatted consistent to allow for extraction and use independent of this TM for ease of application and review by building code officials, design engineers, and architects.

Table 4: Bellevue Pump Station Enhanced Performance Criteria

	Enhanced Performance Criteria as Defined by ASCE 41			
	Lower Level Earthquake (BSE-1)		Higher Level Earthquake (BSE-2)	
	ASCE 41 Structure Performance	ASCE 41 Non-Structural Performance	ASCE 41 Structure Performance	ASCE 41 Non-Structural Performance
New Facility				
Design Earthquake	BSE-1N		BSE-2N	
Risk Category IV[1]	Immediate Occupancy[2]	Operational[2,3]	Immediate Occupancy	Position Retention, Ip=1.5[4]
Risk Category III	Immediate Occupancy	Operational[5]	Damage Control[6]	Position Retention
Existing Facility being Upgraded				
Design Earthquake	BSE-1N[7]		BSE-2N[7]	
Risk Category IV[1]	Immediate Occupancy[2,8]	Position Retention, Ip=1.5[2,4,9]	Immediate Occupancy[8]	Position Retention, Ip=1.5[4,9]
Risk Category III	Immediate Occupancy[8]	Position Retention, Ip=1.5[4,9]	Damage Control[6]	Position Retention

Table Notes:

1) Includes Bellevue Water System facilities required to provide water to Emergency Room Hospitals, designated resilient supply points, backbone routes, and community recovery facilities; in addition to Essential Buildings as defined by IBC Table 1604.5. Refer to categorization of Bellevue Water System facilities included in 2021 Water System Seismic Vulnerability Assessment project documentation.

2) Due to enhanced performance requirements for BSE-2N, the BSE-1N requirements for Category IV structures will not control evaluation or design.

3) Special Certification not required for active mechanical and electrical equipment unless building is categorized as essential as defined by IBC Table 1604.5. Certification is still required for facilities if required by IBC and ASCE 7.

4) Non-structural performance shall be designed for position retention, but with the importance factor increased to 1.5.

5) Special Certification not required for active mechanical and electrical equipment.

6) Structures designed for damage control shall target occupancy within 14 days after the BSE-2N earthquake, in the opinion of a registered design professional.

7) In order to achieve the City of Bellevue Water System Level of Service Goals, Existing facilities must have the same performance as new facilities and shall be evaluated based on the same seismic events used to design new facilities.

8) Destructive testing not required unless recommended by registered design professional or building is categorized as essential as defined by IBC Table 1604.5.

9) Existing facilities' non-structural components should be designed for position retention. If existing active mechanical or electrical equipment is to be replaced as part of or after a structural facility upgrade, the non-structural performance shall be designed in accordance with a new facility as defined in this table.

5. Widespread Pipe Replacement

Widespread distribution system pipe replacement will be considered to determine the potential to reduce the overall number of leaks and breaks that would need to be repaired after a seismic event. This includes evaluation of widespread improvements to the entire system, or just to specific parts of the water system.

The primary focus of this evaluation is to consider the benefits of replacing existing seismically vulnerable asbestos cement (AC) and cast iron (CI) pipe with more seismically resilient materials and pipe joint configurations. As described in TM2: Vulnerability Analysis Methodology and TM2A: Comparison of ALA (American Lifelines Alliance) Equations to Christchurch Earthquake Repair Data, the expected number of repairs for AC or CI pipe is approximately 12 times greater than for unrestrained ductile iron (DI) pipe installed in the same location.

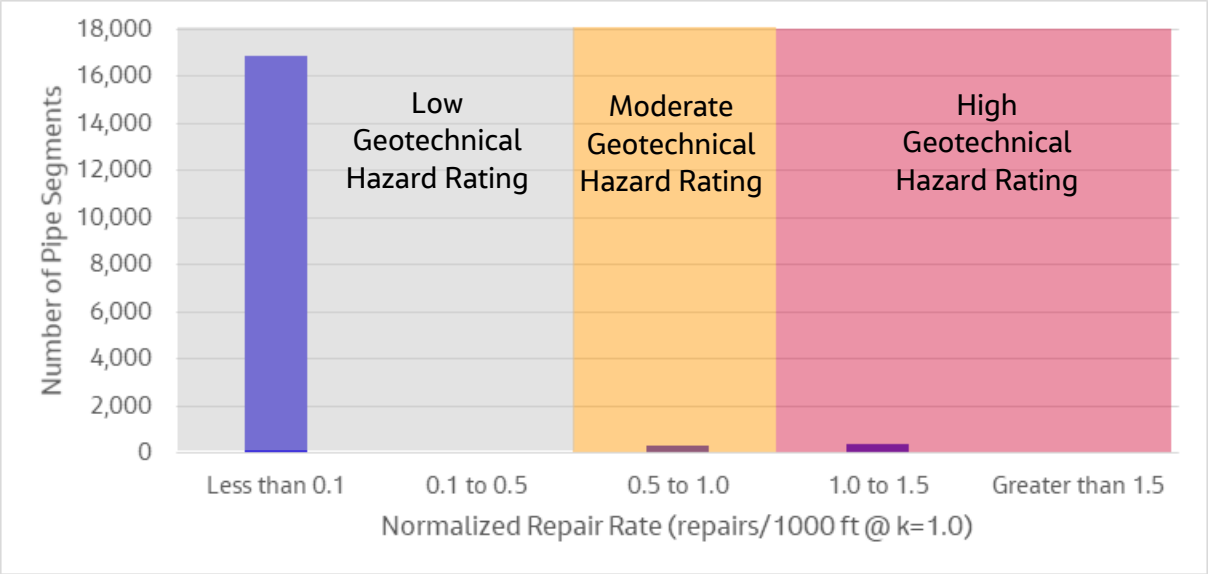
Additionally, this alternative considers the potential benefit of replacing pipe in geologically vulnerable areas (areas with higher potential for liquefaction or earthquake induced landslides) with more resilient piping such as restrained DI or earthquake resistant ductile iron pipe (ERDIP), consistent with the associated ISO 16134 standard. Note that high-density polyethylene (HDPE) fusion welded pipe could also potentially be another seismically resilient piping alternative to consider for vulnerable area installation, but that HDPE was not specifically evaluated because it is a significant departure from the current piping standards for the City, where DI piping is already in common use.

5.1 Pipe Location Vulnerability Rating

In order to identify the relative vulnerability of pipe locations in the water system, a geotechnical hazard rating was developed based on the pipe material normalized repair rate for each pipe in the system. Normalized repair rate represents the expected repair rate in repairs per 1,000 lineal ft (LF) of pipe if the ALA equation pipe K1 and K2 coefficients (measures of pipe material fragility) were assumed equal to 1 for the Seattle Fault Zone East seismic event. This approach allows the vulnerability of every location in the system to be compared to the rest of the system, regardless of the pipe material.

Figure 5 shows a histogram of the normalized repair rate per 1,000 LF of pipe for all pipe locations in the Bellevue Water System. Based on this information, all pipes with a normalized repair rate less than 0.5 repairs/1,000 LF were categorized as low vulnerability. Pipes from 0.5 to 1.0 repairs/1,000 LF were categorized as moderate vulnerability and those with normalized repair rates greater than 1.0 were categorized as high vulnerability. The geotechnical hazard rating information shown in Figure 5 was used in the development of the Pipe Replacement Alternatives discussed in Section 5.3.

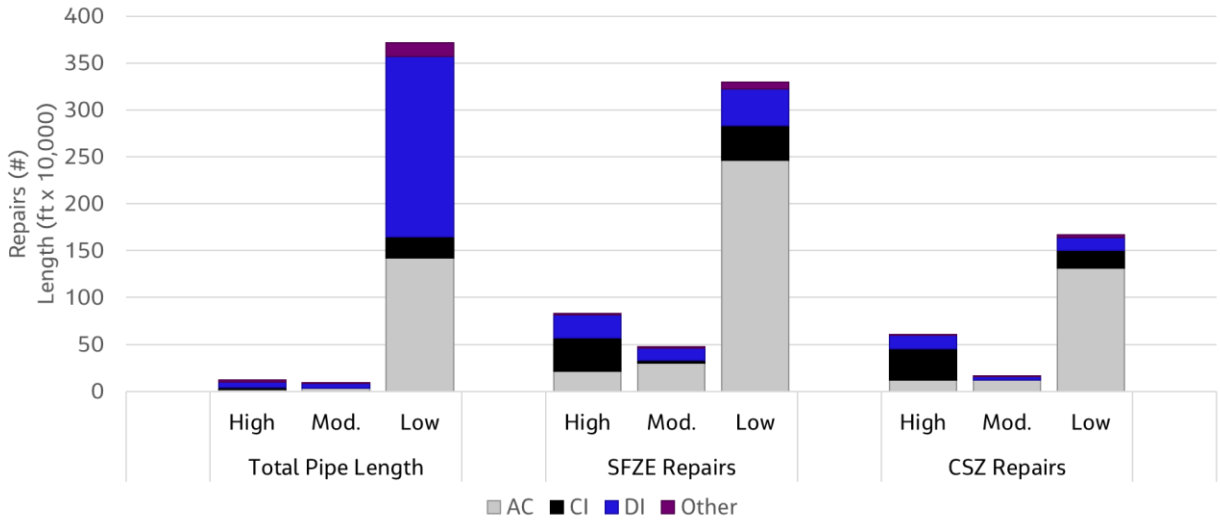
Figure 5: Water System Normalized Repair Rate Histogram



5.2 As-is Contribution of Repairs by Existing Pipe Material

Figure 6 shows the total length of each major pipe material in the water system in each vulnerability rating category as well as the number of expected post-earthquake repairs for each material and vulnerability. This shows that 65 percent of the post-earthquake repairs are expected to be in AC pipe which comprises only 30 percent of the water system by length. Similar to the geotechnical hazard rating information in Figure 5, the pipe repair information shown in Figure 6 was used in the development of the Pipe Replacement Alternatives discussed in Section 5.3.

Figure 6: Expected Repairs to Existing System by Pipe Material and Vulnerability Rating Category



5.3 Pipe Replacement Alternatives

Using the information shown in Figure 6, five pipe replacement alternatives were developed based on potential "design standards" that could be implemented as pipe is replaced and/or pipeline seismic

resilience improvements are completed over the course of the next several decades. The alternatives are defined based on the minimum pipe material in terms of seismic resilience that would be installed in each of the three vulnerability rating categories. Table 5 shows the materials that are proposed under each of the alternatives considered for each geotechnical hazard rating category.

Table 5: Pipe Replacement Alternatives Summary

Geotechnical Hazard Rating	Pipe Material Standards				
	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
High	Unrestrained DI	ERDIP	ERDIP	ERDIP	ERDIP
Moderate	Unrestrained DI	Restrained DI	ERDIP	ERDIP	Restrained DI
Low	Unrestrained DI	Unrestrained DI	Unrestrained DI	Restrained DI	Restrained DI

Figure 7 shows the total amount of pipe that would need to be replaced system-wide to achieve the pipe material combinations shown in Table 5. The primary differences between alternatives 1 through 3 are the amount of pipe to be replaced in high and moderate vulnerability areas, because of the need to essentially replace all pipe in those areas. However, the amount of pipe in such areas is relatively small, so the total replacement length to accomplish that is minimal. Alternatives 4 and 5 require significant additional replacement of pipe because all unrestrained DI pipe in all areas would need to be replaced. However, this has minimal actual increased cost if the replacement of this pipe occurs when the pipe is being replaced for other reasons (i.e., age or capacity) as the only added cost at that time is the cost increase to incorporate restraint at the pipe joints.

Figure 7: Pipe Replacement by Material for Each Alternative

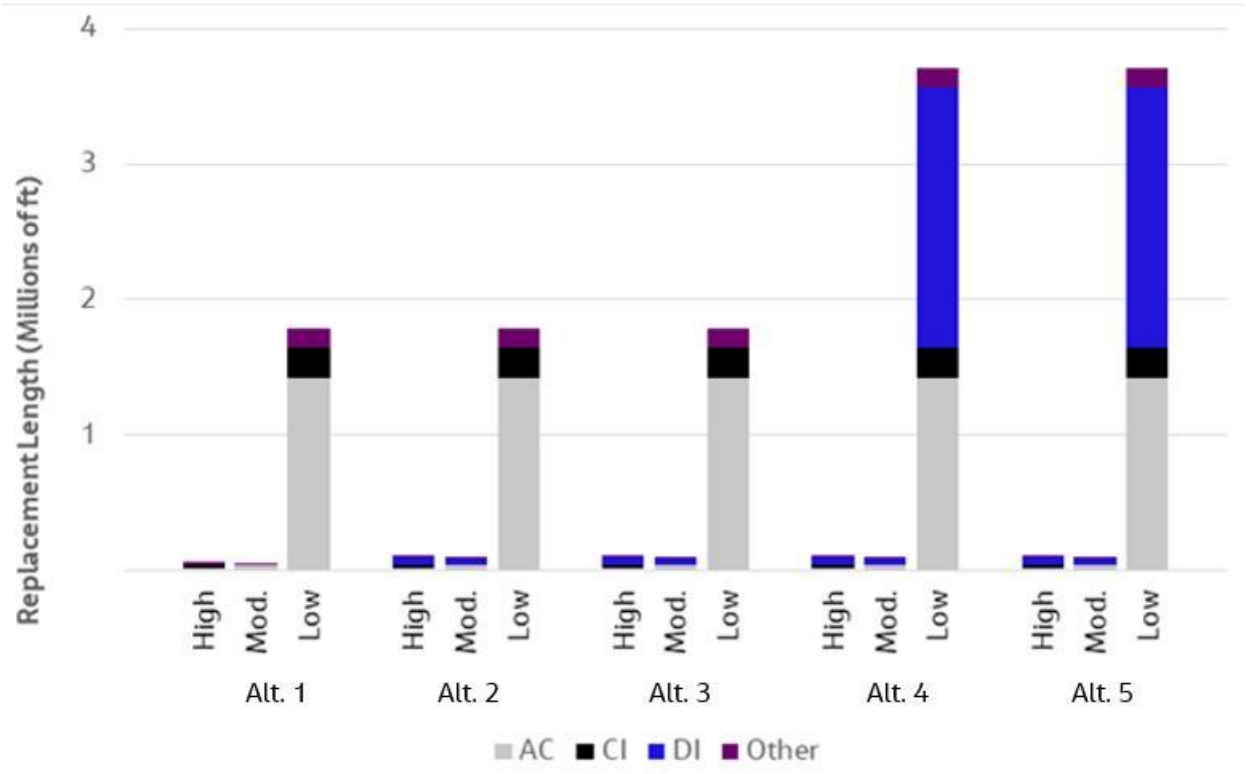


Figure 8 shows the expected number of repairs for pipe in each vulnerability category for the existing system based upon information in Figure 6 for each of the pipe replacement alternatives (assuming that all pipe in the system has been replaced to meet the standard described in the alternative). As illustrated by the repair comparison between the existing system and Alternative 1, the largest impact to the reduction in post-earthquake repairs results from replacing brittle pipe (AC and CI) in low vulnerability areas with DI pipe. Alternative 2 provides a substantial improvement over Alternative 1 in the high vulnerability areas through the implementation of ERDIP in these areas. By replacing existing pipes with ERDIP in moderate and high vulnerability areas under Alternatives 3 and 4, there is a further reduction in expected post-earthquake repairs. Alternatives 4 and 5 incorporate restrained DI pipe in low vulnerability areas, which can be expected to result in a small additional reduction in post-earthquake repairs.

Figure 8: Improvement Alternative Repair Comparison

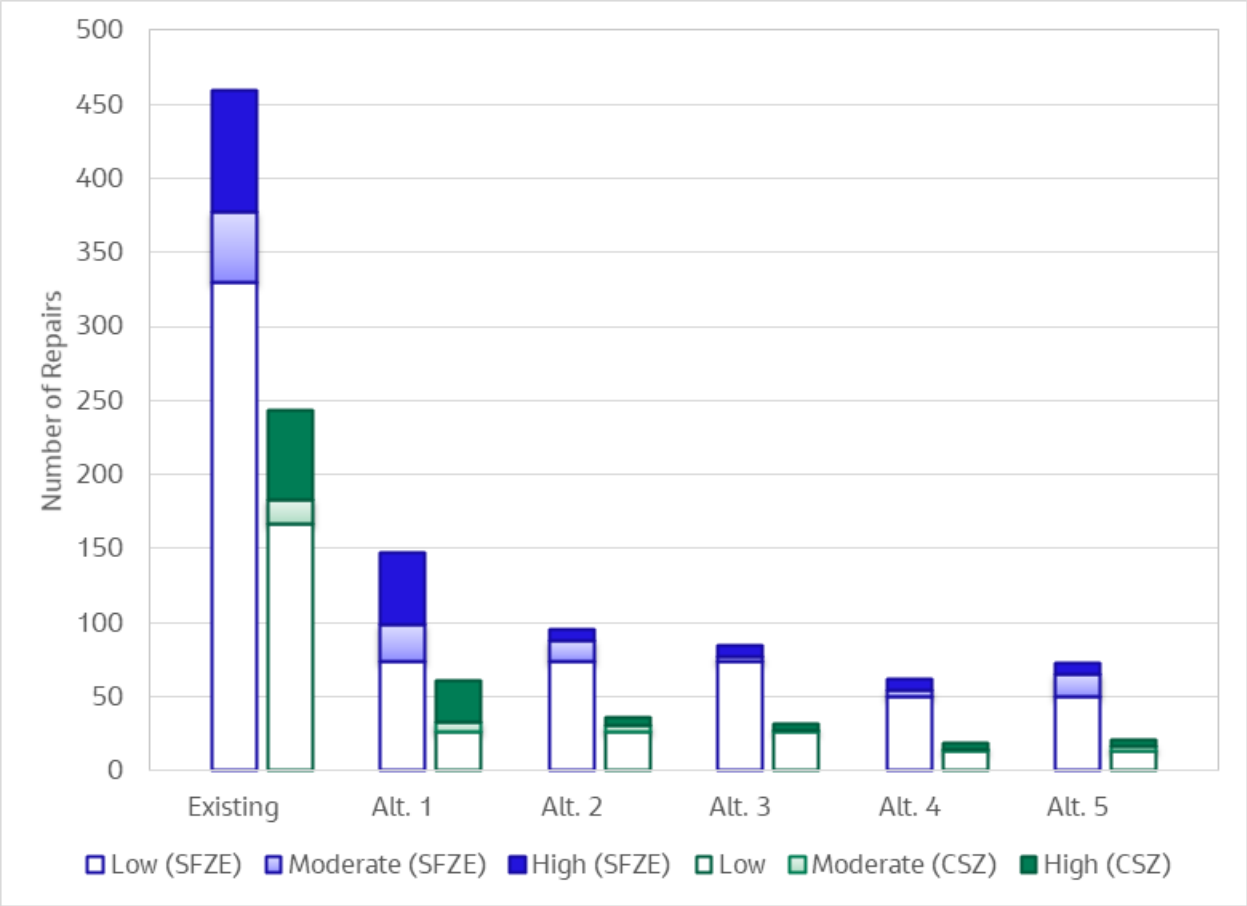


Figure 9 shows the length of pipe and total pipe replacement costs estimated for each of the 5 alternatives. The cost to replace AC pipe is shown separately for the cost to replace other types of pipe. Based on the assumption that the City will replace all of the AC pipe in the system in the next several decades, only the cost to replace other pipe would be considered additive costs over currently planned spending as long as the improvements are phased on a similar pipe replacement timeframe. Alternatives 4 and 5 show a significant jump in the length of pipe and quantity of non-AC pipe that would need to be replaced.

Figure 10 shows a comparison of the pipe replacement cost and the number of repair reductions for the SFZE earthquake scenario. The cost is broken up into the cost to replace pipe with unrestrained or restrained DI pipe. Alternatives 1 through 3 each have gradually increasing reductions in the number of post-earthquake pipe repairs with minimal increase in cost. Alternatives 4 and 5 have limited additional reduction in post-earthquake repairs, but over double the cost.

Because Alternative 3 has a significantly lower cost than alternatives 4 and 5, but similar benefit (reduced leaks and breaks), it was selected to use as the baseline for evaluation of the value of these improvement alternatives and the identification necessary improvements to achieve the target PE-LOS goals.

Figure 9: Pipe Replacement Alternatives Lengths and Costs

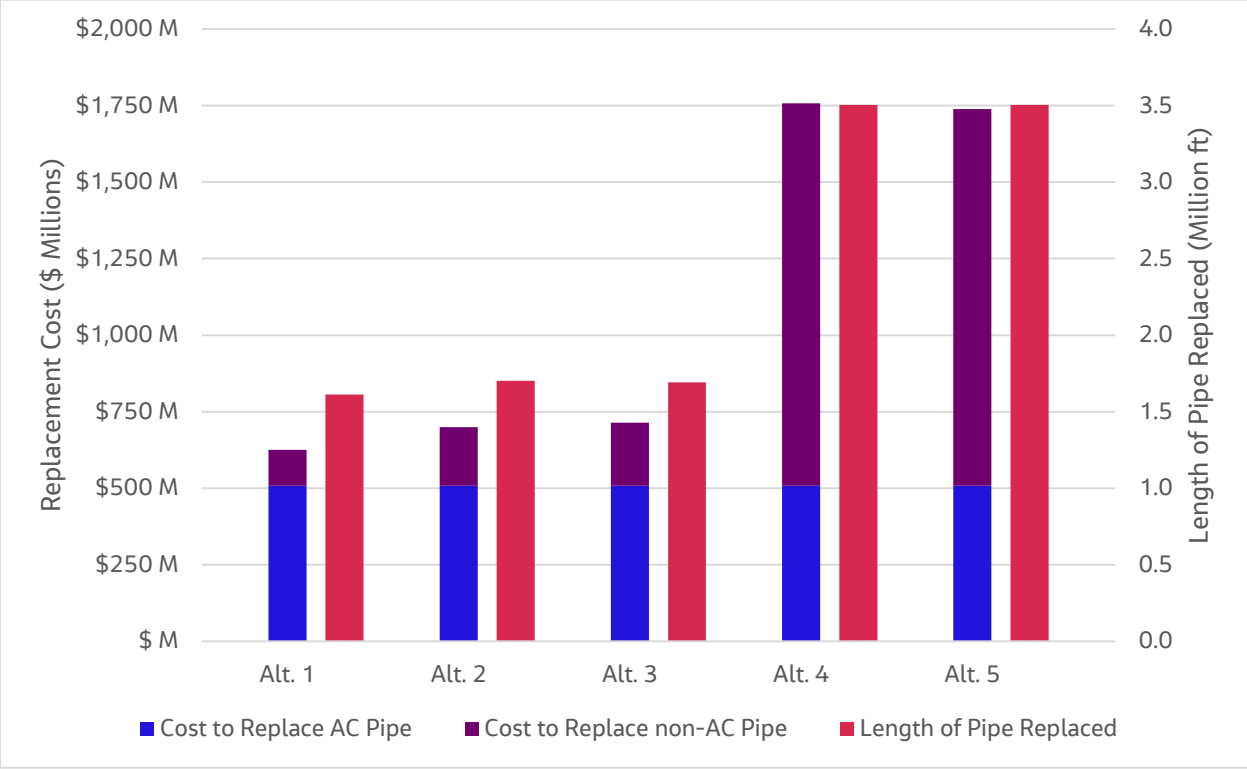
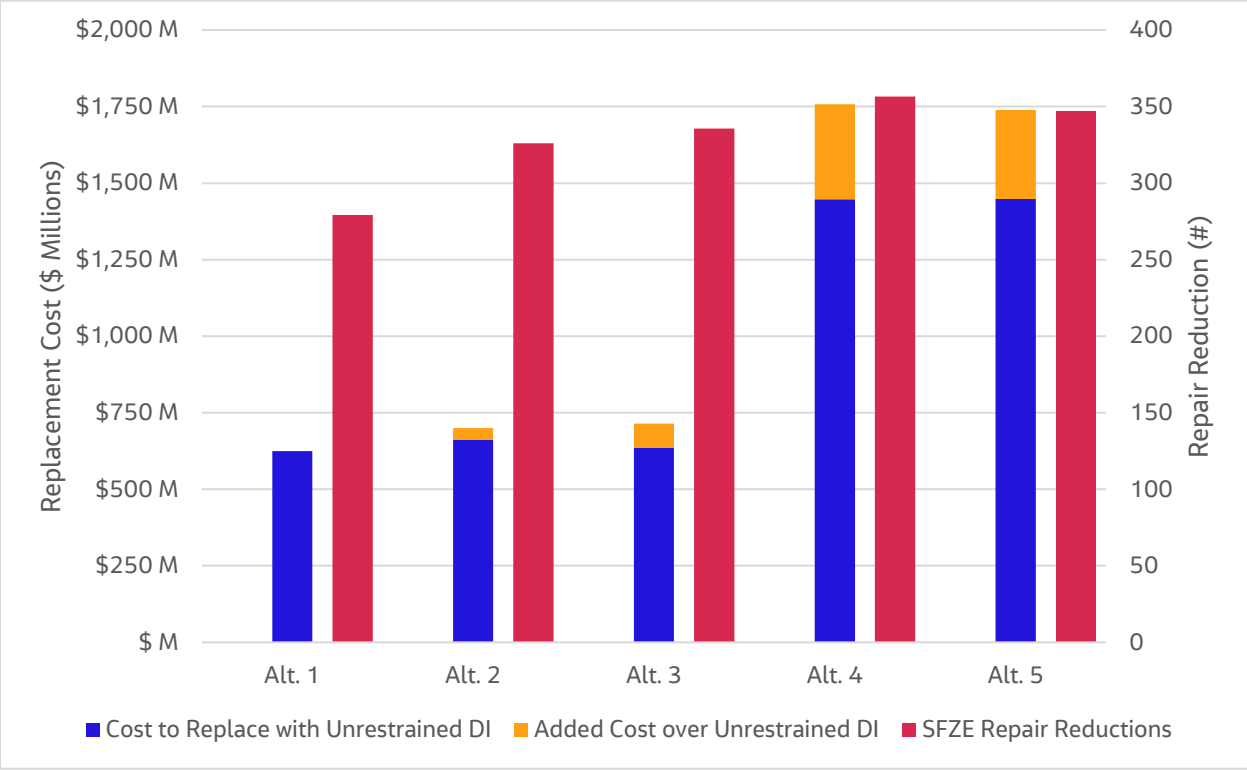


Figure 10: Pipe Replacement Cost and Repair Reduction Comparison



6. Improvement Alternative Cost Assumptions

The following section describes the cost assumptions used for development of improvement alternative costs presented in this TM and the rest of the SVA. For all alternatives, the following markups on recent construction contractor bid prices are included in the costs shown, which are indicative of expected total project costs.

- Sales Tax = 10.1%
- Inflation = 2.5% from 2019 to 2021.
  *All costs shown are in 2021 dollars based on escalation from 2019 budgetary cost information. Abnormal or unusual price escalation due to 2020-2021 market conditions are not included.
- Contingency = 40%
- Non-Construction Costs =total of 37.1%
  - Consultant Design = 15%
  - Services During Construction = 3%
  - City Labor (non-construction management) = 5%
  - Permitting = 1%
  - City Construction Manager = 3%
  - Non-Construction Cost Contingency = 40%

6.1 Facilities

As described in Section 4, facility costs were developed using the City of Bellevue Water System Capital Project Planning Budget Tool. This tool assumes a cost of $393,000/mgd of construction cost for water system pump stations. After applying the markups shown above in the City of Bellevue Water System Capital Project Planning Budget Tool, the total project cost per mgd for pump stations is estimated at $900,000/mgd.

6.2 Distribution Pipe Replacement

Distribution pipe replacement costs were developed using historical City of Bellevue bid prices and cross referenced with the City of Bellevue Water System Capital Project Planning Budget Tool. The budget tool assumes a constant unit cost per inch diameter linear foot value for each pipe material type. Due to the magnitude and extent of the pipe replacement considered in this analysis, it was beneficial to develop representative costs for each pipe size or size range. Table 6 shows the total project pipe replacement cost per linear foot for each size and pipe material considered as part of the alternatives evaluation. This includes all of the markups noted above.

Table 6: Total Project Cost per Linear Foot Used for Pipe Replacement

	Pipe Material		
Pipe Diameter (in)	**Unrestrained Ductile Iron**	**Restrained Ductile Iron**	**Earthquake Resistant Ductile Iron**
4	$250	$300	$440
6	$340	$410	$610
8	$410	$480	$730
10	$450	$520	$830
12	$500	$610	$880
14	$580	$710	$1,030
16	$660	$810	$1,170
18	$740	$910	$1,320
20	$830	$1,010	$1,470
24	$990	$1,210	$1,760
30	$1,240	$1,510	$2,200
36	$1,490	$1,820	$2,640
48	$1,980	$2,420	$3,520

6.3 Cost Assumptions

Planning level costs estimates were developed based on recent City of Bellevue construction contractor bid price history using generic cost curves as described above. These estimates can be considered accurate for a range of +100/-50 percent. These costs are suitable for comparison and evaluation among alternatives. Individual projects or even overall program budgets should be budgeted using more detailed cost estimating methodologies aligned to the specific improvement elements and market conditions anticipated when such improvements will be implemented. The estimated costs outlined herein and throughout the SVA are based on and consistent with information available at the time of development, and may not align with future conditions. The final cost of water system improvement projects will depend upon the actual labor and material costs, competitive market conditions, implementation schedule, and other variable factors.

The purpose of the cost estimates presented herein and throughout the SVA is to provide a basis to make optimized decisions regarding capital expenditures and to provide concept-level guidance for budgeting implementation of mitigation improvements. As a result, the final project costs for each alternative will vary from the estimates presented herein. Because of this variability, project feasibility and funding needs must be carefully reviewed prior to making specific financial decisions.

7. Operational Improvements

In addition to the physical improvement alternatives described above, the team also developed a list of operational improvements. While none of these operational improvements reduce time that it takes to get the system back to a fully restored operational state, they are beneficial and useful to help reduce the impact of water system outages after an earthquake event.

7.1 Surface Water Drafting for Fire Protection

The Bellevue Fire Department regularly practices surface water drafting as a means to supplement fire flow delivery in areas adjacent to surface water bodies and lacking sufficient/convenient potable water supply for fire suppression needs. While this provides the ability to get water supply for fire suppression in areas near surface water, this approach is capacity limited and does not typically provide all the water needed for fire suppression, especially in major fires such as those that may be expected after a major earthquake. This practice is valuable and should be continued, but does not replace the need for a resilient water system that can meet City fire suppression needs immediately after a seismic event.

Figure 11: Bellevue Fire Surface Water Drafting Practice

Figure 12: Bellevue Fire Department Surface Water Drafting Connections

7.2 Emergency Preparedness Education

While Emergency Preparedness Education does not address or reduce the amount of time that water service may not be available during/following water supply emergencies, it does lessen the impact to residents who are more proactively prepared for extended water outages. Previously, preparedness education had focused on a mantra of "3 days, 3 ways". While current education no longer references 3 days, this is still ingrained in many residents' minds. Current recommendations are to be prepared with 3 days of water for evacuation and 14 days of water for home survival. While water system outages may last longer than 14 days, this is a good starting point for initial survival before water replenishment can occur.

Emergency preparedness education should include training on how much water to store, how to properly store water, and how to find and appropriately treat water for consumption when stored water runs out.

7.3 Jumper Hoses

Many utilities have developed plans to use jumper hoses connected between fire hydrants or blowoffs as a means to bypass pipe leaks and breaks in water systems and restore/maintain water supply to critical customers. The use of jumper hoses is a valuable approach for times when a single break is causing the loss of water to a critical customer. However, the use of a jumper hose does not address a wide-spread issue when hundreds of water main breaks are causing loss of continuity and supply pressures in the water system.

Even though the use of jumper hoses may not provide the water supply connectivity needed during the earthquake event, having hoses on hand to bypass a handful of breaks and potentially be able to provide an isolated supply from a nearby tank to the emergency room hospital or other critical customers could be a valuable investment. Operations staff should be properly trained on the storage, transport, deployment, disinfection, and general use of the jumper hoses.

7.4 Community Distribution Points

The City should develop plans and specified locations for community distribution points as a means to provide water during system supply outages. These locations should be prepared with 1) traffic flow management plans, 2) water bottle fill station manifolds, and 3) staff trained in running the facilities.

The improvement prioritization process will determine the proposed approach to increasing the resiliency of the system. Specific locations that can be counted on to serve water will be developed after the improvement approach for the system is identified. In general, these should start with emergency supply well locations and tanks with seismic valves, and then expand to cover a geographically diverse representation of the water system. Figure 13 shows an example of a water distribution manifold developed by Tacoma Water and stored onsite at one of their water supply wells.

Figure 13: Tacoma Water Emergency Water Distribution Manifold

7.5 Blivets

Blivets are collapsible water tanks that can be transported in the back of a truck for emergency water transportation and distribution. The Bellevue Water department has two blivets currently. While blivets do not result in quicker restoration of water system service, they do allow for the city to provide emergency water supply in areas of the city that may not have active water system service. The City should reconsider the available blivets and their condition, and consider having enough blivets on hand to be able to supply

the basic drinking water needs of customers in areas of the City that are furthest from the emergency wells and resilient water supply mains. Operations staff should be properly trained on the storage, transport, deployment, disinfection, and general use of the blivets, as well as regularly inspecting their condition and integrity of them.

While Blivets can be a helpful tool, FEMA and the National Guard also operate water trucks that can provide similar functions and would not require pulling Bellevue water system maintenance staff off of repair work to operate them.

7.6 Spare Repair Parts Inventory Management

The need for spare repair parts after an earthquake is driven by the available crews and equipment to repair damaged pipe, and the number of repairs that will need to be completed. While the expected number of repairs that will be needed greatly exceeds the available spare parts inventory for the City of Bellevue, the availability of crews to execute the repairs is expected to be the limiting factor on the restoration of water system service.

Additionally, repairs to water system piping cannot commence until water supply into the system is available to locate pipe leaks and breaks damage. Supply to the water system is not expected to be available for days or weeks after a major earthquake event, allowing time for emergency managers to begin to request additional spare parts be provided from other parts of the country.

Table 7 shows the available repair parts available (as of Summer 2019). Based on this inventory, it appears that the minimum expected duration after a major SFZE event before additional repair parts would be required is 3 weeks. This is likely adequate to procure additional parts from other areas of the country. The greatest level of uncertainty is repair parts for pipes 14-inches in diameter and larger, due to the limited number of repair parts on hand. Based on this, it is recommended that the City consider the availability and potential need for repair parts for the larger pipe sizes and considering keeping a minimum of 5 to 10 repair sets for each size of pipe on hand at all times.

Table 7: Bellevue Water System Repair Parts Inventory and Time until Additional Repair Parts are Required

Pipe Size	Repair Parts Available	Weeks until more spares needed for SFZE*
4″	51	
6″	70	5 weeks
8″	52	3 weeks
10″	19	
12″	31	3 weeks
14″	5	
16″	2	3 weeks
18″	3	
24″	3	
*Based on duration from when repairs begin, which is based on when water is available at a source to allow for locating and fixing breaks.		

8. Summary

The improvement alternatives defined in this TM will be evaluated based on their ability to help the City achieve the target PE-LOS goals defined as part of the SVA project. Selected improvement will then be prioritized to develop an implementation plan and define funding needs to achieve the target PE-LOS goals.

Appendix I. Recommended Seismic Resilience Improvements

I.1 TM9: Improvement Prioritization

Jacobs

Technical Memorandum

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Subject	**DRAFT FINAL - TM9: Improvement Prioritization**
Project Name	Bellevue Water System Seismic Vulnerability Assessment
From	Jacobs
Date	December 29th, 2021

1. Background

The City of Bellevue (City) Water System Seismic Vulnerability Assessment (SVA) includes identification of the as-is service outage for a selection of seismic scenarios, and then identifying and evaluating improvement alternatives to reduce the water service outage time expected after a seismic event.

This document describes the results of the improvement prioritization process in which the potential improvement alternatives were evaluated and the selected ones prioritized to provide the most cost-effective path towards short-, mid-, and long-term seismic resiliency goals.

The results presented in this document include the following items:

- Prioritization Methodology
- Summary of Post-Earthquake Level of Service (PE-LOS) Goal Targets and Improvement Alternatives
- Improvement Combinations evaluated to achieve the PE-LOS goals
- Selected Improvement Combinations and Prioritization

2. Methodology

The prioritization methodology applied for assessing improvements and combinations of improvements against the target PE-LOS goals is shown in Figure 1. The PE-LOS goals established and summarized in TM 7 and the improvement options for main replacement, facility upgrades/replacement, and backbone development summarized in TM 8 were used to assess system performance against the PE-LOS goals.

For each of the PE-LOS goal timeframes (Long-Term, Mid-Term, Short-Term), multiple improvement combinations were developed to meet the PE-LOS goals and allow for comparison of the improvement combination options. A benefit-cost ratio comparison of the improvement combinations was reviewed with the City, and an improvement combination was selected for prioritization of the improvements included in the set of alternatives.

Figure 1: Prioritization Methodology

3. Post-Earthquake Level of Service Goal Targets

The concept and development of the target Post-Earthquake Level of Service (PE-LOS) goals is detailed in TM 7: Post-Earthquake Level of Service goals. The target PE-LOS goals were developed to guide the evaluation of improvement alternatives, so that the improvement alternatives were focused on achieving the desired performance of the system in a seismic event and meeting utility and customer expectations for water service restoration and outage durations, as well as reduced the potential economic impacts. Refer to TM 7 for the specific goals used for evaluation and prioritization of system improvements.

4. Improvement Alternatives

Improvement alternatives were developed considering the expected damage to the water system due to either of the two seismic events, Cascadia Subduction Zone (CSZ) and Seattle Fault Zone East (SFZE), that were evaluated as part of the SVA. There are four improvement categories that are incorporated into the evaluation of potential options to strengthen the system to provide more seismic resiliency. These improvement categories include:

1) Supply Improvements: Coordination with Cascade Water Alliance and Seattle Public Utilities to increase the resilience of the SPU regional water supply system to Bellevue so that either the regional water supply can be available immediately or could be returned to service within 7 days following a major seismic event (depending on which alternative is being considered as described below)
2) Facility Improvements: Improvements to specified pump stations and facilities to achieve a goal of immediate occupancy and fully operational status following a major seismic event, as described in the facility enhanced performance criteria in TM8: Improvement Alternatives.
3) Widespread distribution system pipe replacement: Strengthening of all vulnerable pipe in specified distribution system zones in accordance with Alternative 3 defined in TM 8: Improvement Alternatives. This includes upgrade to a minimum seismic performance equivalent to unrestrained ductile iron pipe for all pipe in the zone, and earthquake resistance ductile iron pipe (or equivalent performance) for pipes in moderate or high geotechnical hazard areas (those with significant potential for landslide or liquefaction issues, primarily).
4) Development of seismically resilient backbones pipe routes: Strengthening of specific backbone pipe routes using the same criteria summarized above (Alternative 3 from TM8: Improvement Alternatives). Additional consideration could be given to restrained joint ductile iron pipe for backbone routes with low geotechnical hazards, especially for the most critical backbone routes.

Selected improvements are described in the following sections of this TM. For more details on these selected improvements or for details on improvements that were not selected for implementation, refer to TM 8: Improvement Alternatives.

5. Improvement Combinations to Achieve PE-LOS Goal Targets

A summary of the improvement combinations for the Long-Term, Mid-Term, and Short-Term horizons are presented in this section. The restoration curves for each improvement combination are presented with the as-is restoration curve, and the comparison of the reduction in the economic impact is also shown for each improvement combination. The cost is shown for each of the improvement combinations in each tabular summary and the reduction in the economic impact are used in the evaluation of the benefit-cost ratio presented in Section 6.

5.1 Long-Term Improvement Combinations

The improvement combinations to meet the Long-Term PE-LOS goals are summarized for the four improvement categories below in Table 1, and the restoration curves for the CSZ earthquake for each of the long-term combinations are shown in Figure 2 and Figure 3 for critical customers and system-wide, respectively, and in Figure 4 and Figure 5 for the SFZE earthquake. Figure 6 and Figure 7 show the Long-Term risk reduction for the CSZ and SFZE earthquakes in terms of the reduction of the projected economic impact if the improvements in each combination were implemented.

Table 1: Long-Term Improvement Combinations

Combination	Supply	Facility Improvements		Pipe Improvements	Backbone System	Cost
L1	Immediate SPU Supply	Clyde Hill Cougar Mountain 1 Cougar Mountain 2 Cougar Mountain 3 Forest Hills	Lake Hills NE 40th Reservoir PS Newport Parksite Woodridge 670	Strengthening system-wide	No backbone	$847M
L2	Immediate SPU Supply	Clyde Hill Cougar Mountain 1 Cougar Mountain 2 Cougar Mountain 3 Forest Hills	Newport Parksite Woodridge 670	Strengthening key zones (BV 400, EG 300, FA 293, lH 520, SS 850)	Partial backbone[1]	$457M
L3A	Well Supply available immediately; SPU Supply available in 7 days	Clyde Hill Cougar Mountain 1 Cougar Mountain 2 Cougar Mountain 3 Forest Hills	Newport Parksite Woodridge 670	Strengthening key zones (BV 400, EG 300, FA 293, LH 520, SS 850)	Expanded Partial backbone[2]	$447M
L3B	Well Supply available immediately; SPU Supply available in 7 days	Clyde Hill Cougar Mountain 1 Cougar Mountain 2 Cougar Mountain 3 Forest Hills	Newport Parksite Woodridge 670	Strengthening key zones (EG 300, FA 293, LH 520, SS 850)	Full Backbone	$379M

[1]Segments included in L2 Partial Backbone: A, G, L

[2]Segments included in L3A Expanded Partial Backbone: A, B, G, L, M

Figure 2: CSZ Long-Term Critical Customer Restoration Curve

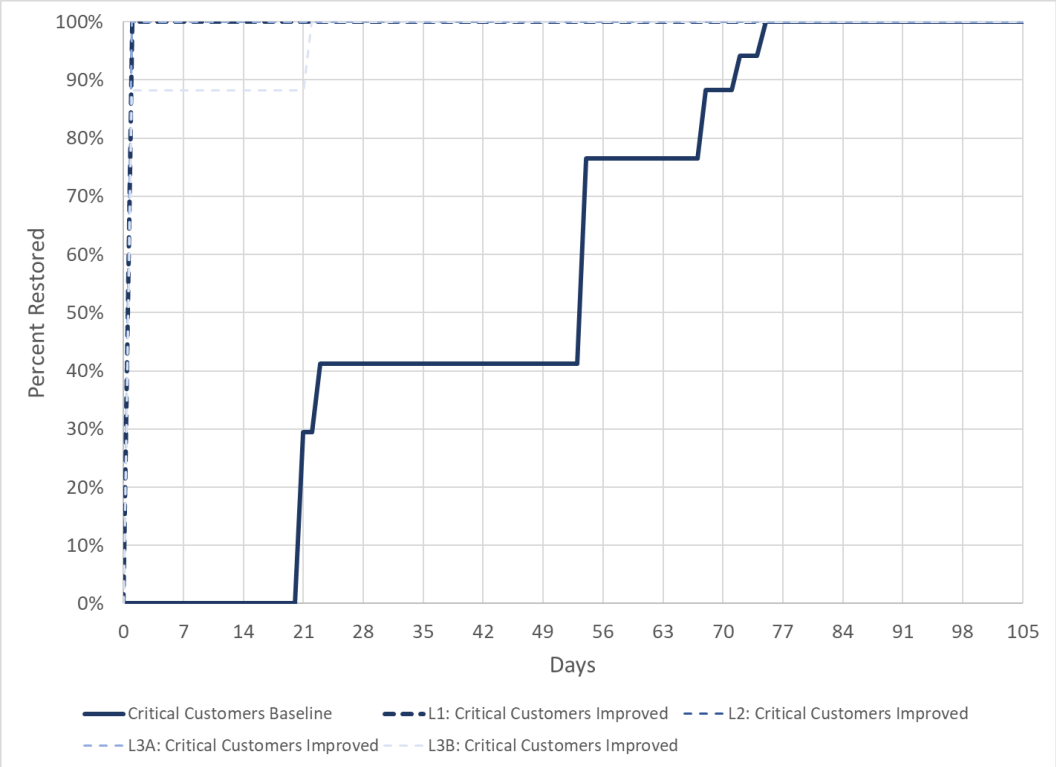


Figure 3: CSZ Long-Term System-Wide Restoration Curve

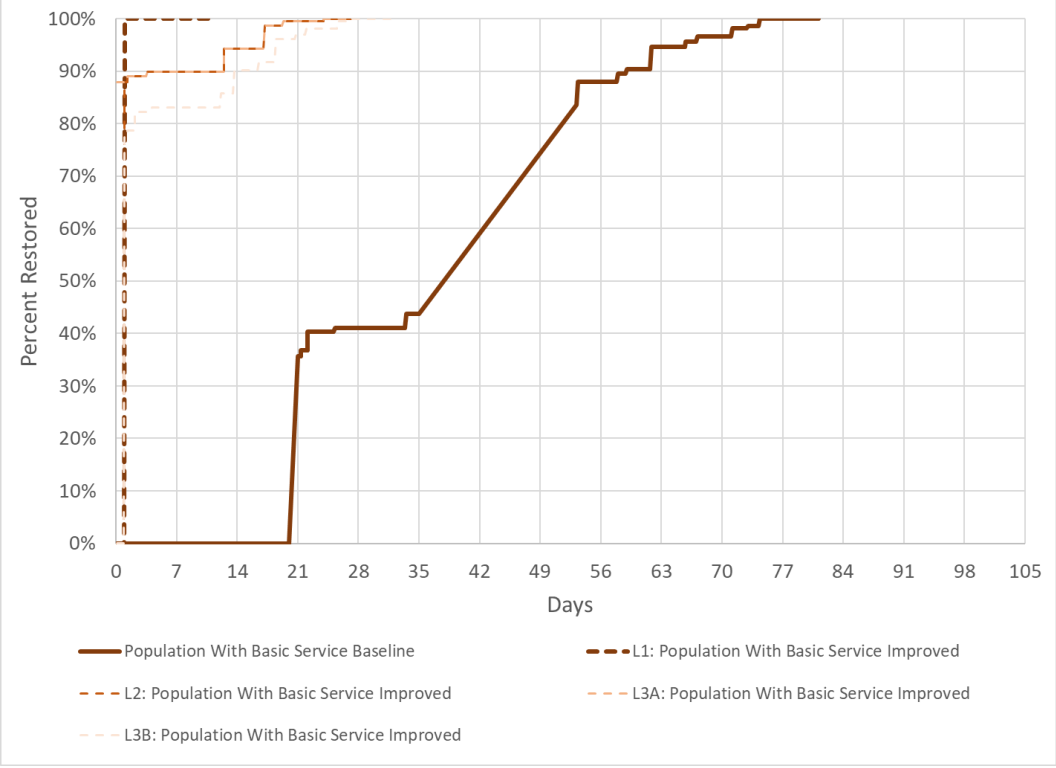


Figure 4: SFZE Long-Term Critical Customer Restoration Curve

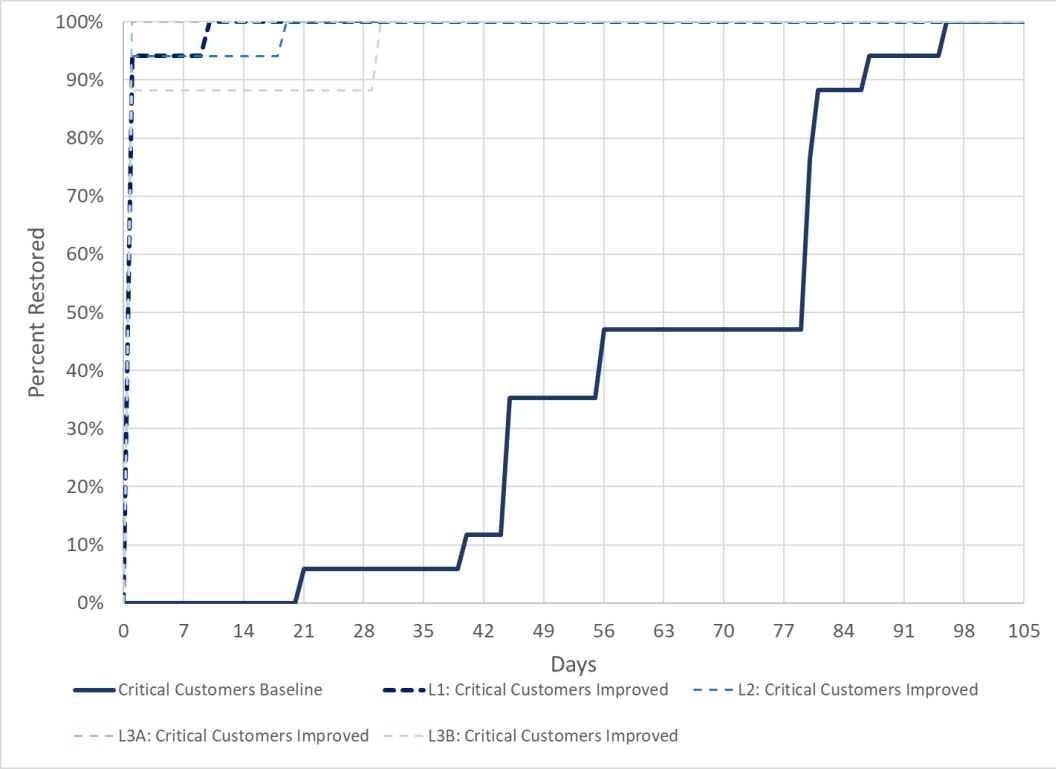


Figure 5: SFZE Long-Term System-Wide Restoration Curve

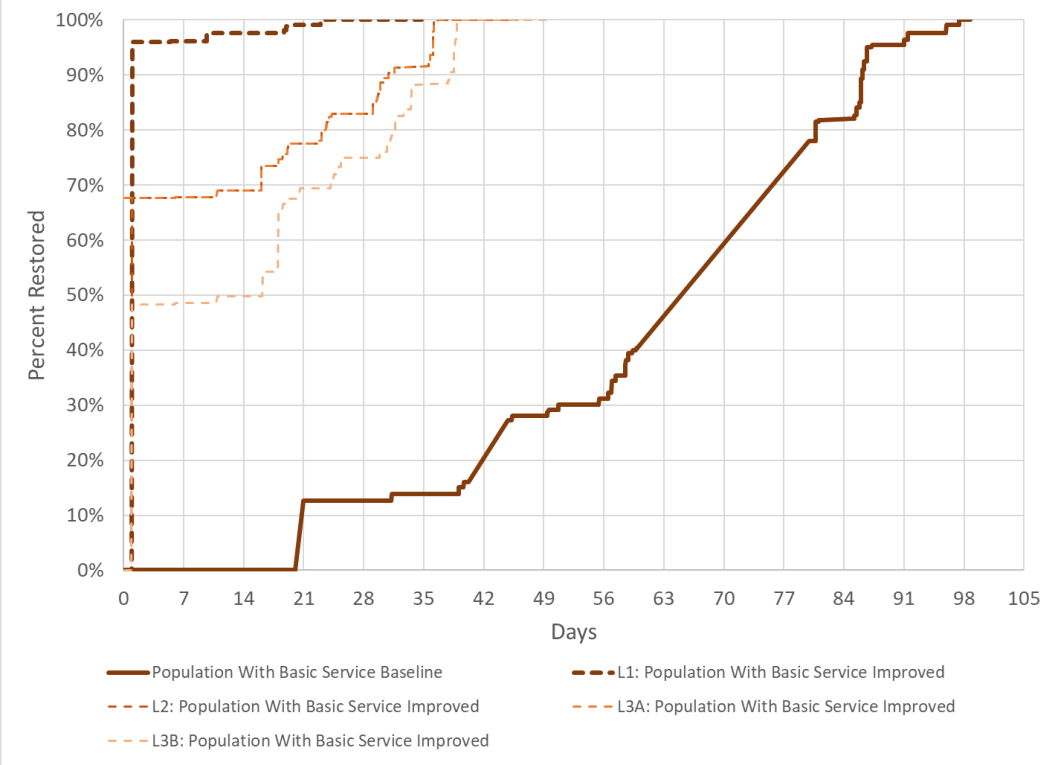


Figure 6: Long-Term CSZ Economic Impact Improvement

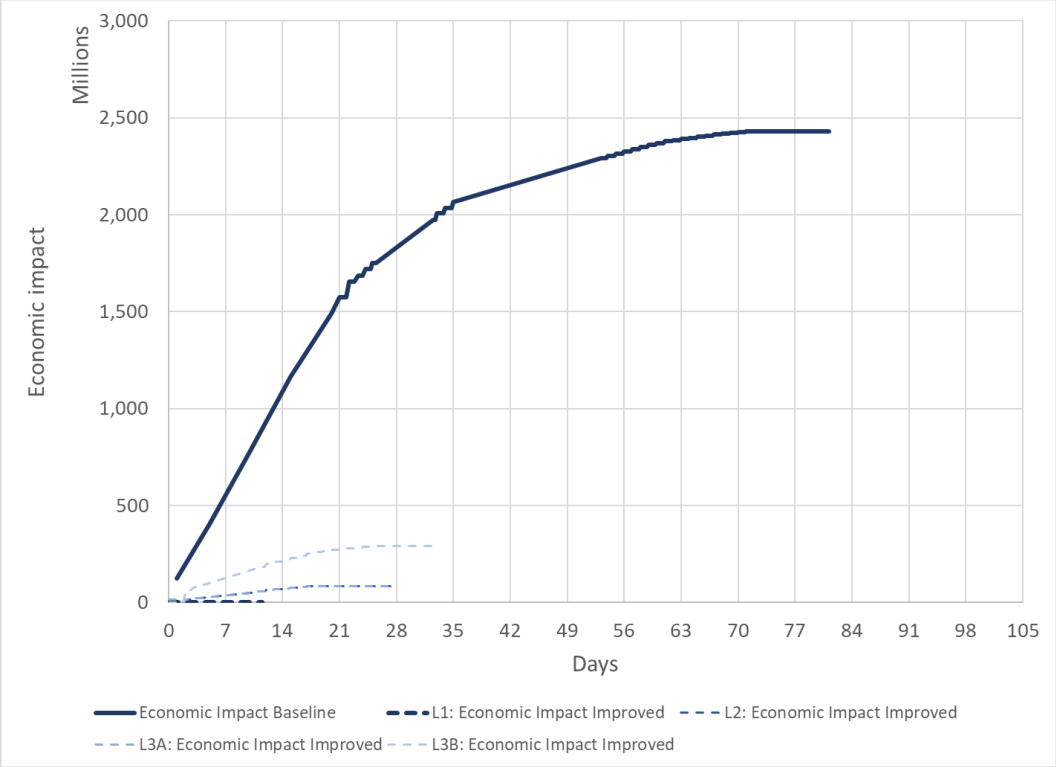
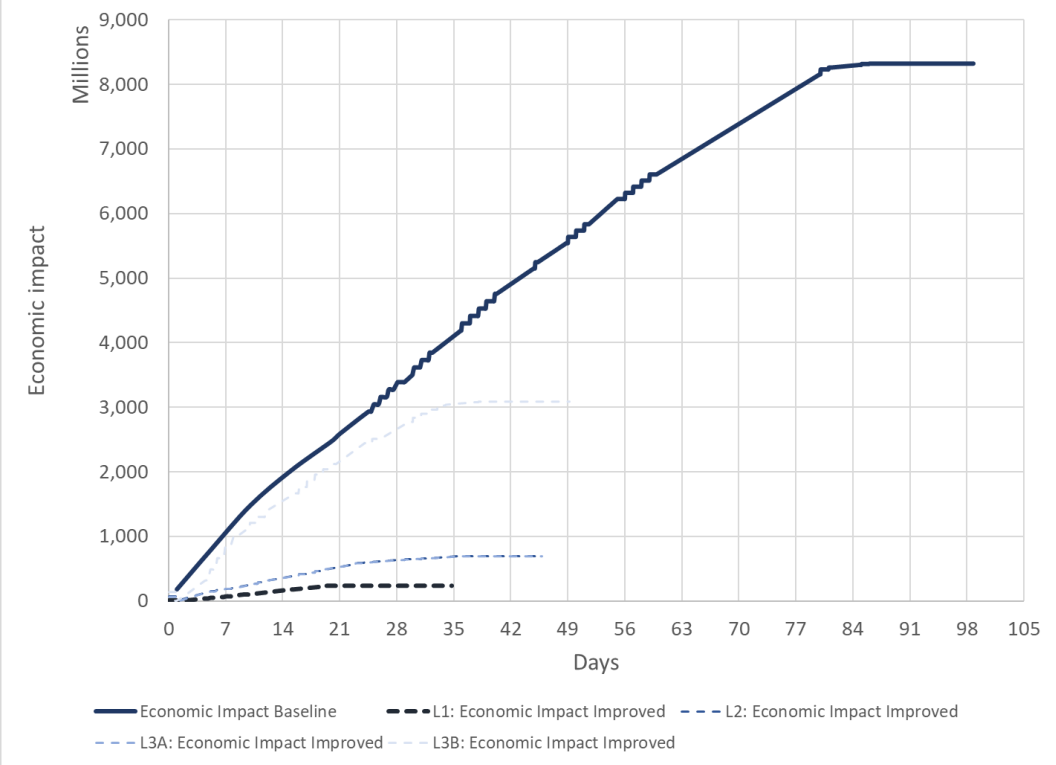


Figure 7: Long-Term SFZE Economic Impact Improvement



For the Long-Term improvement combinations, the capability to have the SPU Supply returned quickly and incorporate significant system strengthening as included in L1 provided the most benefit in terms of restoration times. Both L1 and L2 returned service to critical customers quickly, and L1 returned service more quickly to the entire system as observed with the return of service to more customers across the system as compared to the other Long-Term combinations. Having the emergency well supply available immediately in combinations L3A and L3B and then the SPU supply in 7 days plus the selective strengthening of key pressure zones and incorporation of backbone improvements to move water throughout the system returned service slightly slower than L1 and L2 but also met the PE-LOS goals at a lower cost than L1 and L2. When comparing L3A and L3B, the benefit to strengthening the BV 400 zone vs a full backbone shows that strengthening BV 400 provides more benefit for the rest of the water system due the large area that BV 400 covers. Given that the performance of the SPU supply system is out of the City of Bellevue's control, L1 and L2 were not considered to be viable options.

5.2 Mid-Term Improvement Combinations

Table 2 shows the improvement combinations for the Mid-Term PE-LOS goals, and Figure 8 and Figure 9 show the restoration curves for the CSZ earthquake while Figure 10 and Figure 11 show the restoration curves for the SFZE earthquake. The reduction in the economic impact with the Mid-Term improvements incorporated for the CSZ earthquake is shown in Figure 12 and in Figure 13 for the SFZE earthquake.

Table 2: Mid-Term Improvement Combinations

Combination	Supply	Facility Improvements		Pipe Improvements	Backbone System	Cost
M1	SPU Supply	Clyde Hill Cougar Mountain 1 Cougar Mountain 2 Cougar Mountain 3	Forest Hills Newport Parksite 670	Strengthening key zones (BV0400, FA0293, LH0520)	No backbone	$416M
M2	SPU Supply + Well Supply	Clyde Hill Cougar Mountain 1 Cougar Mountain 2 Cougar Mountain 3	Forest Hills Newport Parksite 670	Strengthening key zones (FA0293, LH0520)	Expanded Partial backbone[1]	$313M
M3	SPU Supply + Well Supply	Clyde Hill Cougar Mountain 1 Cougar Mountain 2 Cougar Mountain 3	Forest Hills Newport Parksite 670	Strengthening key zones (BV0400, FA0293, LH0520)	Expanded Partial backbone[1]	$416M

[1]Segments included in M2 and M3 Expanded Partial Backbone: A, B, G, L, M

Figure 8: CSZ Mid-Term Critical Customer Restoration Curve

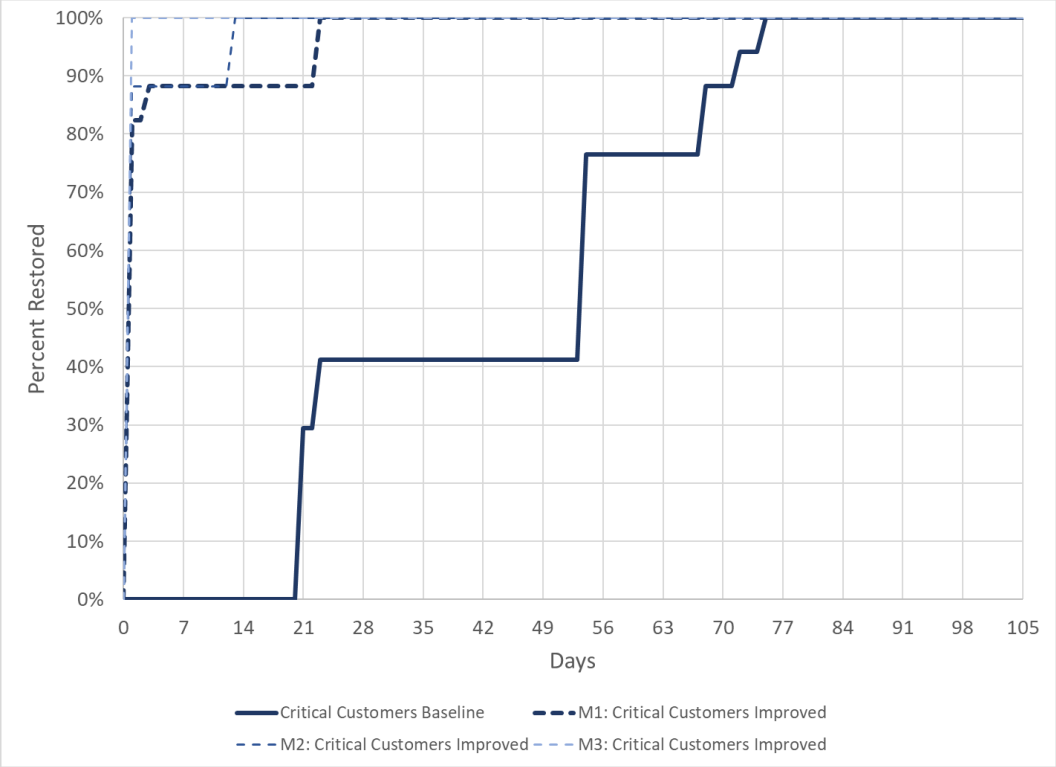


Figure 9: CSZ Mid-Term System-Wide Restoration Curve

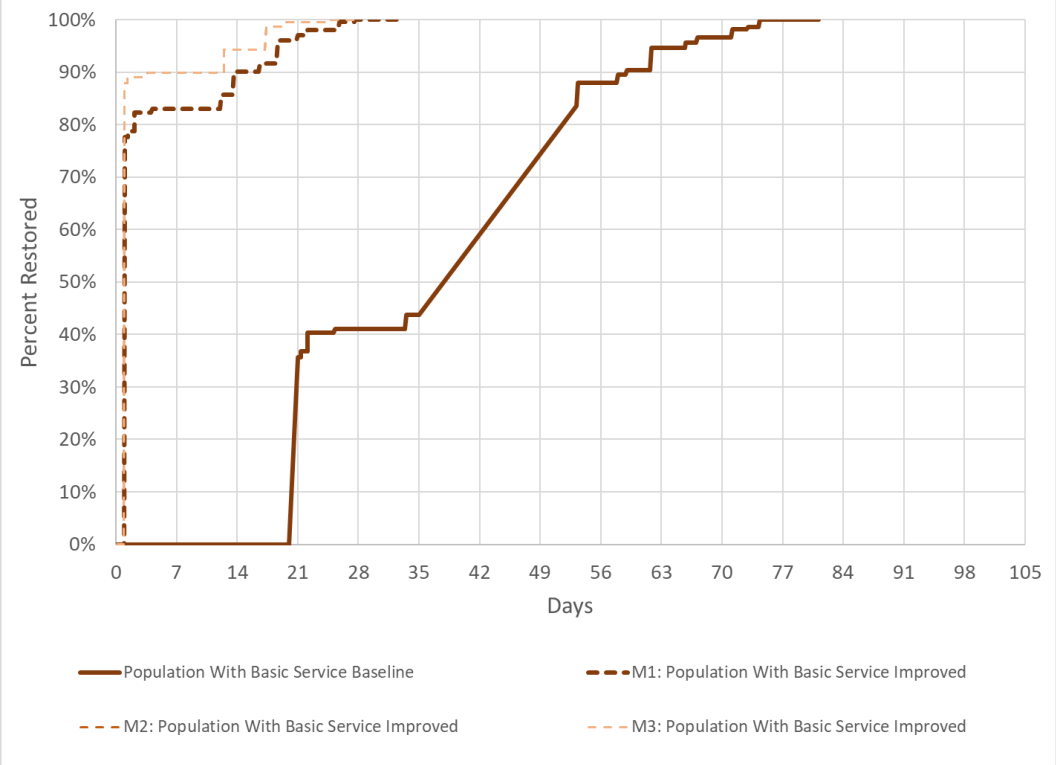


Figure 10: SFZE Mid-Term Critical Customer Restoration Curve

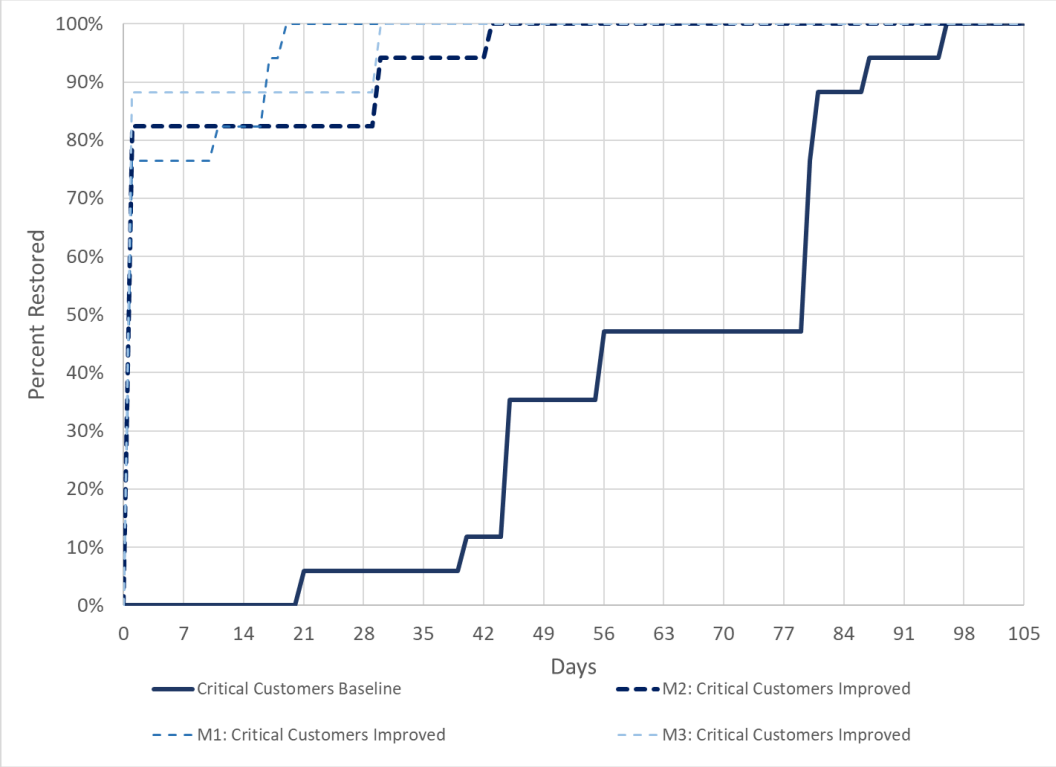


Figure 11: SFZE Mid-Term System-Wide Restoration Curve

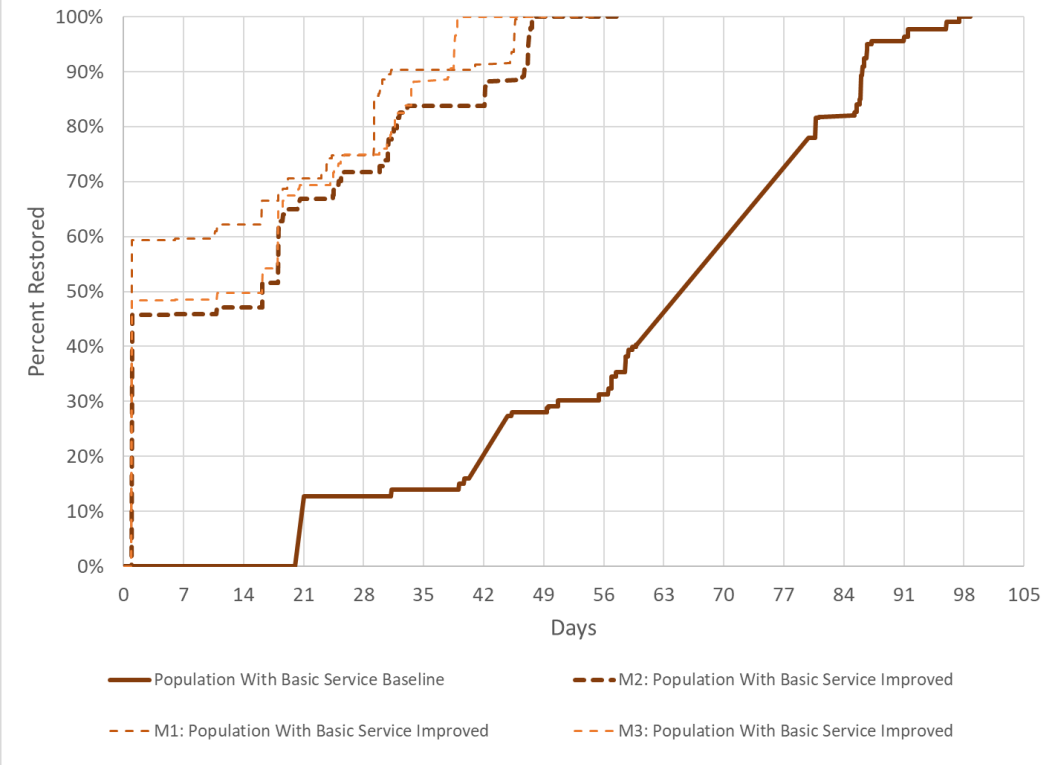


Figure 12: Mid-Term CSZ Economic Impact Improvement

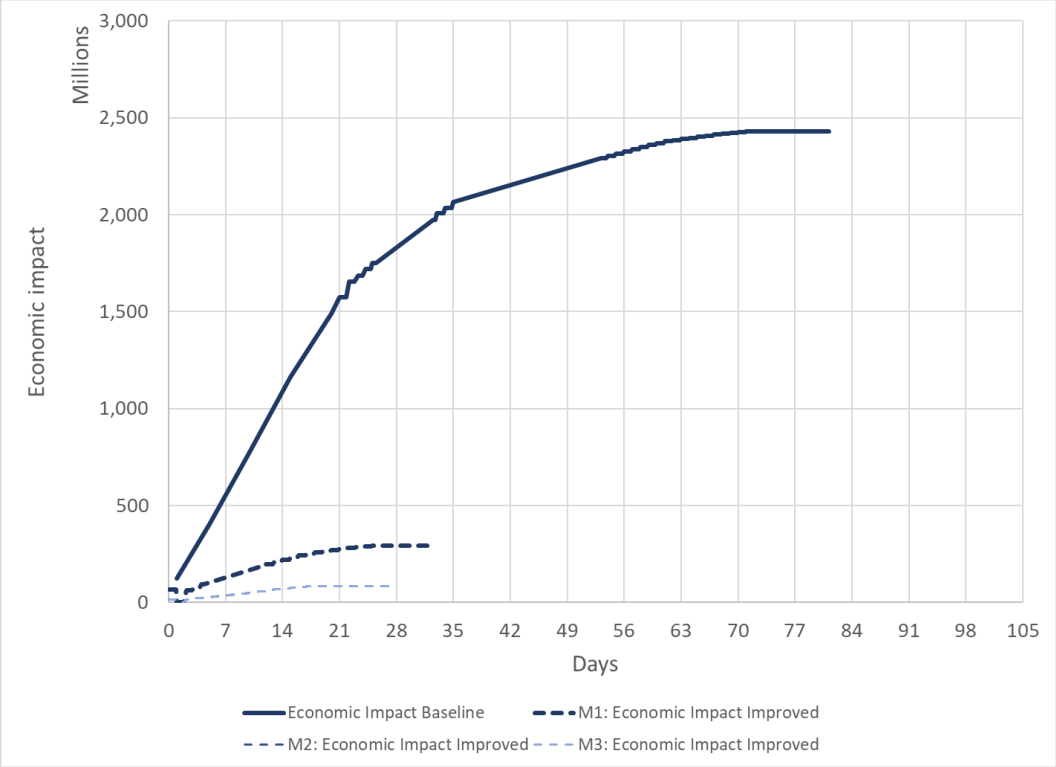
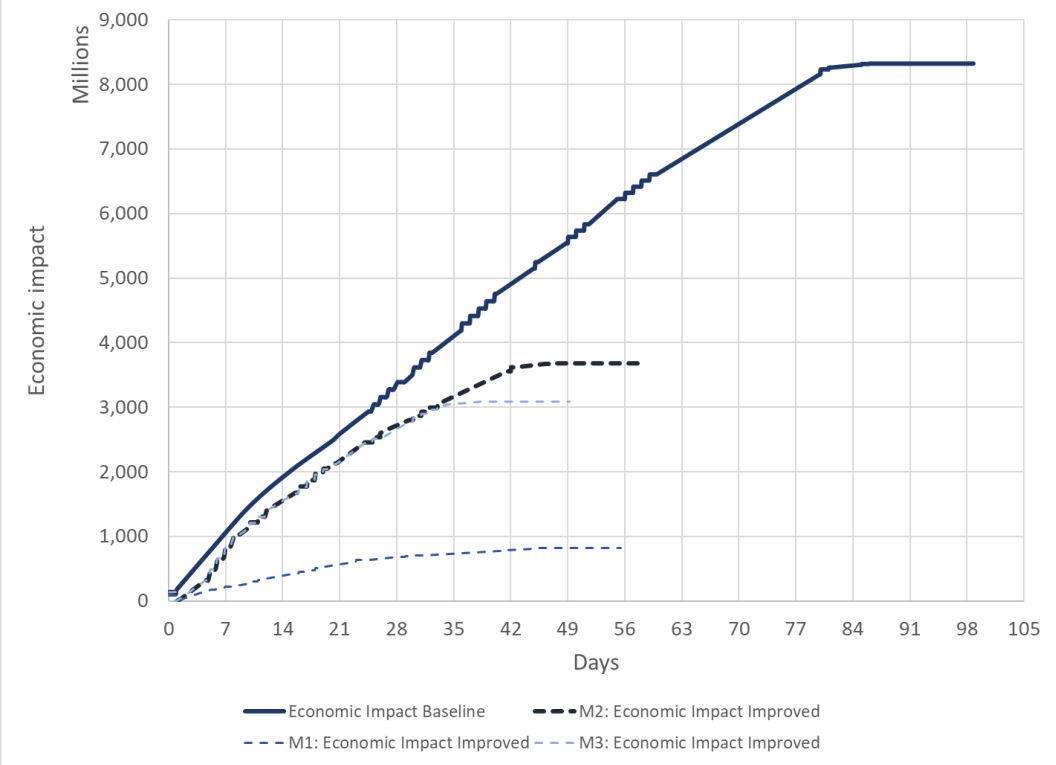


Figure 13: Mid-Term SFZE Economic Impact Improvement



5.3 Short-Term Improvement Combinations

A summary of the Short-Term improvement combinations is presented in Table 3, and the critical customers and system-wide restoration curves for the CSZ earthquake are shown below in Figure 14 and Figure 15 and in Figure 16 and Figure 17 for the SFZE earthquake. Figure 18 and Figure 19 show the reduction in the economic impact with the Short-Term improvements incorporated for the CSZ earthquake and the SFZE earthquake.

Table 3: Short-Term Improvement Combinations

Combination	Supply	Facility Improvements		Pipe Improvements	Backbone System	Cost
S1	Well Supply	Clyde Hill Cougar Mountain 1 Cougar Mountain 2	Cougar Mountain 3 Parksite	No Zone Strengthening	Partial backbone	$55M
S2	Well Supply	Cougar Mountain 1 Cougar Mountain 2	Cougar Mountain 3 Parksite	Strengthening BV400	No backbone	$147M
S3-CSZ	Well Supply	Cougar Mountain 1 Cougar Mountain 2	Cougar Mountain 3 Parksite	Strengthening LH520	No backbone	$231M
S3A-CSZ	Well Supply	Cougar Mountain 1 Cougar Mountain 2	Cougar Mountain 3 Parksite	Strengthening LH520 and BV400	No backbone	$338M
[1]Segments included in S1 Partial Backbone: A, B, L						

The improvement combinations shown in Table 3 were developed to compare the relative benefit that strengthening of select zones versus a partial backbone system. Water supply and facility improvements were the same for each combination, and the variation was the zone strengthening and use of a partial backbone system. The S3 and S3A combinations were also focused on assessing the benefit of additional zone strengthening for the CSZ earthquake.

Figure 14: CSZ Short-Term Critical Customer Restoration Curve

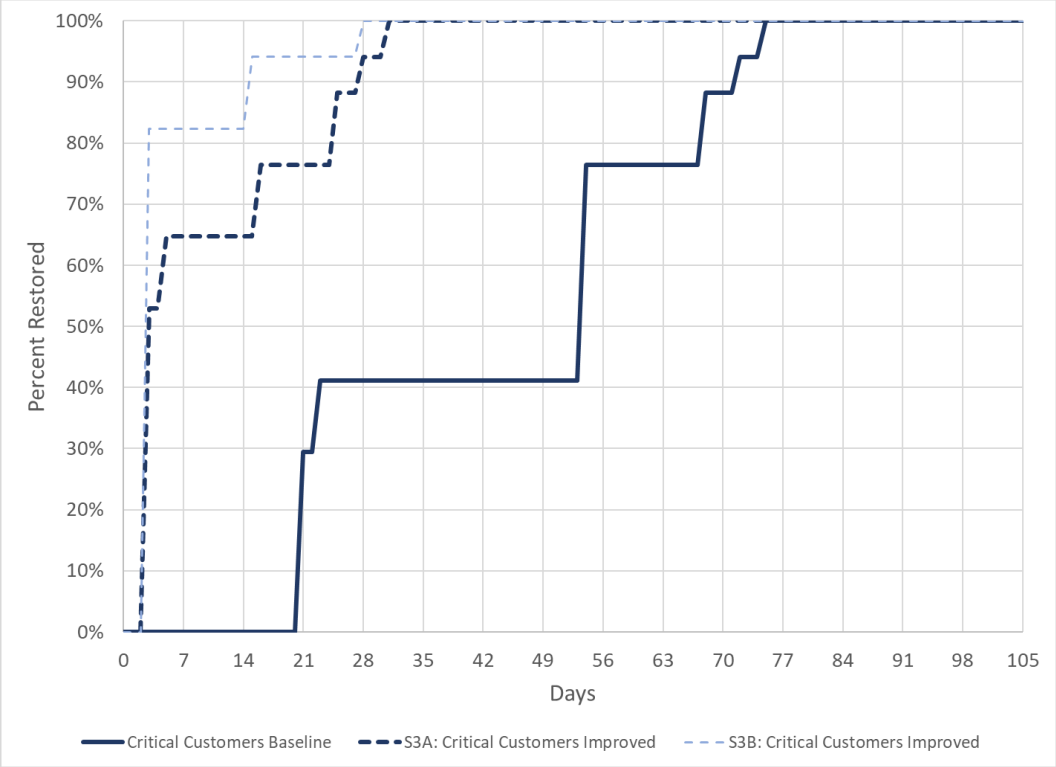


Figure 15: CSZ Short-Term System-Wide Restoration Curve

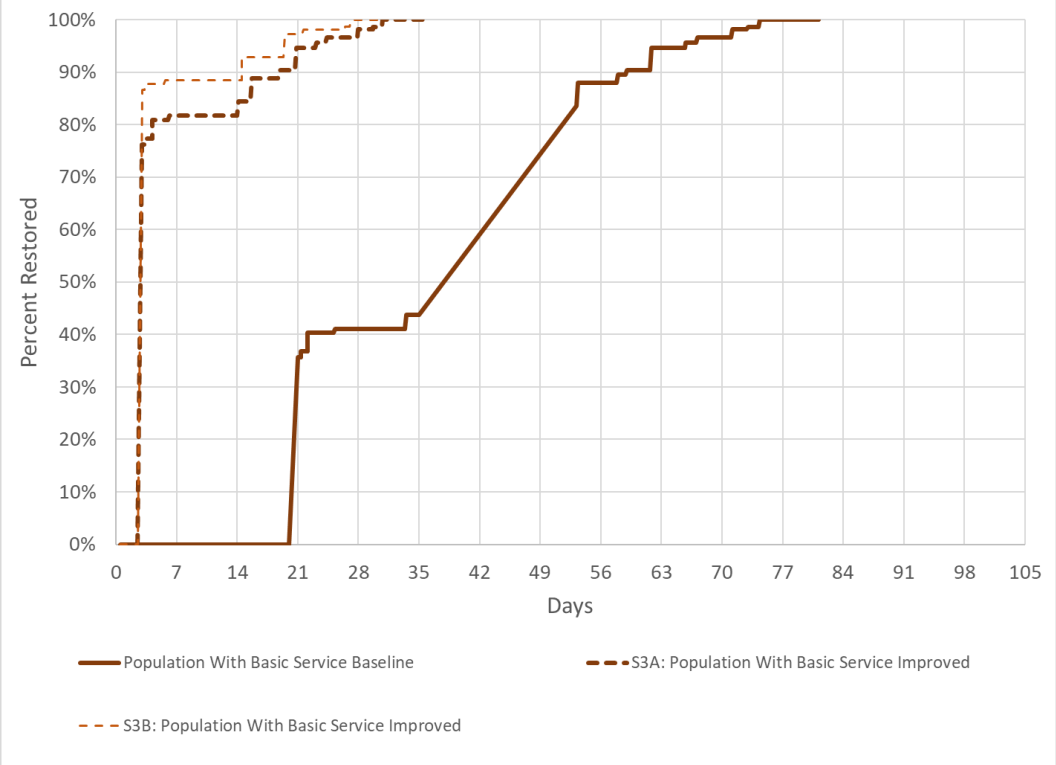


Figure 16: SFZE Short-Term Critical Customer Restoration Curve

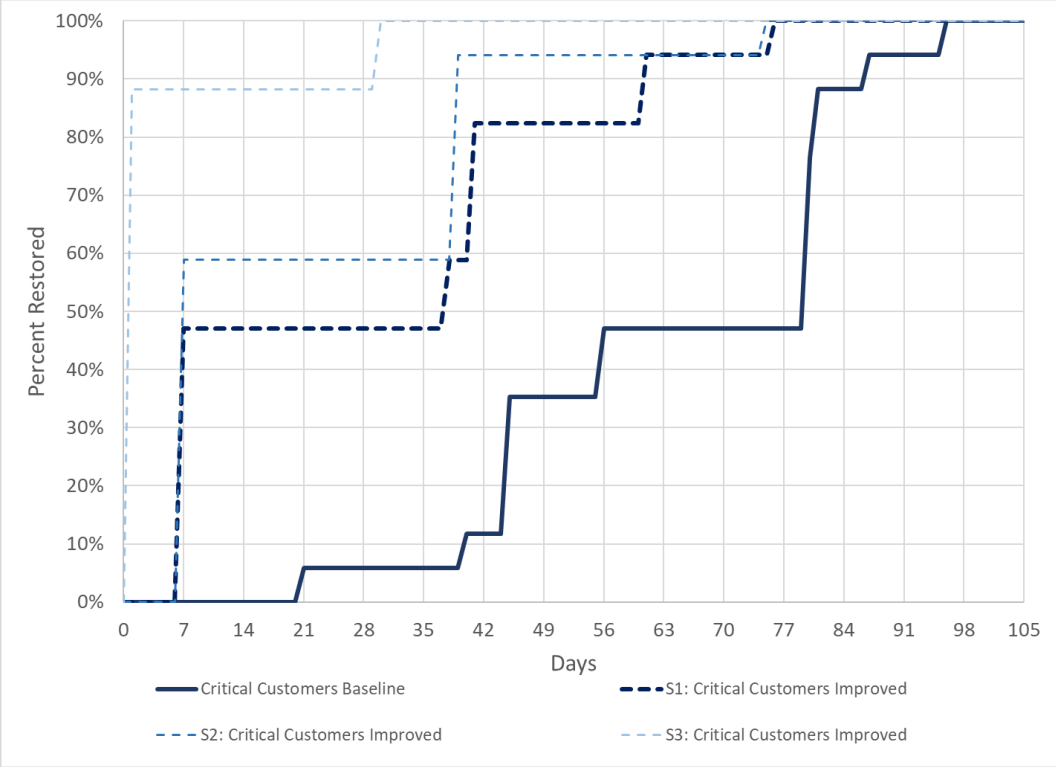


Figure 17: SFZE Short-Term System-Wide Restoration Curve

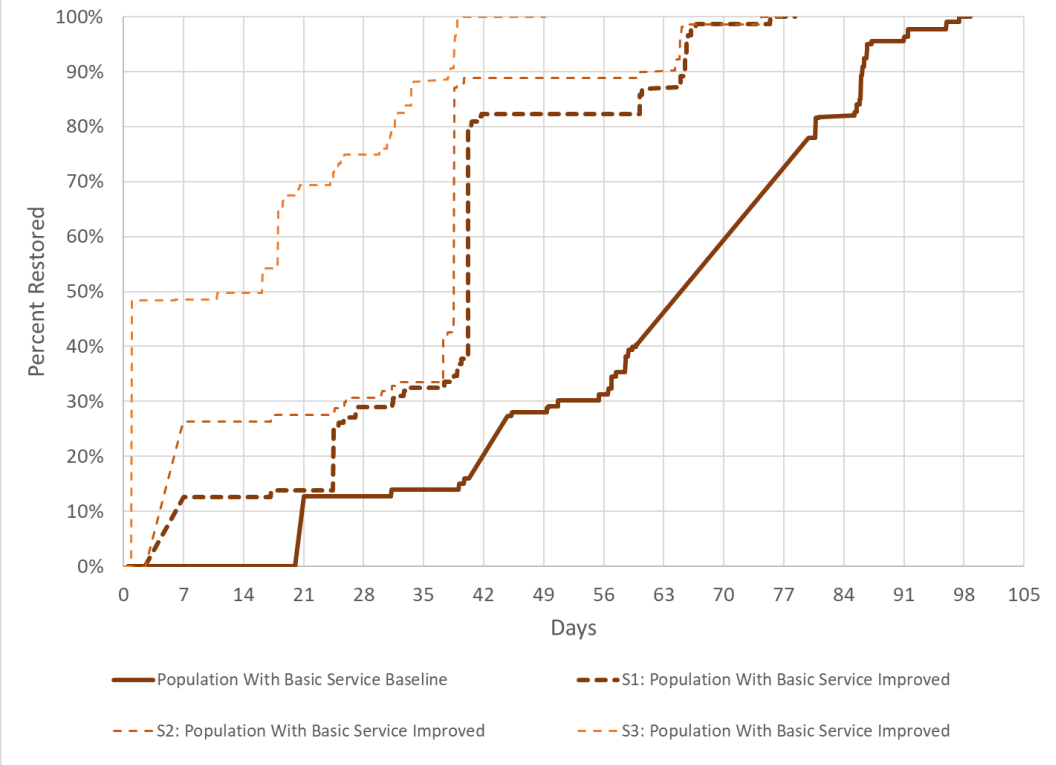


Figure 18: Short-Term CSZ Economic Impact Improvement

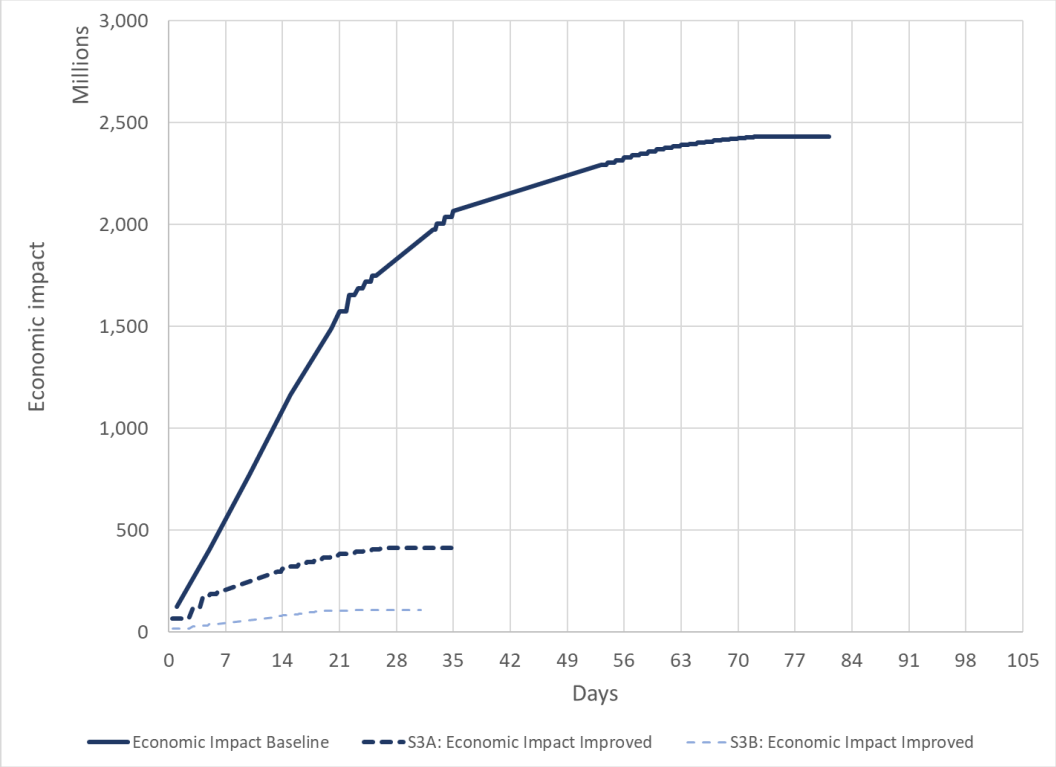
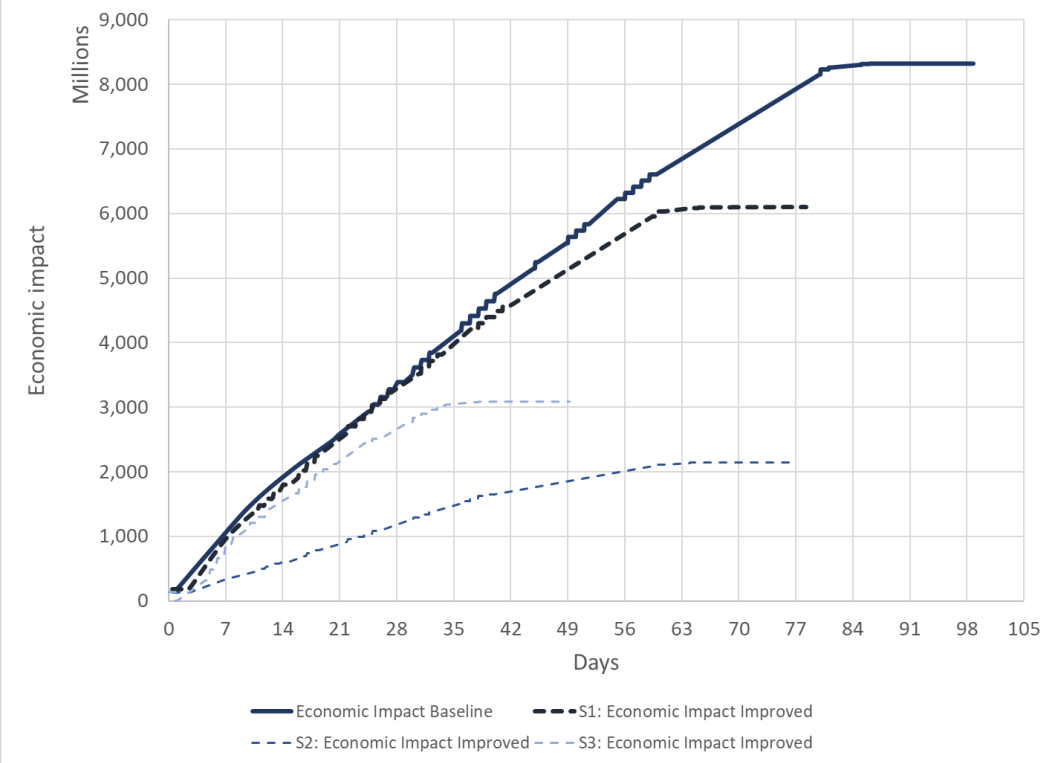


Figure 19: Short-Term SFZE Economic Impact Improvement



Comparing the Short-Term improvement combinations, S3 returned a greater percentage of service to critical customers and the overall water system more quickly but at a higher cost. At 42 days after the earthquake event, all combinations had returned over 80% of the service and by 75 days, all combinations had similar performance of returning service to customers.

6. Improvement Prioritization

To select and prioritize the improvements for the City, the Benefit/Cost ratio was calculated for each combination of improvements for the Long-Term, Mid-Term, and Short-Term horizons. An assessment of the common features of improvement combinations and the phasing potential was also reviewed to support the prioritization.

6.1 Benefit Cost Evaluation

Each of the combinations of improvements was evaluated on a Benefit/Cost Ratio perspective. The Benefit is calculated as the 100-year net present value (NPV) of the reduction in economic risk, and the Cost is the capital cost of the improvements.

To generate the Benefit portion of the Benefit/Cost ratio, the economic risk is calculated by taking the economic impact to the regional economy generated from the economic impact parameters developed as described in TM5: Economic Impact Parameters and multiplying it by the annual likelihood of occurrence of the seismic event (1/500 for CSZ and 1/800*0.5 for SFZE) to get the economic risk for each seismic event in $/year as shown in Equation 1.

Equation 1: Annual Risk Calculation

$$Annual\ Risk\ \left(\frac{\$}{year}\right) = Economic\ Impact\ from\ Seismic\ Event\ (\$) * \frac{1}{Earthquake\ Return\ Period\ (Years)}$$

Where:

Economic Impact from Seismic Event is calculated by the model using economic impact parameters defined in TM5.

Earthquake Return Period = 500 years for CSZ and 800/0.5 for SFZE-

The economic risk reduction associated with a specific improvement combination is calculated by taking the annual economic risk for both earthquake scenarios in the as-is state, and subtracting the annual economic risk for both earthquake scenarios after mitigation from implementing improvements as shown in Equation 2.

Equation 2: Risk Reduction Calculation

$$Risk\ Reduction\ \left(\frac{\$}{year}\right) = Annual\ Risk\ pre\ mitigation\ \left(\frac{\$}{year}\right) - Annual\ Risk\ post\ mitigation\ \left(\frac{\$}{year}\right)$$

The NPV of the risk reduction benefit is then calculated using the following NPV input parameters:

- Discount Rate = 5.0%
- Inflation Rate = 2.0%
- Project Lifecycle = 100 years

Use of the above NPV parameters results in a factor of 32.1 that is multiplied by the annual economic risk (cost) to obtain the 100-year NPV.

Using the calculation of the economic risk reduction for both the CSZ and the SFZE earthquake events, the Benefit/Cost ratio is calculated by dividing the 100-year NPV of the combined economic risk reduction (benefits) generated by implementing the identified improvements by the capital cost of the improvements. Benefit/Cost ratios that are greater than 1 are considered improvements that will pay for themselves from a risk perspective, ratios less than one would require additional justification outside of just risk mitigation. For the seismic improvements described in Section 5, all were developed with a focus on achieving the target PE-LOS goals. When evaluating these improvements against each other, the Benefit/Cost Ratio can be used to determine which of the improvements developed to meet the PE-LOS goals provides the most benefit for the money spent.

A summary of the Benefit/Cost calculations for each of the assessed improvement combinations is presented in Table 4. The Short-Term combinations all showed Benefit/Cost ratios greater than 1, and the Long-Term and Mid-Term Benefit/Cost ratios were slightly lower and less than 1.

The City's existing renewal and replacement program will eventually replace all of the asbestos cement and cast iron pipe in use in the distribution system, so pipe replacement that is targeted at those pipes is not necessarily additive to the current projected spending that is incorporated into water rates. Table 5 shows a comparison of the total cost for each improvement combination and the cost for the improvement combination if replacement of AC and CI pipe is excluded.

Table 4: Improvement Combination Benefit/Cost Summary

Improvement Combination	Total Cost to Achieve	Bellevue Supply Improvements	Bellevue Share of SPU Transmission Improvements	Bellevue Facilities	Bellevue Distribution System	Total Length of Pipe Replacement, ft	Seismic Risk Reduction (Cumulative), $/yr	Total Benefit /Cost Ratio
S1	$55 M	$20 M	$0	$19 M	$16 M	32,732	$4.4 M	2.6
S2	$147 M	$20 M	$0	$17 M	$110 M	244,403	$7.7 M	1.7
S3	$231 M	$20 M	$0	$19 M	$192 M	452,598	$7.3 M	1.0
S3A	$338 M	$20 M	$0	$17 M	$302 M	697,001	$4.6 M	0.4
M1	$416 M	$0	$45 M	$39 M	$332 M	754,085	$9.4 M	0.7
M2	$313 M	$20 M	$15 M	$39 M	$239 M	540,967	$ 7.2 M	0.7
M3	$416 M	$20 M	$15 M	$39 M	$342 M	771,950	$ 8.0 M	0.6
L1	$847 M	$0	$45 M	$65 M	$737 M	1,695,475	$ 9.9 M	0.4
L2	$457 M	$0	$45 M	$48 M	$365 M	825,021	$ 9.5 M	0.7
L3A	$447 M	$20 M	$15 M	$48 M	$365 M	825,021	$ 9.5 M	0.7
L3B	$379 M	$20 M	$15 M	$48 M	$297 M	663,650	$ 7.5 M	0.6

Notes:

- Each Improvement combination is the total cost to achieve that goal, as if no prior improvements had been completed. This means that the costs to achieve a specified long-term goal are all inclusive, and any previous improvements that are part of that improvement can be removed in order to get the incremental cost of the improvement combination.

Table 5: Comparison of cost to replace all pipe vs. only pipe other than AC and CI

Improvement Combination	Including Cost for All Pipe to be Replaced		Excluding Cost to Replace AC and CI Pipe	
	Total Improvement Combination Cost	Bellevue Distribution System	Total Improvement Combination Cost	Bellevue Distribution System
S1	$55 M	$16 M	$27 M	$1 M
S2	$147 M	$110 M	$40 M	$14 M
S3	$231 M	$192 M	$50 M	$24 M
S3A	$338 M	$302 M	$64 M	$38 M
M1	$416 M	$332 M	$121 M	$50 M
M2	$313 M	$239 M	$98 M	$38 M
M3	$416 M	$342 M	$111 M	$50 M
L1	$847 M	$737 M	$198 M	$101 M
L2	$457 M	$365 M	$132 M	$53 M
L3A	$447 M	$365 M	$122 M	$53 M
L3B	$379 M	$297 M	$113 M	$43 M

Notes:

- Each Improvement combination is the total cost to achieve that goal, as if no prior improvements had been completed. This means that the costs to achieve a specified long-term goal are all inclusive, and any previous improvements that are part of that improvement can be removed in order to get the incremental cost of the improvement combination.

6.2 Recommended Improvements

Based upon a review of Benefit/Cost ratio information shown in Table 4, improvements that provided the most benefit were identified, and an implementation strategy from Short-Term to Mid-Term to Long-Term was developed to achieve the most benefit at the least cost, while achieving the target PE-LOS goals. The selected combinations included S1 for Short-Term, M2 for Mid-Term, and L3A for Long-Term. Figure 20 shows the implementation strategy by timeframe, demonstrating how to achieve the long-term goals identified in combination L3A. The improvements are shown with an incremental approach in Figure 20 to highlight the additive nature of the improvements to achieve the improvements selected for the Long-Term L3A combination and how the PE-LOS goals are met for each horizon. By implementing the improvements through the approach outlined in Figure 20, the City will reduce economic risk by executing selected improvements for supply resiliency as well as facility and piping improvements.

Figure 20: Improvement Implementation by Combination

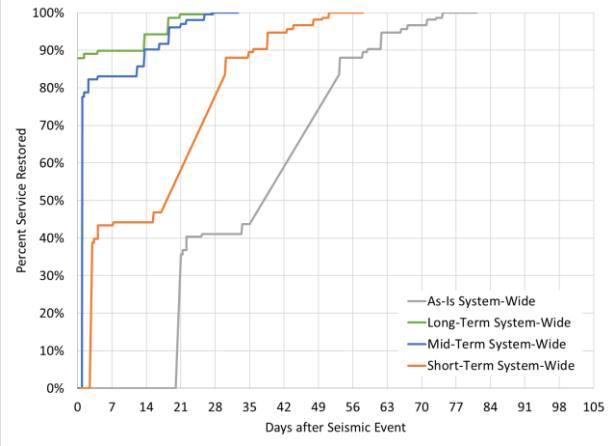
Category	Short-Term (S1)	Mid-Term (M2)	Long-Term (L3A)
Supply Improvements	Emergency Wells	7-day SPU Supply	
Facility Improvements	Clyde Hill Cougar Mountain 1 Cougar Mountain 2 Cougar Mountain 3 Horizon View 2 Parksite	Forest Hills Newport 670	Woodridge
Distribution Strengthening		LH 520 FA 293	BV 400 SS 850 EG 330
Backbone System	Partial Backbone		Expanded Partial Backbone

While only five backbones were identified as being required to achieve the target PE-LOS goals, there is still some value in implementing the other resilient pipe backbone routes evaluated. However, unless backbones are mostly isolated from the rest of the system, they do not provide value until all the connecting valves can be closed, which may be more time consuming than repairing pipe breaks and leaks within the connected piping and zones. As a result, the City could evaluate on a case-by-case basis the value if adding additional backbone routes other than the five identified, but the improvements shown in Figure 20 should be prioritized.

Figures 21 and 22 show the system-wide and critical service restoration curves for the as-is system and each of the three improvement combinations. Figure 23 shows the economic impact for the as-is system and each of the three improvement combinations.

Figure 21: System-Wide Service Improvement with Selected Combinations

Cascadia Subduction Zone Mw 9.0



Seattle Fault Zone East Mw 6.6

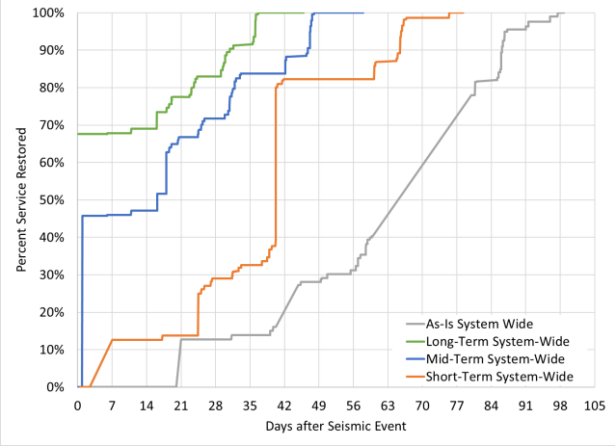
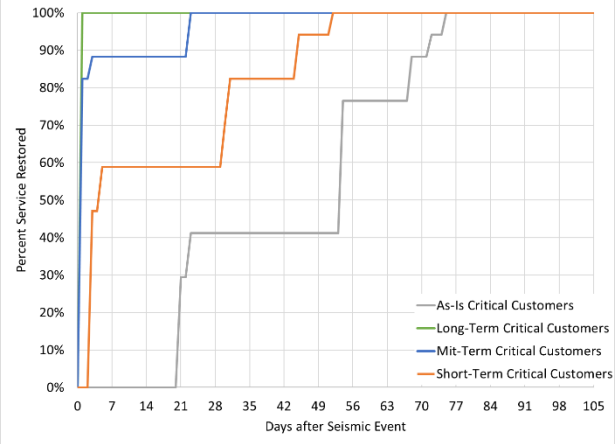


Figure 22: Critical Customer Service Improvement with Selected Combinations

Cascadia Subduction Zone Mw 9.0



Seattle Fault Zone East Mw 6.6

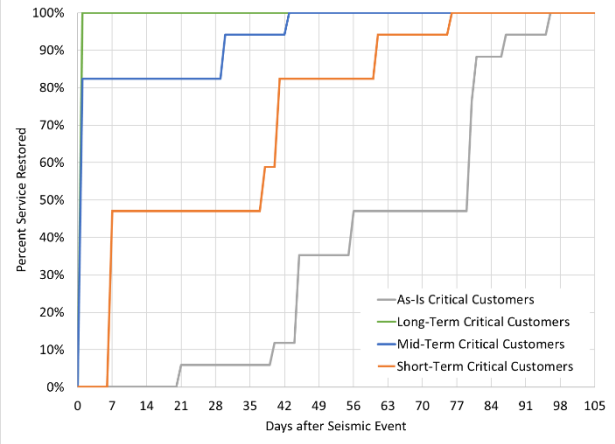
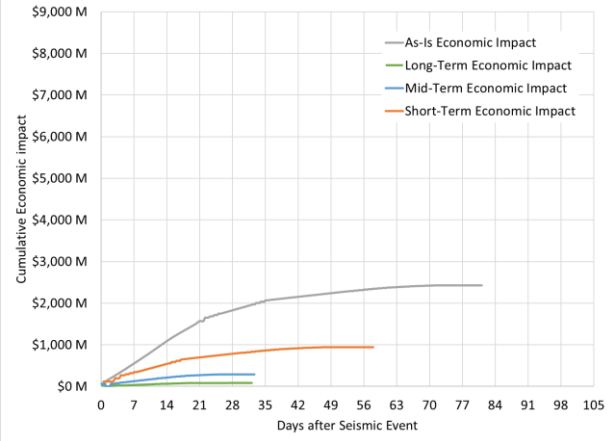
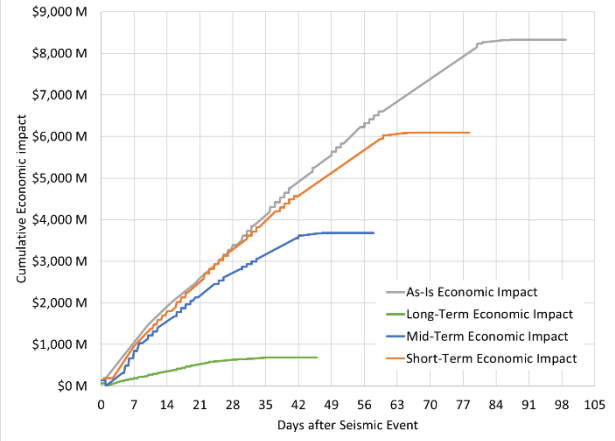


Figure 23: Economic Impact Improvement with Selected Combinations

Cascadia Subduction Zone Mw 9.0



Seattle Fault Zone East Mw 6.6



6.3 Improvement Implementation Timeframe

The City will decide the implementation timeframe for the improvements to achieve the PE-LOS goals, once adopted. As a general guidance, it is assumed that most short-term improvements can be implemented in 10 years, with the exception of the emergency well improvements which are likely to take 15 years. Mid-term improvements can likely be accomplished in 25 to 30 years, primarily due to cost constraints. Long-term improvements are assumed to be achievable in 40 to 50 years.

Once the city has incorporated the proposed improvements into the water system rate model, a more definitive implementation timeframe can be developed.

Attachment A: Improvement Combination Detail Matrix

Improvement Combination	L1	L2	L3A	L3B	M1	M2	M3	S1	S2	S3-CSZ	S3A-CSZ
SPU Supply (Restoration Time)	1 day	1 day	7 days	7 days	1 day	7 days	7 days	N	N	N	N
Emergency Wells at 9 MGD	N	N	Y	Y	N	Y	Y	Y	Y	Y	Y
Pressure Zone											
BV0400	Y	Y	Y	N	Y	N	Y	N	Y	N	Y
EG0300	Y	Y	Y	Y	N	N	N	N	N	N	N
FA0293	Y	Y	Y	Y	Y	Y	Y	N	N	N	N
LH0520	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y
SS0850	Y	Y	Y	Y	N	N	N	N	N	N	N
All other Zones	Y	N	N	N	N	N	N	N	N	N	N
Backbones											
A	N	Y	Y	Y	Y	Y	Y	Y	N	N	N
B	N	N	Y	Y	N	Y	Y	Y	N	N	N
G	N	Y	Y	Y	N	Y	Y	N	N	N	N
L	N	Y	Y	Y	N	Y	Y	Y	N	N	N
M	N	N	Y	Y	N	Y	Y	N	N	N	N
All other Backbones	N	N	N	Y	N	N	N	N	N	N	N
Pump Stations											
Clyde Hill	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N
Cougar Mountain 1	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cougar Mountain 2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cougar Mountain 3	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Forest Hills	Y	Y	Y	Y	Y	Y	Y	N	N	N	N
Lake Hills (Crossroads)	Y	N	N	N	N	N	N	N	N	N	N
NE 40th Reservoir PS	Y	N	N	N	N	N	N	N	N	N	N
Newport	Y	Y	Y	Y	Y	Y	Y	N	N	N	N
Parksite	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Woodridge	Y	Y	Y	Y	N	N	N	N	N	N	N
670	Y	Y	Y	Y	Y	Y	Y	N	N	N	N
Legend:	Purple = Selected Improvement Combination				Blue = Included Improvements				Gray = Not Included		

Bellevue Emergency Water Supply Planning

City of Bellevue

Engineering Support

December 20, 2019

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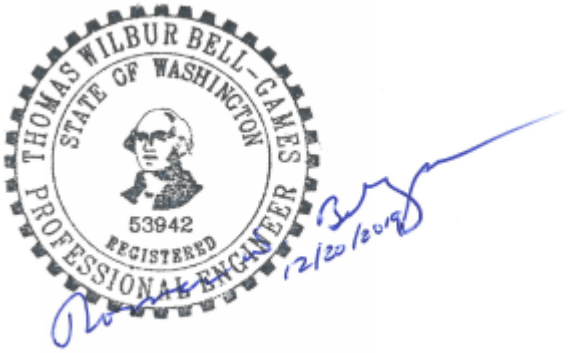
CERTIFICATION

Prepared under the Supervision of:



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I hereby certify that the Bellevue Emergency Water Supply Planning Report was prepared by me or under my direct supervision and that I am a duly registered Engineer under the laws of the State of Washington. The following are primary contributors to this report.

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Appendix F. Emergency Water Needs Assessment F-1
Appendix G. Bellevue Emergency Water Alternatives Analysis G-1

Abbreviations

CDD	chlorine demand and decay
City	City of Bellevue
CWA	Cascade Water Alliance
DBP	disinfection by-product
DOH	Washington Department of Health
Ecology	Washington Department of Ecology
FEMA	Federal Emergency Management Agency
GDP	gross domestic product
Golder	Golder Associates
gpm	gallon(s) per minute
KCWD	King County Water District
L	liter(s)
LCR	Lead and Copper Rule
MCL	maximum contaminant level
mg	milligram(s)
mgd	million gallons per day
POD	point of distribution
SCADA	supervisory control and data acquisition
SOP	standard operating procedure
SPU	Seattle Public Utilities
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
VOC	volatile organic compound
WAC	Washington Administrative Code
WHO	World Health Organization

Executive Summary

The City of Bellevue (City) is in the process of developing a master plan for providing an emergency source of drinking water in the event of a disruption to the water currently supplied by Seattle Public Utilities (SPU). This report provides background for this effort.

The type of event that would result in a complete loss of drinking water would likely have impacts to many sectors, including wastewater collection/treatment, communications, transportation, and power, among others. The focus of this current study is solely on drinking water.

Existing potential sources have been reviewed and include a group of four wells for which the City has municipal water rights and Washington State Department of Health (DOH) approval for use as emergency supply. These wells have been characterized with respect to capacity, water quality, and potential use in supplementing supply during a water supply outage. These wells include former King County Water District 97 Wells Nos. 3, 5, 6, and 7. Their general locations are presented in Figure EX-1.

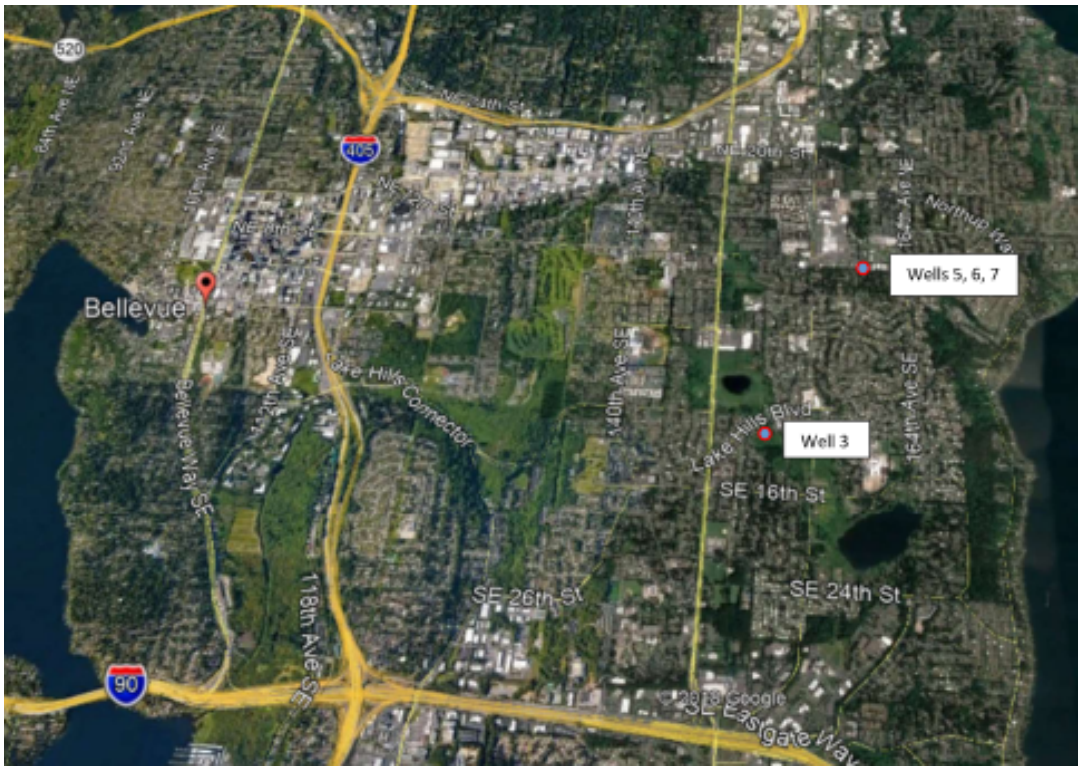

Figure EX-1. Existing Wells

A well condition assessment was performed which reviewed limited available records and direct observation of the wells to the extent possible. Well capacities and testing data from previous studies have been summarized as part of this assessment. Near Wells Nos. 5, 6, and 7 ("Crossroads" Wells), a plume of volatile organic compounds (VOCs) has been detected in a shallow unconfined aquifer and soils near the ground surface, due to an underground gasoline storage tank, removed in 1989. The wells are regularly sampled to monitor for impacts to the deeper, confined aquifer. Detailed information about this is summarized in the assessment.

An aquifer characterization and well yield assessment was performed. This analysis characterizes the nature and hydraulic performance of the aquifer(s) that might potentially be used for groundwater sources. Two scenarios were evaluated with respect to potential wells: a single well and a set of four wells at each of multiple well sites. The well capacity evaluation predicts pumping of 500 to 850 gpm from a single well with drawdown less than the estimated available drawdown. Additional hydrogeological investigations including test well drilling, step-pumping tests, and longer duration pumping tests are recommended to confirm the preliminary estimates for well and wellfield capacity.

A related analysis was performed on the estimated aquifer-stream interface. This assessment presents an initial assessment of the potential effects on surface water flow resulting from pumping theoretical emergency supply wells for up to 100 days in an emergency situation. This focuses on Kelsey Creek (not believed to be in hydraulic continuity with the aquifer) and Wilkins Creek (assumed to be in hydraulic continuity with the aquifer). The predicted depletion in Kelsey Creek is estimated to be about 3.7 percent of the low-flow streamflow for a single well and up to 16 percent for a four-well wellfield. Collection of additional data is recommended to refine the conceptual hydrogeological model of the aquifer and stream system in order provide more reliable estimates of potential stream depletion and wellfield yield.

System-wide economic losses due to a potential complete water outage have been reviewed from the perspective of commercial users (lost business activity), individuals (lost wages), and the City itself (lost tax and rate collections). Lost business activity represents the greatest numerical loss at an estimated $1.4 billion after 30 days and $2.9 billion after 60 days. Recovery taking longer than 60 days assumes that a portion of the population would leave the region.

The following three ground water supply alternatives have been evaluated for supplementing the supply during an outage:

1. Provide drive-up/walk-up emergency points of distribution (PODs)
2. Provide ability to temporarily connect to the distribution system in the event of an outage
3. Provide permanent connections to the distribution system

Alternative 1 is appropriate for residential uses and may involve approximately 6 sites to allow for some system-wide accessibility. Alternative 2 is suitable for addressing the needs of critical users such as healthcare facilities, for example, a well adjacent to a hospital. Alternative 3 is feasible within the withdrawal limits of the City’s existing municipal water rights but is not recommended.

Water quality has been reviewed with respect to both the water itself and the potential implications of blending this groundwater with the treated surface water from SPU. Treatment for iron and manganese is recommended if the emergency supply water is sent into the distribution system. Prior to using the emergency supply in this manner for extended periods, additional water stability analysis should be performed to determine the potential for corrosion, metals release, aesthetic changes, or deposition of solids within the pipelines.

Preliminary discussions with the Washington State Department of Ecology (Ecology) indicate that approval for new emergency water rights, in which groundwater withdrawal occurs only during an emergency, is feasible. Full treatment, including disinfection, is recommended for Alternative 2. The City has the option of providing disinfection for Alternative 1. Because of a likely discrepancy between public expectation of system recovery and the potential duration of an extensive outage,

public outreach and messaging prior to and during a disruptive event will be required to effectively manage these expectations. This also applies to water quality.

Benchmark studies and policies of regional entities including planning commissions, utilities, and state agencies were reviewed for consideration in developing recommendations for emergency supply goals. Using a discounted winter average daily demand as an estimate of essential water demand, a shortfall of approximately 9 million gallons per day (mgd) is estimated in the event of a full outage. To improve the likelihood of distribution of emergency supplies of water throughout the City, a geographically distributed series of wells used as PODs are recommended. Estimated land and facility requirements recommended by the Federal Emergency Management Agency (FEMA)/ United States Army Corps of Engineers (USACE) IS-26, *Guide to Points of Distribution* (2008) are presented in this report. Based on the approved capacities of the existing emergency supply wells, approximately six additional wells would be required if a goal of providing up to 9 mgd in supplemental capacity is established.

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1 Introduction and Background

The City of Bellevue (City) is located in the greater Seattle-Tacoma metropolitan area within King County, Washington. Bellevue receives all drinking water from Seattle Public Utilities (SPU). SPU water is sourced from the Tolt and Cedar Rivers. Before becoming part of the City's system, several water districts in the City operated their own wells and surface water treatment facilities. The City assumed control of all the local water districts and, still owns several of the wells. All water is now purchased and the City has no treatment facility.

The City recognizes that the transmission mains, distribution system, storage, and other facilities are vulnerable to several potentially disruptive events that could result in a short- or long-term drinking water outage for Bellevue. In an effort to improve overall resiliency of the water supply, the City has initiated a review of options for developing an emergency source of supply.

This analysis includes high-level evaluation of several items including:

- anticipated water demand;
- potential shortfall in supply following a disruptive event;
- potential resulting economic loss associated with a water outage;
- and a review of alternatives for providing emergency supply of water.

Additional analysis includes a preliminary evaluation of water rights associated with the existing wells, many of which are not currently functional.

Preliminary discussions with the Washington State Department of Ecology (Ecology) indicate that the pursuit of emergency water rights may be the most appropriate approach to gaining additional sources of emergency water supply sufficient to meet anticipated needs in the event of a major interruption in drinking water supply.

The following are supporting technical memoranda developed as part of the evaluation of sources for emergency water. Each is a separate appendix within this report:

- Golder Associates (Golder), *Well Condition Assessment*, 2018
- Golder, *Aquifer Characterization and Well Yield Assessment*, 2018
- Confluence Engineering Group, *Water Quality Analysis Technical Memorandum*, 2018
- HDR, *Economic Losses Due to Potential Water Outage*, 2018
- Golder, *Aquifer-Stream Delineation and Assessment*, 2019
- HDR, *Emergency Water Needs Assessment*, 2019
- HDR, *Bellevue Emergency Water Alternatives Analysis*, 2019

2 Existing Water Sources

The City uses water from SPU for its regular potable water supply. The City also has four active wells: Samena Well No. 3 and Crossroads Wells Nos. 5, 6, and 7, which have been approved by the Washington Department of Health (DOH) as emergency sources. These are former King County Water District (KCWD) 97 wells that have been incorporated into the City.

Six additional wells from KCWDs 68 and 97 and the former Washington Water Service Company were also incorporated into the City. These are on property no longer owned by the City.

Two surface water sources on Lake Washington from KCWD 68 and at least one source on Lake Sammamish from KCWD 97 are believed to no longer have active water rights.

2.1 Existing Well Condition Assessment

In early 2018, Golder conducted a well condition assessment, based primarily on review of well logs, water quality reports, water district records, and other documentation. The four wells for which DOH has approved an emergency source are listed in Table 1. These wells were drilled in the late 1950s and early 1960s, and are regularly sampled by the City for water quality analysis.

Table 1. Existing Wells with DOH-Recognized Water Rights

Well		DOH Qi		Notes
KCWD 97 Well 3	Samena Well	850 gpm	1.22 mgd	100 gpm capacity pump
KCWD 97 Well 5	Crossroads Well	500 gpm	0.72 mgd	No pump
KCWD 97 Well 6	Crossroads Well	600 gpm	0.86 mgd	No pump
KCWD 97 Well 7	Crossroads Well	700 gpm	1.01 mgd	100 gpm capacity pump

Qi = instantaneous flow
gpm = gallons per minute
mgd = million gallons per day

Short-term pumping tests in 2013 indicated that the Crossroads Wells Nos. 5, 6, and 7 could be continuously pumped at the water right maximum instantaneous withdrawal for at least short-term periods (days to weeks). Samena Well No. 3 pumping was restricted by materials filling the screen. Longer-term well capacity is uncertain based on current conditions.

Sanitary surface seals have been installed at all four of these wells.

Inspections of the wells completed in 2008 indicate that all well screens and casings are encrusted or scaled to varying degrees, and the well screens are partially to completely backfilled with sand and/or scale. The well screen in Well 3 appears to be completely filled with sand and/or scale.

Pumping tests completed in 2013 indicated that the wells had varying amounts of turbulent flow losses, which result in greater than anticipated drawdown during pumping. The relatively close proximity of Wells Nos. 5, 6, and 7 may result in interference drawdown and may limit pumping capacity when more than one well is pumped at the same time. This may result in an inability to pump at the full water right capacity except for a very short period of time. It may be possible to site new wells under the existing rights a bit further away depending on the original water right applications with respect to place of withdrawal.

All four wells have elevated levels of iron. Manganese levels are near the secondary maximum contaminant level (MCL) of 0.050 milligram per liter (mg/L) in Wells Nos. 5, 6, and 7 and above the secondary MCL in Well 3. Observations made by KCWD 97 when the wells were in operation suggest that iron bacteria may be present.

In the areas of Wells Nos. 5, 6, and 7, a 10,000-gallon leaking underground storage tank was removed in 1989. A vapor extraction system was operated at the site between 1990 and 1999. Measurable free product has not been detected at the site since 2003. Styrene and toluene were detected at Well 6 in a 2008 volatile organic compound (VOC) sample. Toluene was detected in one sample at Well 7 collected in August 2008. Although specific sampling events have occurred at different times for individual wells in this group, no additional VOCs have been detected in the Crossroads wells during sampling after 2008 through 2016.

A group of 16 shallow (<40’ deep) monitoring wells are installed for the purpose of vapor monitoring and detecting any VOC movement in the soil or perched groundwater.

2.2 Aquifer-Stream Delineation and Assessment

A general assessment was performed on the interface between surface water and groundwater in the area with the goal of assessing the potential impact of pumping from the City’s groundwater wells on surface water flow. The assessment focuses on the effects of pumping the four KCWD 97 wells (Wells Nos. 3, 5, 6, and 7) or new similarly located and constructed wells. The assessment focuses on two areas of surface water: Kelsey Creek, located west of Wells Nos. 5, 6, and 7, and tributary flow to Lake Sammamish from springs and small streams on the hillside west of Lake Sammamish, east of the KCWD 97 wells.

The assessment evaluated the following scenarios in desktop simulations based on known information:

- Pumping a single well at rates ranging from 500 to 850 gallons per minute (gpm)
- Pumping a four-well wellfield with a combined pumping rate of 2,600 gpm
- Evaluating the sensitivity of the predicted results to changes in the input parameters

Depending on distance and hydrogeological conditions, pumping can result in a decrease in stream flow through interception of groundwater that would otherwise discharge to a surface water or by inducing leakage from the stream or lake into the groundwater.

Total stream depletion over the reach of Kelsey Creek was modeled during 100 days of pumping (the assumed maximum emergency pumping duration) followed by 300 days of recovery to estimate the general magnitude of impact of pumping. Table 2 summarizes estimated depletion in Kelsey Creek flow.

The same modeling period and conditions are summarized for Lake Sammamish tributaries in Table 3.

Table 2. Estimated Impact to Kelsey Creek

Condition	Depletion (gpm)		
	1 Well 500 gpm	1 Well 850 gpm	4 Wells 2,600 gpm
7 days pumping	0.06	0.10	0.31
30 days pumping	1.00	1.80	5.40
100 days pumping	8.70	14.90	45.60
300 days after pumping stopped	9.50	16.20	49.50

Table 3. Estimated Impact to Lake Sammamish Tributaries

Condition	Depletion (gpm)		
	1 Well 500 gpm	1 Well 850 gpm	4 Wells 2,600 gpm
7 days pumping	219	373	1,143
30 days pumping	349	593	1,816
100 days pumping	415	705	2,159
300 days after pumping stopped	6.60	11.10	34.10

For Kelsey Creek, the fact that greatest depletion in surface water occurs after pumping stops is due to the hydrogeological conditions where the surface water in Kelsey Creek is separated from the pumped aquifer by lower permeability material (an aquitard). The pumped aquifer (where the emergency wells are completed) is confined by the lower permeability material (aquitard) near Kelsey Creek. The aquitard attenuates the effects of pumping on streamflow over a longer period of time than if the well was completed in an unconfined aquifer in direct hydraulic communication with surface water. In the case of western Washington hydrologic conditions, it means that if the emergency wells are used in the summer, ending pumping in say the end of September, the maximum groundwater impact on Kelsey Creek would occur in say November/December when streamflows will have increased following fall rains. This means that the potential impact could be lower than if the maximum depletion occurred in parallel with the low-flow conditions in August/September.

For tributary flow to Lake Sammamish, springs and small tributaries were modeled as a stream that at least partially penetrates the aquifer and is in continuity with groundwater in the aquifer. Precipitation recharge and leakage from overlying hydrogeological units to the aquifer were not simulated.

The estimated rate of depletion increases with increasing pumping rates and pumping duration, and decreasing distance between the pumping activity and the surface water

bodies. Although the predicted rate of depletion in Kelsey Creek is relatively small while the estimated rate of depletion in springs and small tributaries to Lake Sammamish is greatest, it is proportionally more significant in Kelsey Creek. Depletion in Kelsey Creek may pose a greater risk than in the springs because of the potential impact to ecological conditions (i.e. salmonid habitat) in the creek. The springs feed steep, short tributaries draining to Lake Sammamish that appear to have different, and potentially lower ecological conditions that may not support salmonid habitat. They likely support other ecological values, which are unknown at this time. This comment emphasizes the need to develop a good understanding of the physical and biological habitat in both hydrologic systems concurrent with developing the groundwater supply strategy.

The analytical model provides a preliminary assessment of the potential impacts to surface water from pumping, incorporating many simplifying assumptions for a relatively complex groundwater-surface water system. Recommendations for additional analyses are included at the end of the technical memorandum in Appendix E should the City proceed with the development of emergency wells.

3 Water Quality Analysis

Distribution system water quality data were reviewed for the period July 2016 through June 2017 for the Tolt River supply entry point and one distribution system location. In addition, data analysis and June 2016 field sampling completed as part of the Chlorine Residual Evaluation project for the Cougar Mountain area were also reviewed.

Water quality of groundwater wells was evaluated for the following three alternatives described in more detail in Section 6:

1. Drive-up/walk-up emergency-only use for filling trucks or other containers
2. Wells disconnected under normal operating conditions, but plumbed for quick connection to the distribution system in an emergency
3. Full-time continuous use of the well waters as permanent sources for the water system

The existing distribution system water quality was considered in evaluating the potential impact of blending groundwater into the distribution system from an emergency source in the event of an outage. New supply wells that would be used as emergency sources of water could be expected to potentially have elevated iron and manganese levels similar to water quality seen in the existing wells. The analysis includes the assumption that in all cases, potable water would be provided by addition of chlorine, although that is a policy decision the City will need to make as supply of non-potable (i.e., groundwater that has not been disinfected with chlorine) is an alternative possibility.

The four existing wells include municipal water rights and have been approved by DOH for emergency supply purposes. If additional wells are added, the new wells would need regulatory approval by Ecology as an emergency source. DOH would also need to be notified at the time of use for any emergency wells.

For Alternative 1, the equipment to support the trucking or filling stations should be installed and standard operating procedures (SOPs) for trucking water should be updated. Regulatory requirements for trucking potable water, outlined in Washington Administrative Code (WAC) 246-290-131(4), include the following:

- Obtaining permission from the local authority for using trucked water.
- Addition of chlorine to maintain a minimum free chlorine residual of 0.5 mg/L at time of delivery, and performing chlorine demand and decay (CDD) testing to verify dose needed.
- Use of contaminant-free equipment (e.g. NSF/ANSI 61 certified).
- Maintaining records of trucking, chlorine addition, and testing results.
- Monitoring acute contaminants (i.e., coliform and nitrate) before wells are placed into service. Monitoring should be performed annually to minimize delay in use of the wells during an emergency.

For Alternative 2, groundwater would be pumped into the distribution system as emergency supply using a temporary connection. The wells would need to be maintained in operating condition and, again, an SOP would need to be developed for their use. This alternative would allow for substantially higher flow delivery, as it would not be constrained by the logistics of POD site management or surface transportation.

For Alternative 3, the wells would be used as permanent sources of supply, requiring approval from DOH and Ecology for permanent use of the sources. For the existing wells, this would require well rehabilitation to remove iron. Collection of baseline water quality data to document existing distribution system conditions and evaluation of changes in water quality as these and/or new wells are placed in service is also recommended. Disinfection treatment including 4-log inactivation/removal of viruses and treatment to remove ammonia, iron, and manganese to meet the secondary MCL requirements should also be installed. Monitoring plans for coliform, disinfection by-products (DBPs), and for the Lead and Copper Rule (LCR) should be revised as well. Because the wells would include treatment, they would be subject to periodic sanitary surveys by DOH, once every three to five years.

Blending Considerations

Water quality in the distribution system will change if the well water and SPU supplies blend in the system as would be expected with Alternatives 2 and 3. Blending ratios would change as SPU supplies decrease or increase over time. If the City does not provide treatment to remove iron and manganese but does provide chlorination, these metals will be oxidized and will form brown and black precipitates. Chlorine demand and decay testing would be required to determine the extent of chlorine dosing required to maintain adequate chlorine residual under Alternatives 2 and 3.

If the wells are used only during rare emergencies as with Alternative 2, the cost and operations and maintenance complexity of pH adjustment are not likely justified. However, if Alternative 2 is used, treatment for iron and manganese removal is recommended to avoid potential long-term negative impacts to the distribution system.

Some customers may find the well water mildly objectionable given the difference in mineral content between the well waters and the existing surface water supplies from SPU. If wells are used without pH adjustment, some disruption to existing scales and increased corrosion could be anticipated because of the difference in pH compared to the current source. A formal corrosion control study would be required if the wells were to be used as regular sources of supply to determine optimal corrosion control measures required.

4 Economic Impact of Potential Water Outage

Analysis was performed evaluating the economic impact of a potential water outage. Three components of the local economy were reviewed: businesses, wage earners, and City government. As would be expected, the study concluded that a water outage would have a very significant impact on all three components analyzed. These impacts would become more severe with increasing duration of the outage.

Cumulative impacts over time were evaluated for a disruptive event ranging between 3 and 60 days. Analysis assumed that economic impacts were limited to just the impact of a water outage and did not address other disruptions that could occur in conjunction with the disaster. Damage to the water system was not evaluated because, without specifying the nature of the type and magnitude of the event, repair and restoration costs cannot be estimated.

To provide a reasonable estimate of the cost of an outage, the study was limited to information and data readily available from the City as well as information from similar studies conducted for other agencies and professional publications. Measured impact of the disaster is expressed as a monetary value, which can include several types of costs, either directly or indirectly caused by the event. These include direct losses, market losses, non-market losses, indirect losses, and negative costs. The analysis assumes a full water outage, not just contamination, and no alternative sources such as through inter-ties, the City's wells, or surface water sources.

Three economic approaches can be used for measuring gross domestic product (GDP): production, income, and expenditure. The three methods of presenting projected losses show the economic losses from three perspectives: businesses, individuals, and the City itself.

Using the production approach, business and occupation tax collection data were used to estimate gross receipts. Business resiliency factors (i.e., the impact of loss of water varies by business type and by duration of loss of water) were used in conjunction with estimated gross receipts to generate cumulative loss in business activity. The results of the analysis were that a 3-day outage would yield a $54 million loss in business activity while a 60-day water outage would yield a nearly $3 billion loss in business activity. While the projected lost business activity per day varies over time, it averages $39 million per day for the first 2 weeks, and between 2 weeks and 60 days it averages $52 million per day.

The income approach method of calculating GDP sums employment compensation, corporate business profit, and interest income. Data for the wages component of this approach are readily available. Resiliency factors used in the production approach also apply to the loss of wages. For a 3-day outage the estimated lost wages are approximately $29 million while the 60-day outage would yield a $1.5 billion loss in wages. As with projected lost business activity, projected lost wages per day vary over time. These average about $21 million per day for the first 2 weeks, and between 2 weeks and 60 days they average more than $27 million per day.

Taxes collected were used as a surrogate for government spending, a component of the expenditure approach to estimating GDP. The analysis included evaluation of potential impacts to the City itself through reduced business and occupation tax, sales taxes, and water and sewer rate collections. Loss in tax collections would vary over time with the duration of the outage; loss in water and sewer revenue would be constant for the duration of the outage. As with the other analyses, resiliency factors were applied against tax collections. The estimated total cumulated losses to the City itself are projected to be $1.7 million for the first 2 weeks up to $19.8 million after 60 days.

Discussion and Additional Issues

Economic impact analysis was limited to a period of 60 days. Beyond 60 days, it is assumed that conditions would be such that people and businesses would move out of the region. The analysis assumed complete loss of water for the duration of the period considered and did not consider other potential sources of water (potable or non-potable) or partial return of service during this period.

5 Emergency Water Needs

While SPU, as the regional source and transmission of drinking water, has a long-term goal (year 2045) of restoring winter demand, non-potable water to 75% of wholesale meters within 14 days of a disruptive event and normal potable water supply within two months (*Seattle Public Utilities, Water System Seismic Study Summary Report, 2018,* Table 6-1). Until significant improvements are in place, restoration of service will likely fall short of stated goals. This is true for both transmission of water to the City as well as distribution within the City itself.

It is generally impractical for both technical and economic reasons to upgrade all components of a water system to fully resist the impacts of a disruptive event like a significant earthquake. Therefore, post-event service levels will necessarily be below normal performance. A prudent approach to this issue would be to anticipate the need for some amount of water to be stored by individuals/businesses to supplement the normal supply.

It is recognized that an event that disrupts the drinking water infrastructure is likely to have far-ranging impacts affecting many, if not all, public sectors. Other impacted public sectors would most likely include transportation, power, wastewater collection and treatment, first responders, and communications. Disruption of these services would

have a compounding effect on the ability of the City to bring essential services back up to pre-event performance.

A review of benchmark studies and policies is presented in Appendix F. The studies and policies reviewed include the following:

- Mercer Island 2015 Water System Plan
- Oregon Resilience Plan
- Portland, Oregon, and the Regional Water Providers Consortium
- San Francisco Area Planning
- SPU: Water System Advisory Committee
- Washington State Emergency Management Council
- Water Supply Forum, Central Puget Sound

These policy statements, plans, and guidance documents exhibit an array of recovery expectations and goals. They do not lend themselves to direct comparison on a common set of criteria. However, some general trends and points of commonality are noted below:

- Recognition that the existing state of infrastructure is inadequately resilient and long-term recovery goals are required
- Prioritization based on usage type (e.g., goals for critical uses such as health and safety are more aggressive)
- Recognition that restoration to normal service may take 6 months or longer
- Performance of water systems at recent events, in particular Christchurch, New Zealand, and Tohoku, Japan, used as a reference to anticipated level of disruption and recovery
- Use of some percentage of winter average daily demand as a benchmark for anticipated need
- Most have set a goal of 2 weeks or longer for significant return of supply
- Trend toward recommending individual self-sufficiency for longer than the previously suggested 3 days

The benchmark studies reviewed identify critical services and facilities. Most typically, these include the following:

- Medical facilities including hospitals, urgent care facilities, and nursing homes
- Command and control centers
- Industries essential to recovery and restoration of services
- Schools and other public buildings
- Fire and police facilities

The 5-year average annual average daily water demands for Bellevue's major healthcare facilities is approximately 0.17 million gallons per day (mgd) distributed among eight facilities. Among essential industries, the Coca-Cola bottling facility would be assumed to bottle only water in the event of a disruption to the water supply. Following a major disruption in water services, schools would be expected to close.

The City and the Bellevue School District have signed a memorandum of understanding regarding the use of schools as shelters and/or points of distribution (PODs) for emergency supplies. This agreement addresses emergency assistance in the form of resources, such as equipment, supplies, facilities, and personnel. Middle schools and high schools would be more likely to be used as shelters because of the availability of facilities such as showers, assuming that an emergency supply of water is available. Elementary schools would be more likely to be used as PODs as they are able to accommodate incoming and outgoing traffic and are generally well distributed geographically. Further discussion of these types of critical services and facilities specific to Bellevue is presented in Appendix F.

Probable Needs

The actual needs throughout the system will vary depending on the severity and extent of the disruptive event. The Washington State Emergency Management Division currently recommends 2 weeks of self-sufficient preparedness for individuals.

A reasonable expectation of domestic water demands in the City's service area following a major disaster is approximately 9 mgd. This is based on 80 percent of winter average daily demand, discounted by an additional 11 percent due to conservation. Currently this would be approximately 40 gpd/capita based on an estimated daytime population of 223,900. Assuming a total loss of water supply following a significant event, this shortfall would need to be made up with alternative or emergency supplies.

This does not take into account disruption of typical water demand due to public reaction to the event. Water demand could rise dramatically immediately following a disruption as people attempt to stockpile what water they can. If a longer-term recovery is experienced, a portion of the population may move out of the impacted area, further reducing demand.

An alternative approach to determining potential need would be to assume complete failure of the existing system and emergency water supplied for essential use only, as is proposed by Mercer Island's plan of 5 gallons per person per day. This is equivalent to the upper range referenced by the United States Environmental Protection Agency (USEPA) (*Planning for an Emergency Drinking Water Supply,* 2011). The 2017 *Bellevue Water Quality Report* indicates an average daytime population of 223,900 served. Using 5 gallons per person per day corresponds to a net need of 1.12 mgd (780 gpm). This is less than 13 percent of the previously suggested discounted winter average daily demand. However, this is in line with World Health Organization (WHO) estimates of 15 to 20 liters per person per day (4 to 5 gallons per person per day), (WHO, *Technical Notes on Drinking Water, Sanitation, and Hygiene in Emergencies*, 2013) and is more reasonable in terms of dealing with the logistics of distributing water to large numbers of people with a limited number of PODs.

While the Mercer Island approach of 5 gallons per person per day is currently achievable with existing emergency wells, this would be at the low end of the level of service the City may desire. Further, having only two sites for use as PODs for emergency supplies would not be feasible because of the logistics of moving more than 200,000 people through the sites daily. It may be appropriate to assume total loss of water in the near term with a period of recovery of 45 to 60 days noted by SPU. For current conditions and assuming emergency water would be provided through distributed PODs, 5 gallons per person per day is recommended. A more conservative approach of providing up to 9 mgd in emergency water through a series of additional new emergency wells could be considered as a long-term goal.

The four existing emergency supply wells can provide up to 3.8 mgd assuming 24-hour per day operation. Six additional wells with an average production of 650 gpm each (based on average production of the existing wells) would be required to meet a goal of 9 mgd, again assuming 24-hour per day operation. Locating some of these wells at critical healthcare facilities could serve as both PODs and sources of water for the healthcare facility's local distribution system.

6 Emergency Water Supply Opportunities

A disruptive event with a 2-week duration is considered significant enough that reliance on emergency sources would be warranted to meet immediate needs. A longer-term event of 3 months is assumed as a reasonable degree of need, beyond which more permanent relocation and changes in water needs could be expected.

Three alternatives for groundwater supply were initially identified in previous studies (Robinson Noble, *Emergency Well Evaluation*, Technical Memoranda 2 and 4, 2015).

1. Drive-up/emergency use only, for filling trucks or other containers
2. Wells disconnected under normal operating conditions, but plumbed for quick connection to the distribution system in an emergency
3. Full-time continuous use of well water as permanent supplemental, non-emergency sources for the water system

For each of the three alternatives the City would need to maintain physical control of an area with a radius of at least 100 feet around each well. Each alternative requires varying degrees of supporting infrastructure and an emergency source of power, assuming that power would also be disrupted. Emergency power could be a permanently installed generator at each site or the City could potentially use portable generators. The following summarizes each of the alternatives considered.

Alternative 1: Drive-up

Alternative 1 drive-up sites would require development of facilities for a POD at each emergency well. At a presumed usage of 5 gallons per person per day, the capacity of a single well could potentially serve more than 90,000 people based on the production capacity of existing wells in the City. However, the logistics of moving this number of

people through a single POD would be difficult. It is also likely that isolated sites would be difficult to reach for many residents, particularly those with limited mobility (elderly, disabled, transit-dependent or otherwise vulnerable populations) and those located far from the POD, because of potential disruption of roadways and transportation providers. To reduce the number of people moving through a single POD and to improve the geographic distribution of POD sites throughout the City, a total of six sites has been assumed for this alternative.

These facilities would require some form of delivery of water through very small, temporarily installed manifolded piping with taps at the POD site. A hydropneumatic tank would be required to minimize cycling of well pumps.

POD requirements and recommended configurations of facilities are described in detail in the Federal Emergency Management Agency (FEMA)/United States Army Corps of Engineers (USACE) IS-26, *Guide to Points of Distribution* (2008). These facilities are designed to address distribution of multiple types of commodities including food, water, ice, and other provisions. In addition to the well, emergency power, a holding tank, and temporary piping to distribute water from the tank to local pickup points at the POD, some means of handling traffic would be required. Identification of potential POD locations is beyond the scope of this study. In planning POD locations, existing infrastructure that could handle traffic (e.g., schools), geographic dispersion, and location of areas of high demand should be factored into consideration.

The following two options can be considered with respect to treatment under this alternative:

- Provide potable water by disinfecting the well water with some form of chlorine, most likely calcium hypochlorite, which can be stored for extended periods of time in dry form.
- Alternatively, provide non-potable water and instruct the public to boil and/or disinfect if used for drinking water. This option could include distribution of calcium hypochlorite tablets with the water.

Public outreach and effective dissemination of information about emergency water planning is critical for successful implementation of this and the other alternatives. To manage expectations and improve effectiveness, the City's emergency water supply plans will need to be fully understood by the public prior to any event that disrupts the water supply.

Permitting and regulatory requirements for Alternative 1 include the following:

- Building, site, electrical, stormwater, and related permits.
- Approval from DOH for the use of the sources.
- Approval from Ecology for emergency water rights.
- If treated to potable standards (i.e., maintaining a required free chlorine residual), negative bacteriological testing results would need to be documented at the time of the event. Until this is received, the water would be considered non-potable.

Staffing of the POD could be by City employees, emergency services staff, or certified volunteers. Operation is assumed to be during daylight hours only because of security concerns during an emergency event. The emergency wells would require periodic exercising to verify that all components remain functional. The wells would need to be tested annually for VOCs, coliform, and nitrate. Residents would supply their own portable storage containers for walk-up or drive-up collection of water.

Alternative 2: Quick Connection to the Distribution System

In Alternative 2, emergency supply wells would normally be disconnected from the distribution system. During an emergency, temporary piping stored at the well site would be used to quickly connect to the distribution system. This temporary piping would be stored at the site and could be expected to be plumbed within a matter of hours provided that the local distribution system is modified to facilitate this installation, staff are available, and the site is accessible. Connection to the existing distribution system would require a new valve vault for this purpose.

To meet water quality standards, all emergency wells would need to be disinfected and maintain at least a 0.5 mg/L chlorine residual at the time of delivery to ensure adequate microbial control throughout the distribution system. Damaged portions of the distribution system would need to be valved off to isolate compromised pipelines. Portions of the system would also need to be isolated simply due to well capacity limitations.

Based on recommendations from the *Water Quality Analysis Technical Memorandum* (Confluence Engineering, 2018), iron and manganese removal and pH adjustment would be needed to avoid introducing oxidized iron and manganese into the distribution system as these could cause longer-term water quality problems within the distribution system. Treatment in the form of disinfection would be similar to Alternative 1, but with the addition of pressure filters using either pyrolusite or manganese greensand. Temporary connection to the sanitary sewer for disposal of waste backwash water from the filters would be required. A hydropneumatic tank, again similar to Alternative 1, would be required to minimize cycling of well pumps.

Permitting and regulatory requirements for Alternative 2 include the following:

- Building, site, electrical, stormwater, and related permits.
- Approval from DOH for the use of the sources.
- An engineering report to DOH complying with WAC 246-290.
- Approval from Ecology for emergency water rights unless at an existing well site.
- If treated to potable standards (i.e., maintaining a required free chlorine residual), negative bacteriological testing would need to be documented at the time of the event. Until this is received, the water would be considered non-potable.

Staffing would be by City employees but, unlike Alternative 1, staff would need only periodic visits to the emergency well sites. The level of staff presence at each site would be dependent on the level of automation and supervisory control and data acquisition (SCADA), but would be similar to existing booster pumping stations. Unlike Alternative 1, the wells used with a temporary connection to the distribution system could be operated

24 hours per day. The emergency wells would require periodic exercising to verify that all components remain functional. The wells would need to be tested annually for VOCs, coliform, and nitrate.

If the distribution system can be adequately isolated, this is an appropriate approach to providing an emergency source of water for critical users and to allow occupancy of nearby buildings (e.g., schools and community centers). There may be opportunities with such facilities for the City to partner with critical customers on installation of such an emergency source, recognizing the mutual benefits of improved reliability. Depending on the specific needs and infrastructure at these facilities, it might be possible for such a source to also serve as a modified POD for Alternative 1 type distribution.

Alternative 3: Full-time Use of Well Water as a Permanent Source

Use of new, permanent sources of water to supplement the existing water supply during an emergency is very similar to Alternative 2, excluding the need for temporary connection facilities. The overall layout would be similar to Alternative 2. Treatment would be similar to Alternative 2. However, a full corrosion study is recommended to be performed if this alternative is selected because of the long-term implications to water quality should water stability be an issue.

To meet water quality standards, all wells would need to be disinfected and maintain at least a 0.5 mg/L chlorine residual at the time of delivery to ensure adequate microbial control throughout the distribution system. As with Alternative 2, damaged portions of the distribution system would need to be valved off to isolate compromised pipelines.

Based on recommendations from the *Water Quality Analysis Technical Memorandum* (Confluence Engineering 2018), iron and manganese removal and pH adjustment would be needed to avoid introducing oxidized iron and manganese into the distribution system as these could cause longer-term water quality problems within the distribution system. Treatment in the form of disinfection would be similar to Alternative 1, but with the addition of pressure filters using either pyrolusite or manganese greensand similar to Alternative 2. A permanent connection to the sanitary sewer for disposal of waste backwash water from the filters would be required.

Permitting requirements for Alternative 3 include the following:

- Approval from DOH for the use of the sources
- An engineering report to DOH complying with WAC 246-290
- Approval from Ecology for full water rights
- Negative bacteriological testing would need to be documented prior to use

Staffing would be by City employees and, like Alternative 2, staff would need only periodic visits to the well sites. Like Alternative 2, the level of staff presence at each site would be dependent on the level of automation and SCADA, but would be similar to existing booster pumping stations. Unlike Alternative 1, the wells could be operated 24 hours per day. And unlike Alternative 2, these could be operated during normal conditions and would not be restricted to operating only under emergency conditions. If not normally operated, the wells would require at least periodic exercising to verify that

all components remain functional. The wells would need to be tested annually for VOCs, coliform, and nitrate.

Discussion and Additional Considerations

Alternative 1 is generally more resilient than Alternatives 2 and 3 as it is independent of the condition of the distribution system following a disruptive event. However, it is not appropriate for meeting the emergency water needs of critical facilities. Alternative 1 would require more staffing for each POD than Alternatives 2 and 3.

The decision regarding disinfection of this water is a policy decision the City will need to consider. Potential liability is associated with both disinfection and no disinfection of the water. If the decision is made to supply non-potable water, an effective public notification plan including boil advisories will need to be implemented. This will be required to be communicated in all languages spoken by 5 percent or more of the population. If the decision is made to supply potable water, measures will be required to ensure that an adequate chlorine residual is maintained.

Alternative 2 may be useful for local supply, but is dependent on the distribution system remaining intact for distributing water beyond the immediate area near the well.

Alternative 3 presents several challenges, not the least of which is obtaining water rights. This relies on the ability to rehabilitate existing wells and repurpose those sites, or to transfer existing water rights as new municipal water rights are no longer available. Permitting through Ecology is likely to be very difficult. DOH may not allow full-time use of existing wells because of historical site contamination at some. As with Alternative 2, this alternative relies on the distribution system remaining intact in the area of each well.

7 Recommendations

Recommendations resulting from this study are listed below:

1. Because of a likely discrepancy between public expectation of system recovery and the probable duration of an extensive outage, public outreach and messaging prior to and during a disruptive event will be required to effectively manage expectations and assist community recovery. Messaging should address vulnerability of existing infrastructure (supply, transmission, and distribution) and should clarify current recommended preparedness guidelines. Washington State Emergency Management Division currently recommends individuals prepare for up to two weeks of emergency supplies and resources (www.mil.wa.gov/preparedness).
2. Establish a short-term goal for the quantity of emergency water supply. Based on WHO recommendations, 5 gallons per person per day or 1.12 mgd is recommended assuming water is provided through PODs distributed throughout the City.
3. Establish a long-term goal for the quantity of emergency water supply. Based on discounted winter average daily demand, 9 mgd is recommended. With an estimated daytime population of 223,900, this would supply up to 40 gpd per capita. This would require a minimum of six additional emergency wells. More may be required if

capacity is less than 650 gpm per well, assuming that the goal is established at 9 mgd from all emergency wells.

4. Continue to participate in the work of the Water Supply Forum to coordinate emergency water planning with other utilities in the region.
5. Prepare a numerical groundwater flow model representing the geological, hydrogeological, and hydrological conditions to provide more reliable estimates of wellfield yield, pumping interference effects, and potential stream depletion.
6. Conduct further geological and hydrogeological characterization of the emergency wells and surrounding area.
7. Complete longer pumping tests (3 to 7 days) and stream gaging to evaluate the aquifer hydraulic properties and boundaries and the response in the streams to extended pumping.
8. Complete stream surveys to characterize the physical hydrologic conditions.
9. Conduct groundwater level and stream flow monitoring to characterize seasonal changes in the groundwater and surface water systems.
10. Before any improvements are made to the Crossroads Wells, pump drawdown testing should be performed to determine the potential for interference drawdown when operating multiple pumps simultaneously.

Alternatives for Configuring Emergency Wells

A combination of Alternatives 1 and 2 could provide emergency water supply to meet both residential and critical facilities' needs. This would require installation of emergency wells adjacent to critical facilities such as hospitals. These would include treatment facilities (filtration for iron and manganese removal and disinfection) and capability to connect to the distribution system in an emergency. In developing these wells, additional water quality analysis should be conducted to evaluate relative water stability and to determine if additional treatment is required.

Using this approach would also require installation of emergency wells distributed throughout the City for walk-up/drive-up distribution of water. All wells, both those at critical facilities and those distributed throughout the City, will need a minimum 100-foot radius of control around the wells as part of a wellhead protection program. This required size limits the number and location of properties that would be large enough to host the wells. Further, a formalized wellhead protection plan will be required. These plans are typically site specific and conform to standards established by community or utility policy. AWWA G-300, Source Water Protection is a management standard that gives guidance in recommended components of wellhead protection plans and their execution.

Alternative 1: Drive-up Emergency-Only Use

The key recommendations for the City for Alternative 1 are as follows:

1. Conduct an evaluation of potential well sites to serve as PODs

2. Develop wells with ancillary equipment
3. Conduct water quality analysis on any new wells added to the system to verify assumptions in this report regarding water quality and quantity
4. Include piping/plumbing that can be quickly installed to support the trucking or filling station
5. Maintain the wells in operable condition and develop SOPs for activating and operating the wells in an emergency; ensure that the SOPs include current regulatory requirements and are easy for lay people to understand.
6. Test annually for VOCs, coliform, and nitrate.
7. Complete CDD tests at the wells to better quantify chlorine dosing requirements for each truckload
8. Maintain the appropriate equipment needed for adequate chlorine addition and testing

Alternative 2: Disconnected and Plumbed for Quick Connection to the Distribution System

The key recommendations for the City for Alternative 2 are as follows:

1. Conduct an evaluation of potential well sites to serve critical users
2. Develop wells with ancillary equipment
3. Conduct water quality analysis on any new wells added to the system to verify assumptions in this report regarding water quality and quantity
4. Maintain the appropriate equipment needed for temporary connection of the wells to the distribution system
5. Maintain the wells in operable condition and develop SOPs for activating and operating the wells in an emergency; ensure that the SOPs include current regulatory requirements
6. Provide disinfection treatment at the wells and maintain the ability to monitor for free and total chlorine
7. Provide treatment for removal of iron and manganese
8. Continue annual monitoring of VOCs, coliform, and nitrate at the wells
9. Complete CDD tests to better estimate the required chlorine dose, needed oxidation time, and ability to maintain an adequate disinfectant residual
10. Develop and implement a baseline water quality monitoring program to allow changes in water quality to be tracked when the wells are placed in service and during the recovery period when the SPU water supply is brought back to full capacity
11. Be prepared to respond to customer inquiries due to difference in water quality

12. Be prepared to issue a boil water advisory if adequate disinfection treatment cannot be maintained
13. Be prepared to complete unidirectional flushing of the distribution system in the area served by the wells once the SPU supply is back online and the wells are no longer in service

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Appendix A. Well Condition Assessment

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TECHNICAL MEMORANDUM

Date:	March 13, 2018	**Project No.:**	1775477.3.1
To:	Laurie Fulton PE, Stantec Thomas Bell-Games PE – HDR Inc.	**Company:**	Stantec/HDR
From:	Michael Klisch LHG and David Banton LHG, RG		
cc:	Doug Lane, PE, City of Bellevue	**Email:**	mklisch@golder.com
RE:	**CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLANNING – WELL CONDITION ASSESSMENT**		

1.0 INTRODUCTION

This technical memorandum provides an assessment of the condition of the City of Bellevue (City) wells formerly operated by King County Water Districts (KCWD) 68 and 97 and the Washington Water Service Company (WWSC) for municipal water supply. KCWD 68 and 97 and the WWSC were incorporated into the City's Utility's Department as the City grew. The wells include the following:

- KWCD 97 Wells No. 1 and 3 (Samena Wells) and Wells No. 5, 6, and 7(Crossroads Wells),
- KCWD 68 Wells No. 1, 2, and 3, and
- WWSC Well No. 1 and Hill-Aire Well.

The well locations are shown on Figure 1. KCWD Wells No. 3, 5, 6, and 7 were designated as emergency supply wells by the Washington State Department of Health in 2010. The current well site conditions at these wells do not meet wellhead protection requirements for municipal water supply. The remaining wells are designated as reserve wells in the City's Water System Plan (City of Bellevue 2017).

This assessment was based on the following:

- Information provided by the City including well logs, consultant reports, water quality reports, and water district records.
- City of Bellevue Groundwater Mapping Project (2013).
- Well video logs completed in 2008 by JKA Well Drilling and provided by the City.
- Well logs on file with the Washington State Department of Ecology.
- Water quality data available from the Washington State Department of Health.

1.1 Scope of Work

This memorandum was prepared to address part of Subtask 3.1 Existing Conditions in Golder Associates Inc (Golder) scope of work for Stantec/HDR as part of the City of Bellevue Emergency Water Planning to document the existing conditions at the City of Bellevue Wells. Additional memoranda will be prepared to

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address aquifer characterization and well yield, and assess groundwater-surface interaction as part of Subtask 3.1.

2.0 KING COUNTY WATER DISTRICT 97 WELLS

The KCWD 97 Wells No. 1 and 3 (Samena Wells) are located east of 151st Avenue SE. KCWD 97 Wells No. 5, 6, and 7 (Crossroads Wells are located south of NE 8th Street at the City Parks Department Resource Management facility between 156th Avenue NE and 164th Avenue NE. The wells were originally drilled for KCWD 97 in the 1950s. Information on the original well construction is summarized in Table 1, and information on the original pumping tests completed in the wells at the time of well construction are summarized in Table 2. The well locations are shown on Figure 1.

The Crossroads and Samena supply wells are completed in a 40 to 50-foot thick, confined sand and gravel aquifer at an approximate elevation of 149 to 196 feet above sea level (NAVD 88). This unit may be Hydrostratigraphic Unit A3 (pre-Vashon permeable deposits) defined by Troost (2015). The sand and gravel aquifer is overlain by glacial till and advance outwash sands.

Available well logs are included in Attachment A, and photographs of the wells are included in Attachment B.

2.1 KCWD 97 Well No. 1

KCWD 97 Well No. 1 was drilled in 1955 to a depth of 160 feet below ground surface (bgs) on the same parcel as KCWD 97 Well No. 3. Based on the well log, Well No. 1 is completed with 30 feet of 12-inch diameter 0.040-inch (40 slot) stainless steel wire-wrap well screen from 130 to 160 feet bgs. There is no information on the well log about a surface seal. The water right (G1*04058CWRIS, certificate number 03539) for KCWD 97 Well No. 1 specifies an instantaneous quantity (Qi) of 400 gallons per minute (gpm) and an annual quantity (Qa) of 450 acre-feet (AF). The well was pump tested at a rate of 420 gpm after drilling. The drawdown reported on the log of 140 feet appears to be an error, the depth to static water after drilling was about 102 feet bgs. The test duration was not specified.

A video log was completed in KCWD 97 Well No. 1 in 2008. The well was observed to be filled to a depth of 104 feet bgs; the type of fill material could not be determined from the video log because of limited visibility. No water was observed above the fill materials.

There are limited water quality data available for KCWD 97 Well No. 1. Information provided by the City suggests elevated iron and iron bacteria were present in KCWD 97 Well No. 1; an iron treatment system was reportedly installed on the well. Iron was detected at a concentration of 0.56 mg/L in a sample collected in September 1956.

KCWD 97 Well No. 1 is housed in a vault and does not have a pump installed.

2.2 KCWD 97 Well No. 3

2.2.1 Well Condition

KCWD 97 Well No. 3 was drilled in 1956 to a depth of 229 feet bgs. A well log is available for Well No. 3. Well construction based on the well log is:

- 18-inch diameter steel casing from 0 to 187 feet
- 12-inch diameter steel casing from 0 to 220 feet bgs
- 12-inch diameter stainless steel wire-wrap well screen assembly from 195 to 220 feet bgs:
  - 0.030-inch (30 slot) from 195 to 215 feet bgs
  - 0.020-inch (20-slot) from 215 to 220 feet bgs

The City installed a sanitary surface seal in 2010. A pumping test was completed in Well No. 3 in 1956 at the time the well was drilled. The well was pumped at 900 gpm; the drawdown at the end of the test was 93 feet. The test duration was not specified. This corresponds to a specific capacity (pumping rate divided by drawdown, which is a commonly used measure of well performance) of 9.7 gallons per minute per foot of drawdown (gpm/ft).

The water right for KCWD 97 Well No. 3 (G1-*04201CWRIS, certificate number 3252) is for a Qi of 850 gpm and a Qa of 1,120 AF.

A downhole well video log was completed in 2008. The following details were observed:

- The depth to water was about 106 feet below the top of casing (btc).
- There was poor visibility because of low light and floating material in the water column.
- There was minor scale or encrustation on the well casing.
- The bottom of the well was observed to be at about 192.3 feet btc. The material filling the well appears to be fine sand and scale. The bottom of the well was measured at a depth of 191 feet btc in 2013 when a temporary pump was installed. This suggests that the entire screened interval is filled with fine sand.

KCWD 97 Well No. 3 is currently equipped with 5 horsepower (HP) Goulds G80GS50 submersible pump set at a depth of 168 feet bgs and capable of pumping about 100 gpm. A 1-inch diameter sounding tube was installed to facilitate groundwater level measurements. A locking cabinet that was installed over the well that houses the electrical controls for the well (see photographs in Attachment B). A receptacle for plugging in a generator for emergency power is installed at the wellhead.

2.2.2 2013 Step-Rate Pumping Test

A 4.4-hour step-rate pumping test was completed in KCWD 97 Well No. 3 in 2013 using a temporary submersible pump. KCWD 97 Well No. 3 was pumped at rates of 100 to 312 gpm over 6 steps of increasing pumping rate. The duration of the pumping steps ranged from about 40 minutes for the first 5 steps to

61 minutes for the last step (GeoEngineers 2014a). The total drawdown at the end of the test was about 35.6 feet.

Table 3 summarizes the observed drawdown and specific capacity at the end of each step. The specific capacity at the end of the first five steps (40 minutes duration) decreased from 9.3 gpm/ft to 8.8 gpm/ft, respectively. The drawdown had not stabilized at the end of each step. The estimated 40-minute specific capacity for the last pumping step was 8.8 gpm/ft. The specific capacity at the end of the last step (after 240 minutes of pumping) was 8.8 gpm/ft.

GeoEngineers (2014a) interpreted the results of the step-pumping test and groundwater level recovery following the step pumping test. They estimated that the portion of drawdown attributed to well losses (turbulent flow) increased from about 4 percent at 100 gpm to 11 percent at 312 gpm.

The recovery data were analyzed to estimate the aquifer transmissivity. The aquifer transmissivity was estimated to be about 7,400 feet squared per day (ft^2/d).

2.2.3 Groundwater Quality

Inorganic water quality data obtained from the City and the Washington Department of Health is summarized on Table 4. Data are available from five samples collected from 2011 through 2016. Groundwater from KCWD 97 Well No. 3 meets all primary and secondary Maximum Contaminant Levels (MCLs) with the exception of iron and manganese. Iron was detected in the sample collected in 2016 at 0.67 milligrams per liter (mg/L), exceeding the secondary MCL of 0.3 mg/L. Manganese was detected at 0.049 mg/L to 0.06 mg/L, ranging from just below the secondary MCL of 0.05 mg/L to above the secondary MCL mg/L.

Volatile organic compounds (VOC) have not been detected in Well No. 3 based on seven samples collected between 2008 and 2016 with the exception of one apparent detection of toluene in 2008 (0.69 μg/L). Synthetic Organic Compounds (SOC; including pesticides and herbicides) have not been detected in five samples collected between 2012 and 2016.

2.3 KCWD 97 Well No. 5

2.3.1 Well Condition

KCWD 97 Well No. 5 was drilled at the Crossroads site in 1959 to a depth of 293 feet bgs. The well is 8 inches in diameter and is reported to be completed from 263 to 293 feet bgs. No well log is available for KCWD 97 Well No. 5. The City installed a sanitary surface seal in 2010 but details of the well screen including slot size or perforations are uncertain, and there is no information on any pumping tests completed at the time the well was drilled and completed. The water right for KCWD 97 Well No. 5 (G1-*06470CWRIS, certificate number 4454) is for a Qi of 500 gpm and a Qa of 800 AF.

A downhole well video log was completed in 2008. There was poor visibility on the video log because of low light levels but the following details could be observed:

- The depth to water was about 173 feet btc.
- There was some scale or encrustation on the well casing.
- The top of the screen was observed at a depth of about 263 feet btc. The well screen is stainless steel wire-wrap well screen of unknown slot size. The screen appears to be partially to almost completely blocked by reddish-orange scale or encrustation.
- The bottom of the well was observed to be at about 285 feet btc suggesting there is about 8 feet of material filling the bottom of the well. The fill material appears to be fine sand and scale. The bottom of the well was measured at a similar depth in 2013 when a temporary pump was installed.

KCWD 97 Well No. 5 is currently housed in a vault with a manhole lid. There is no pump installed in the well (see photographs in Attachment B).

2.3.2 2013 Step-Rate Pumping Test

A 3.3-hour step-rate pumping test was completed in KCWD 97 Well No. 5 in 2013 using a temporary submersible pump. Well No. 5 was pumped at rates of 100 to 480 gpm over 5 steps of increasing pumping rate. The duration of the pumping steps ranged from about 20 minutes for the first 4 steps to 120 minutes for the last step (GeoEngineers 2014b). The total drawdown at the end of the test was about 17.9 feet. About 8 feet of interference drawdown (i.e. drawdown resulting from pumping Well No. 5) was observed in KCWD 97 Wells No. 6 and 7 at the end of the test; KCWD 97 Wells No. 6 and 7 are located about 25 feet and 80 feet from Well No. 5, respectively.

Table 3 summarizes the observed drawdown and specific capacity at the end of each step. The specific capacity over the first four steps of approximate equal duration (20 minutes) decreased from 33.3 gpm/ft at the end of the first step to 28.4 gpm/ft at the end of the fourth step. The estimated 20-minute specific capacity for the fifth pumping step was 27.3 gpm/ft. The drawdown had not stabilized at the end of each step. The specific capacity at the end of the last step (after 120 minutes of pumping) was 26.8 gpm/ft.

GeoEngineers (2014b) interpreted the results of the step-pumping test and groundwater levels recovery following the step pumping test. They estimated that the portion of drawdown attributed to well losses increased from about 7 percent at 100 gpm to 28 percent at 480 gpm. An increase in turbulent loss with increasing pumping rate is typical.

The recovery data were analyzed to estimate the aquifer transmissivity. The transmissivity was estimated to be about 7,400 ft^2/d. GeoEngineers interpreted the presence of a low-permeability aquifer boundary in their evaluation of the pumping test data from KCWD 97 Well No. 5 (and from evaluation of the test data from adjacent KCWD 97 Wells No. 6 and 7).

2.3.3 Groundwater Quality

Inorganic water quality data obtained from the City and the Washington State Department of Health is summarized on Table 5. Groundwater from KCWD 97 Well No. 5 meets all primary and secondary MCLs with the exception of iron, which exceeded the secondary MCL of 0.3 mg/L in all three samples. Iron concentrations in the three samples ranged from 0.6 to 0.82 mg/L. Manganese concentrations were just below the secondary MCL of 0.05 mg/L, ranging from 0.04 to 0.044 mg/L. In August 2008, a bacterial sample was positive for Heterotrophic Plate Count (HPC) bacteria at 54 colony forming units per milliliter (cfu/mL). There have been no other positive bacterial samples from Well No. 5.

Elevated iron concentrations and potential iron bacterial activity in Well No. 5 were also noted in KCWD 97 KCWD 97 records. The records also noted the presence of hydrogen sulfide in Well No. 5 (and Well No. 3).

A leaking 10,000-gallon underground gasoline storage tank was removed from the Crossroads site in April 1989. Site explorations, including completion of 16 monitoring wells to depths of 43 feet bgs were completed to determine the nature and extent of contamination resulting from the leaking tank. Gasoline contamination was observed in soils extending to a depth of about 35 feet bgs (GeoEngineers 1989) and floating free product was identified in three monitoring wells. A vapor extraction system was operated at the site from 1990 to 1999. Measurable free product has not been observed since 2003 (GeoEngineers 2013).

VOCs (including constituents associated with the gasoline contamination) have not been detected in KCWD 97 Well No. 5 based on samples collected in 2008, 2013, 2015, and 2016. SOCs (including pesticides and herbicides) have not been detected in samples collected in 2013, 2015, and 2016.

2.4 KCWD 97 Well No. 6

2.4.1 Well Condition

KCWD 97 Well No. 6 was drilled at the Crossroads site in 1959 to a depth of 302 feet bgs. The well is 16 inches in diameter and is reported to be completed with a well screen from 282 to 302 feet bgs and a riser pipe extending from 262 feet to the top of the well screen at 282 feet bgs. No well log is available for KCWD 97 Well No. 6 and details of the well screen including slot size are uncertain. The City installed a sanitary surface seal. There is no information on any pumping tests completed at the time the well was drilled and completed. The water right for Well No. 6 (G1-*06472CWRIS, certificate number 4453) is for a Qi of 600 gpm and an additive Qa of 750 AF and a non-additive Qa of 210 AF.

Information in KCWD 97 files indicate the production in KCWD 97 Well No. 6 decreased from about 750 gpm in 1959 to about 450 gpm in 1961. The well screen was reportedly pulled from the well in 1962 and found to be about 50 percent blocked with what was described as very hard, fine black sand-like crystals.

A stainless steel well screen with filter pack was re-installed but there is no information on the well screen size or filter pack gradation or any pumping test completed following well modifications.

A downhole well video log was completed in 2008. There is poor visibility on the video log because of low light levels but the following details could be observed:

- The depth to water was about 173 feet btc.
- There was minor scale or encrustation on the well casing.
- There appears to be evidence of bacterial activity in the water column (i.e. floating biological materials).
- The top of the screen was observed at a depth of about 281 feet btc. The well screen is stainless wire-wrap well screen of uncertain slot size. The screen appears to be fairly free of scale or encrustation, no reddish-orange scale or encrustation similar to that observed in Well No. 5 was observed.
- The bottom of the well was observed to be at about 298 feet btc on the well video, and was measured at 297 feet during installation of a temporary pump in 2013. This suggests there is about 4 to 5 feet of material filling the bottom of the well. The fill material appears to be fine sand and scale.

KCWD 97 Well No. 6 is currently housed in a vault with a manhole lid. There is no pump installed in the well (see photographs in Attachment B).

2.4.2 2013 Step-Rate Pumping Test

A 2.1-hour step-rate pumping test was completed in KCWD 97 Well No. 6 in 2013 using a temporary submersible pump. KCWD 97 Well No. 6 was pumped at rates of 95 to 450 gpm over 5 steps of increasing pumping rate. The duration of the pumping steps ranged from about 15 to 18 minutes for the first 4 steps to 61 minutes for the last step (GeoEngineers 2014b). The total drawdown at the end of the test was about 35.6 feet. About 7 feet of interference drawdown was observed in KCWD 97 Wells No. 5 and 7 at the end of the test; KCWD 97 Wells No. 5 and 7 are located about 25 feet and 80 feet from KCWD 97 Well No. 6, respectively.

Table 3 summarizes the observed drawdown and specific capacity at the end of each step. The specific capacity over the first four steps of approximate equal duration (15 minutes) decreased from 22.6 gpm/ft at the end of the first step to 14.5 gpm/ft at the end of the fourth step. The estimated 15-minute specific capacity for the fifth pumping step was 12.3 gpm/ft. The drawdown had not stabilized at the end of each step. The specific capacity at the end of the last step (after 61 minutes) was 11.8 gpm/ft.

GeoEngineers (2014b) interpreted the results of the step-pumping test and groundwater levels recovery following the step pumping test. They estimated that the portion of drawdown attributed to well losses (turbulent flow) increased from about 21 percent at 95 gpm to 66 percent at 450 gpm.

The recovery data were analyzed to estimate the aquifer transmissivity. The transmissivity was estimated to be about 6,600 ft^2/d, similar to the transmissivity estimated from the Well No. 5 recovery data.

2.4.3 Groundwater Quality

Groundwater quality data from KCWD 97 Well No. 6 are limited to two analyses of nitrate in 2008 and 2012 and an analysis of VOC and bacteria in 2008. Nitrate was not detected, HPC bacteria were detected at 4 cfu/mL. Coliform bacteria were present, but E. coli were not present. Styrene and toluene were detected at 8.53 μg/L and 0.8 μg/L respectively, in the 2008 VOC sample.

2.5 KCWD Well No. 7

2.5.1 Well Condition

KCWD 97 Well No. 7 was drilled at the Crossroads site in 1962 to a depth of 300 feet bgs. A well log is KCWD 97 available for Well No. 7. The well construction based on the well log is:

- 12-inch diameter steel casing from 0 to 275 feet bgs
- 12-inch diameter stainless steel wire-wrap well screen assembly from 275 to 299 feet bgs:
  - 0.060-inch (60 slot) from 275 to 284 feet bgs
  - 0.040-inch (40-slot) from 284 to 299 feet bgs

The City installed a sanitary surface seal in 2010. A pumping test was completed in KCWD 97 Well No. 7 in 1962 at the time the well was drilled. Well No. 7 was pumped at 590 gpm; the drawdown at the end of the test was 38 feet. The test duration was not specified. This corresponds to a specific capacity of 15.5 gpm/ft. Anecdotal information in KCWD 97 files provide by the City indicated KCWD 97 Well No. 7 produced sand during pumping and the KCWD was evaluating alternatives.

The water right for KCWD 97 Well No. 7 (G1-*06350CWRIS, certificate number 4391) is for a Qi of 700 gpm and a Qa of 1,120 AF.

A downhole well video log was completed in 2008. The following details were observed:

- The depth to water was about 173 feet btc.
- There was minor scale or encrustation on the well casing.
- The top of the screen was observed at a depth of about 278 feet btc. The screen appears to be partially fouled with scale or encrustation.
- The bottom of the well was observed to be at about 297.5 feet btc however the bottom of the well was measured at a depth of 300 feet btc in 2013 when a temporary pump was installed suggesting some filling of the bottom of the well.

KCWD 97 Well No. 7 is currently equipped with 7.5 HP Goulds G80GS75 submersible pump set at a depth of 273 feet bgs and capable of pumping about 100 gpm. A 1-inch diameter sounding tube was installed to facilitate groundwater level measurements. A locking cabinet was installed over the well also houses the

electrical controls for the well (see photographs in Attachment B) and a receptacle for plugging in a generator for emergency power.

2.5.2 2013 Step-Rate Pumping Test

A 4.8-hour step-rate pumping test was completed in KCWD 97 Well No. 7 in 2013 using a temporary submersible pump. KCWD 97 Well No. 7 was pumped at rates of 568 to 710 gpm over 3 steps of increasing pumping rate. The duration of the pumping steps ranged from about 20 to 30 minutes for the first 2 steps to 240 minutes for the last step (GeoEngineers 2014a). The total drawdown at the end of the test was about 35.3 feet. About 11.2 feet and 10.8 feet of interference drawdown was observed in KCWD 97 Wells No. 5 and 6 at the end of the test; respectively. KCWD 97 Wells No. 5 and 6 are located about 80 feet from KCWD 97 Well No. 7. There was no mention of sand pumping during the pumping test.

Table 3 summarizes the observed drawdown and specific capacity at the end of each step. The specific capacity at the end of the first two steps of 20 and 30 minutes was 43.7 gpm/ft and 41.6 gpm/ft, respectively. The estimated 20-minute specific capacity for the third pumping step was 38.4 gpm/ft. The specific capacity at the end of the last step (after 240 minutes) was 35.3 gpm/ft. The drawdown had not stabilized at the end of each step. The specific capacities measured during the 2013 pumping test are significantly higher than the specific capacity of 15 gpm/ft measured after the well was drilled. The reason for this is unknown.

GeoEngineers (2014a) interpreted the results of the step-pumping test and groundwater level recovery following the step pumping test. They estimated that the portion of drawdown attributed to well losses (turbulent flow) increased from about 62 percent at 568 gpm to 67 percent at 710 gpm.

The recovery data were analyzed to estimate the aquifer transmissivity. The transmissivity was estimated to be about 6,600 ft^2/d similar to the transmissivity estimated from the Wells No. 5 and 6 recovery data.

2.5.3 Groundwater Quality

Inorganic water quality data obtained from the City and the Washington State Department of Health is summarized on Table 6 (one sample collected on May 27, 2014). Groundwater from KCWD 97 Well No. 7 meets all primary and secondary MCLs with the exception of iron, which was 0.58 mg/L, exceeding the secondary MCL of 0.3 mg/L. Manganese was just below the secondary MCL of 0.05 mg/L at 0.048 mg/L.

VOCs (including constituents associated with the gasoline contamination) have not been detected in KCWD 97 Well No. 7 based on seven samples collected between 2008 and 2016 with the exception of one detection of toluene (0.73 μg/L) in a sample collected in August 2008. SOCs (including pesticides and herbicides) have not been detected in the six samples collected between 2012 and 2016.

2.6 Summary of King County Water District 97 Wells

The following is a summary of KCWD 97 Wells No. 1 and 3 (Samena) and KCWD 97 Wells No. 5, 6, and 7 (Crossroads):

- The wells were drilled in the late 1950s and early 1960s. Well logs are only available for KCWD 97 Wells No. 3 and 7. The wells are completed in a 40- to 50-foot thick, confined, sand and gravel aquifer that is at an approximate elevation of 149 to 196 feet mean sea level.
- The City installed sanitary surface seals in designated emergency supply wells in 2008 (Wells No. 3, 5, 6, and 7).
- Video inspections of the wells completed in 2008 indicated the well screens and casings are encrusted or scaled to varying degrees, and the well screens are partially to completely backfilled with sand and/or scale. The well screen in Well No. 3 appears to be completely filled with sand and/or scale.
- The short-term pumping tests completed in 2013 indicated the wells could be pumped at the water right capacity in the present condition for at least short periods (i.e. days to weeks) with the exception of KCWD 97 Well No. 3 where pumping was restricted by the materials filling the screen. The longer-term water right pumping capacity is uncertain and will depend on pump depth sets, interference drawdown, and potential influence of aquifer boundaries on pumping water levels.
- The pumping tests completed in 2013 indicated the wells had varying amounts of turbulent flow losses which result in greater than anticipated drawdown during pumping. This could be attributed to the observed scaling or encrustation of the well screens, backfilling of the well screens with sediment and scale, or as a result of the original well construction or any reconstruction that was done.
- KCWD 97 Wells No. 3 and 7 are currently equipped with submersible pumps capable of pumping about 100 gpm. Wells No. 5 and 6 are housed in vaults with manhole lids, and Well No. 1 is housed in a small vault. Wells No. 1, 5, and 6 are not equipped with pumps.
- Groundwater quality data indicate that iron concentrations are above the secondary MCL in all of the wells and manganese concentrations are near the secondary MCL in KCWD 97 Wells No. 5 and 7 and above the secondary MCL in Well No. 3. Observations of floating biological materials in the water column in the wells and observations made by KCWD 97 when the wells were operating suggest iron bacteria may be present in the wells. Iron bacterial deposits may be responsible for the observed encrustation of the well screens and casings.
- The groundwater quality data indicates that VOCs have not been detected in KCWD 97 Wells No. 5, 6, or 7 with the exception of detections of toluene and styrene in Well No. 6 and toluene in Well No. 7 in samples collected in August 2008, however, it appears that there is residual shallow soil and groundwater contamination remaining at the Crossroads site. It is unknown if concentrations of VOCs could change if the wells were to be pumped for an extended period. No VOCs were detected in KCWD 97 Well No. 3 with the exception of one detection of toluene in August 2008.

3.0 KING COUNTY WATER DISTRICT 68 WELLS

KCWD 68 operated three wells. The locations of the KCWD 68 wells are shown in Figure 1. Well logs are available for all of the KCWD 68 wells. Information on the well construction based on the well logs is summarized on Table 1.

The KCWD 68 wells are completed over a range of depths in different aquifers that may correspond to the Qva (undifferentiated advance outwash), A3 (pre-Vashon permeable deposits), and A4 (combined) hydrostratigraphic units defined by Troost (2015).

Available well logs are included in Attachment A and photographs of the wells are included in Attachment B.

3.1 KCWD 68 Well No. 1

KCWD 68 Well No. 1 was drilled in 1946 to a depth of 1,125 feet bgs at a location near 106th Avenue NE and NE 10th Street. 24-inch diameter steel casing was installed to a depth of 170 feet bgs, 18-inch diameter steel casing was installed to a depth of 641 feet bgs, and 12-inch diameter steel casing was installed to a depth of 1,125 feet bgs. There is no information on the well log regarding a surface seal. Well No. 1 was completed with shutter perforations from 247 to 370 feet bgs, 530 to 621 feet bgs, and 974 to 1,115 feet bgs. The well casing appears to have been perforated in place using a casing perforator. The size of the perforations was not specified. The water right (G1*00182CWRIS, certificate number 00518) for KCWD 68 Well No. 1 specifies a Qi of 300 gpm and a Qa of 487 AF.

The well was pump tested after drilling at a rate of 600 gpm with 100 feet of drawdown. The depth to water prior to testing was about 120 feet bgs. The test duration was not specified.

KCWD 68 Well No. 1 was redeveloped in 1951. During the work, it was discovered that the well was filled with sand to a depth of 357 feet bgs and the pump impellers and shaft bearings were worn from sand pumping. The sand was removed from the well and the well was redeveloped by swabbing and chlorination. Following redevelopment, the well was pump tested at about 323 gpm, but the drawdown and duration were not specified.

Anecdotal information on groundwater quality in City records indicated methane and hydrogen sulfide were present in KCWD 68 Well No. 1, and water from the well was aerated prior to introduction to the distribution system.

KCWD 68 was forced to sell the property in 1961 to facilitate extension of 106th Ave NE. The parcel where KCWD 68 Well No. 1 was drilled was developed in the early 1980s as a Cadillac dealership. There is no information on whether KCWD 68 Well No. 1 was properly decommissioned at that time. The current property owner is planning to redevelop the site into a new mixed-use multi-family residential and commercial office building.

3.2 KCWD 68 Well No. 2

KCWD 68 Well No. 2 was drilled in 1947 to a depth of 1,056 feet bgs at a location on NE 6th Street between 102th Avenue NE and 104th Avenue NE (now Bellevue Way). The well log indicates 24-inch diameter steel casing was installed to a depth of 32 feet bgs, and 12-inch diameter steel casing was installed to a depth

of 485 feet bgs. There is no information on the well log regarding a surface seal. KCWD 68 Well No. 2 was completed with 8 rows per foot of 0.25-inch by 3-inch perforations from 270 to 475 feet bgs; the 12-inch diameter casing appears to have been perforated in-place using a casing perforator. There is no information on the well log on what was done to the borehole below 475 feet bgs. The water right (G1*00490CWRIS, certificate number 00360) for KCWD 68 Well No. 2 specifies a Qi of 700 gpm and a Qa of 780 AF.

The well was pump tested at the time of drilling at a rate of 900 gpm with 90 feet of drawdown. Prior to testing, the well was flowing at about 60 gpm indicating flowing artesian conditions. The test duration was not specified.

The parcel where KCWD 68 Well No. 2 was drilled was developed in the early 1980s as a small 6-unit apartment building. There is no information on whether KCWD 68 Well No. 2 was properly decommissioned at that time. Notes on a drawing provided by the City indicate the 8-inch water line to the well house was cut and capped in August 1957.

3.2.1 KCWD 68 Well No. 2 Site Visit

A site visit by the City, HDR, and Golder was made to the location of KCWD 68 Well No. 2 on November 2, 2017. The well was not found. Information from the City files suggests that the well is in the corner of a parcel now partly developed as a parking area for an apartment complex. The area where the well is thought to be located was partially in the paved parking lot and partially vegetated. The City arranged for utility locates in the area of the well. In addition, ground-penetrating radar and a utility locate tool (magnetometer) were used to attempt to locate the well and also locate the former service line from the well to the water main. Several locations outside the paved parking area were identified in the surveys and were potholed to a depth of about 5 to 6 feet using a vactor truck operated by the City. The magnetometer was also lowered into the excavations to evaluate the potential presence of nearby metallic objects (i.e. the steel well casing).

The well was not located in any of the excavations, and the former service line from the well was also not located. Several of the excavations encountered unmarked polyvinyl chloride (PVC) pipes that appeared to be stormwater pipes. One additional target was identified in the paved parking area that was potholed by the City on December 14, 2017. The well was not located during the second attempt.

3.3 KCWD 68 Well No. 3

KCWD 68 Well No. 3 was drilled in 1947 to a depth of 244 feet bgs at a location along the south side of Northup Way between 108th Avenue NE and 104th Ave NE (Bellevue Way). The well log indicates 24-inch diameter steel casing was installed to a depth of 48 feet bgs, and 12-inch diameter steel casing was installed to a depth of 244 feet bgs. There is no information on the well log regarding a surface seal. Well No. 3 was completed with 8 rows per foot of 0.25-inch by 3-inch perforations from 60 to 244 feet bgs. The casing

appears to have been perforated in place with a casing perforator. The water right (G1*00582CWRIS, certificate number 00521) for KCWD 68 Well No. 3 specifies a Qi of 700 gpm and a Qa of 780 AF.

The well was pump tested after drilling at a rate of 712 gpm with 72 feet of drawdown. The test duration was not specified. Prior to testing, the well was flowing but the flow rate was not given on the well log. Water from the well was observed to have a hydrogen sulfide odor.

Notes on a drawing provided by the City indicate the 8-inch water line to the well house was cut and capped in November 1959. There is a well log on file with Ecology dated October 2012 for the decommissioning of a 12-inch diameter well that appears to be KCWD 68 Well No. 3 based on location, well construction, and flowing artesian conditions. The decommissioning log indicates a 12-inch diameter, 182-foot-deep well was decommissioned by perforating the steel well casing and pressure grouting the well with neat cement grout. There is no information on the log indicating if the steel casing was cut off below the ground surface. Prior to decommissioning, the well was observed to be flowing at about 150 gpm. The decommissioning was performed as part of the Washington State Department of Transportation's State Route 520 improvements.

4.0 WASHINGTON WATER SERVICE COMPANY WELLS

WWSC operated two wells (Figure 1; Well No. 1 and the Hill-Aire Well). Well logs are available for the two wells. Information on well construction summarized from the well logs is in Table 1.

4.1 WWSC Well No. 1

WWSC Well No. 1 was drilled in 1954 to a depth of 105 feet bgs near the intersection of 150th Avenue SE and SE 38th Street. The well log indicates a 12-inch diameter steel casing was installed to a depth of 86 feet bgs, and 8-inch diameter steel casing was installed to a depth of 93 feet bgs. There is no information on the well log regarding a surface seal. Well No. 1 was completed with stainless steel wire-wrap well screen from 93 to 98 feet (0.060-inch or 60-slot) and from 98 to 103 feet (0.040-inch or 40-slot). The water right (G1*03251CWRIS, certificate number 02429) for WWSC Well No. 1 specifies a Qi of 300 gpm and a Qa of 480 AF.

The well was pump tested after drilling at a rate of 120 gpm. The drawdown of 96 feet reported on the log may be an error. The depth to water prior to testing was 51 feet bgs. The test duration was not specified.

Site plans dated 1971 for the retail development for the area of the well provided by the City include notes about removing a brick wellhouse. There is no information on whether the well was properly decommissioned. The City visited the well site area in April 2016 and could not locate any surface features indicative of the well.

4.2 WWSC Hill-Aire Well

The WWSC Hill-Aire Well was drilled in 1951 to a depth of 183 feet bgs on the south side of NE 6thth Street between 156th Avenue NE and 164th Avenue NE. The well log indicates an 8-inch diameter steel casing was installed to a depth of 183 feet bgs. There is no information on the well log regarding a surface seal. The well log reports the Hill-Aire Well was completed with stainless steel wire-wrap well screen from 183 to 193 feet bgs but does not specify a screen slot size and the reported screen depth is deeper than the well was reportedly drilled. The water right (G1*01214CWRIS, certificate number 02630) for the WWSC Hill Aire Well specifies a Qi of 80 gpm and a Qa of 40 AF. There is no information on the well log regarding any testing.

The WWSC Hill-Aire Well appears to have been taken out of service sometime in the late 1950s or early 1960s. The property where the well was developed was sold in 1967 to the adjacent landowner, but has not been redeveloped.

4.2.1 Site Visit

A site visit by the City, HDR, and Golder was made to the WWSC Hill-Aire Well on October 13, 2017. The well is located in the back yard of a residence at 16225 NE 6th Street. The City located the well and excavated the area around the well. The well was buried under about 2 to 3 feet of soil. A existing cap was welded onto the top of the casing, and was removed by the City for inspection. Limited excavation around the well casing did not indicate the presence of any surface seal materials such as bentonite or cement. The depth to water was measured at 124.11 feet btc once the cap was removed. The depth to water noted on the well log was 155 feet bgs; the date was not specified but was likely following completion of construction in 1954.

The City installed a temporary sampling pump in the well at a depth of about 175 feet bgs in order to collect a groundwater quality sample and to improve the clarity of the water column for the video log. The temporary pump was capable of pumping at about 10 gpm. The well was pumped for about 15 minutes at about 10 gpm before the pump shut down; the pump was restarted but no water was discharged. The pump was then lowered to about 185 feet bgs and restarted. The pump operated for a short period of time and then stopped. The pump was then pulled from the well. The water pumped from the well was reddish brown in color with some fine scale. A groundwater quality sample was not collected.

Following removal of the pump, a Laval R1000 downhole down- and side-looking video camera was used to collect a video log of the well. The following are observations from the video log:

- The inside of the well casing was observed to be heavily scaled and encrusted with what appeared to be iron oxide or hydroxide scale. Casing welds were visible in some areas. The welds appeared to be in relatively good condition with no evidence of seepage through any welds.

- The depth to water was about 176 feet btc at the time of logging. The water in the well was turbid, reducing visibility.
- The bottom of the well was intersected at about 193 feet btc. There appeared to be some fine sand and scale at the base of the well. Any well screen or perforations in the lower portion of the well (indicated to be from 183 to 193 feet bgs based on the well log) were not visible because of the heavy scale and incrustation and poor water visibility.

The well video was provided to the City via the City's file transfer site on October 14, 2017. Based on the results of the pumping with the temporary pump and the well video log, it appears that any perforations or well screen that was installed in the well are almost completely blocked with scale and encrustation, limiting groundwater inflow to the well.

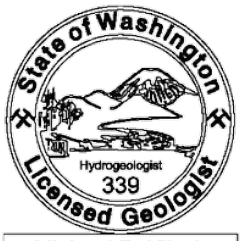
Following completion of the video log, the City welded the existing cap back onto the casing and backfilled the excavation around the well.

4.3 Summary of KCWD 68 and WWSC Wells

The following summarizes the condition of the KCWD 68 and WWSC Wells:

- All of the KCWD 68 and WWSC Wells were drilled between the mid-1940s and early 1950s. There is no information on the well logs regarding the presence of sanitary surface seals in any of the wells.
- There is only limited information on groundwater quality in the KCWD 68 and WWSC Wells in City records. The deep KCWD 68 wells were noted in City records as having hydrogen sulfide and methane present.
- All of the KCWD 68 and WWSC Wells appear to have been taken out of service sometime in the late 1950s or early 1960s.
- The current status of most of the wells is uncertain. All of the wells are located on property that has been redeveloped, but with the exception of KCWD 68 Well No. 3, there are no records of proper well decommissioning.
- The WWSC Hill-Aire Well is located in the backyard of a private residence under about 2 to 3 feet of fill and has not been decommissioned. The well casing and screen are heavily scaled and encrusted, and the well could not sustain pumping at a rate of 10 gpm.

GOLDER ASSOCIATES INC.



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5.0 REFERENCES

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TABLES

Table 1: City of Bellevue Well Information

Well Number	Location	Date Drilled	Depth Drilled (feet bgs)	Diameter (inches)	Completion Interval (feet bgs)	Completion Type	Surface Seal	Water Right File Number	Water Right Certificate Number	Instantaneous Water Right (gpm)	Annual Water Right (acre-feet)	Notes
KCWD 97 Well No. 1	Samena	1955	160	12	130 to 160	Wire wrap screen, 40 slot	Unknown	G1-*04058C	03539	400	450	No pump installed
KCWD 97 Well No. 3		1956	229	12	195 to 220	Wire wrap screen?, 20 and 30 slot	Cement/ Concrete	G1-*06472C	3252	850	1,360	Pump installed, DOH Emergency Well
KCWD 97 Well No. 5	Crossroads	1959	293	8	263 to 293	Wire wrap well screen, unknown	Cement/ Concrete	G1-*06470C	4454	500	800	No well log, no pump installed, DOH Emergency Well
KCWD 97 Well No. 6		1959	302	16	282 to 302	Wire wrap well screen, unknown	Cement/ Concrete	G1-*06472C	4453	600	750/210[a]	No well log, no pump installed, DOH Emergency Well
KCWD 97 Well No. 7		1963	300	12	275 to 299	Wire wrap screen, 40 and 60 slot	Cement/ Concrete	G1-*06350C	4391	700	1,120	Pump installed, DOH Emergency Well
KCWD 68 Well No. 1	KCWD 68	1946	1,125	12	247 to 370 530 to 621 974 to 1,115	Perforated/ Shutter Screen	Unknown	G1-*00182C	00518	300	487	Unknown condition
KCWD 68 Well No. 2		1947	1,056	12	270 to 475	0.25"x4" perforations, 8	Unknown	G1-*00490C	00360	700	780	Unknown condition
KCWD 68 Well No. 3		1947	244	12	60 to 244	0.25"x3" perforations, 8	Unknown	G1-*00582C	00521	700	780	Decommissioned 2012
WWSC Well No. 1	WWSC	1954	105	8	93 to 103	Wire wrap screen, 40 and 60 slot	Unknown	G1-*03251C	02429	300	480	Decommissioned?
WWSC Hill-Aire		Unknown	183	8	183 to 193?	Unknown	Unknown	G1-*01214C	02630	80	40	Capped and buried

Notes:
bgs - below ground surface
gpm - gallons per minute
See Figure 1 for well locations
a. 750 acre-feet additive, 210 acre-feet supplemental (non-additive)

Table 2: Post-Construction Well Testing Information

Location	Well Number	Depth to Water at Time of Test (feet bgs)	Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity (gpm/ft)	Duration (hours)
Samena	KCWD 97 Well No. 1	102	420	140	3.0	na
	KCWD 97 Well No. 3	102	900	93	9.7	na
Crossroads	KCWD 97 Well No. 5	na	na	na	na	na
	KCWD 97 Well No. 6	na	na	na	na	na
	KCWD 97 Well No. 7	170	590	38	15.5	na
KCWD 68	KCWD 68 Well No. 1	120	600	100	6.0	na
	KCWD 68 Well No. 2	Flowing 60 gpm	900	57	15.8	na
	KCWD 68 Well No. 3	Flowing	712	75	9.5	na
WWSC	WWSC Well No. 1	51	120	96	1.3	na
	WWSC Hill-Aire	155	na	na	na	na

Notes:
na - no information
gpm - gallons per minute
a. 750 acre-feet additive, 210 acre-feet supplemental

Table 3: 2013 Well Testing Summary

Well Number	Pumping Rate (gpm)	Drawdown (feet)	Specific Capacity at End of Step (gpm/ft)	Step Duration (minutes)	Notes
KCWD 97 Well 3 (Samena)	100	10.8	9.3	40	
	137	15	9.1	40	
	190	21.1	9.0	40	
	236	26.8	8.8	40	
	312	35.6	8.8	61	
KCWD 97 Well 5 (Crossroads)	100	3	33.3	20	
	200	5.8	34.5	20	
	280	9.1	30.8	20	
	380	13.4	28.4	21.5	
	480	17.6	27.3	20	Estimated
	480	17.9	26.8	119.5	
KCWD 97 Well 6 (Crossroads)	95	4.2	22.6	18.5	
	195	10	19.5	15	
	300	19.7	15.2	15	
	400	27.6	14.5	15	
	450	36.5	12.3	15	Estimated
	450	38	11.8	61	
KCWD 97 Well 7 (Crossroads)	568	13	43.7	20	
	624	15	41.6	30	
	710	18.5	38.4	20	Estimated
	710	20.1	35.3	240	

Notes:

Summarized from GeoEngineers (2014 a, b)

Shaded specific capacity estimated from plots presented in GeoEngineers (2014 a, b)

Table 4: KCWD 97 Well No. 3 Inorganic Groundwater Quality

Analyte Name	Maximum Contaminant Level	Units	December 21, 2011		August 20, 2013		May 27, 2014		August 20, 2015		October 24, 2016	
			Result Range	Result	Result Range	Result	Result Range	Result	Result Range	Result	Result Range	Result
Primary Constituents												
ANTIMONY	0.006	mg/L	LT	0.005	LT	0.006	LT	0.006	LT	0.006	LT	0.006
BARIUM	2	mg/L	LT	0.1	LT	0.4	LT	0.4	LT	0.4	LT	0.4
BERYLLIUM	0.004	mg/L	LT	0.003	LT	0.0008	LT	0.0008	LT	0.0008	LT	0.0008
CADMIUM	0.005	mg/L	LT	0.002	LT	0.002	LT	0.002	LT	0.002	LT	0.002
CHROMIUM	0.1	mg/L	LT	0.01	LT	0.02	LT	0.02	LT	0.02	LT	0.02
COPPER[a]	1.3	mg/L	LT	0.2	LT	0.02	LT	0.02	LT	0.02	LT	0.02
CYANIDE	0.2	mg/L	LT	0.05	LT	0.01	LT	0.01	LT	0.01	LT	0.01
FLUORIDE	4	mg/L	LT	0.2	LT	0.5	LT	0.5	LT	0.5	LT	0.2
LEAD[a]	0.015	mg/L	LT	0.002	LT	0.001	LT	0.001	LT	0.001	LT	0.001
MERCURY	0.002	mg/L	LT	0.0005	LT	0.0004	LT	0.0004	LT	0.0004	LT	0.0004
NICKEL	0.1	mg/L	LT	0.04	LT	0.1	LT	0.1	LT	0.1	LT	0.1
NITRATE-N	10	mg/L	LT	0.05	LT	0.2	LT	0.2	LT	0.2	LT	0.2
NITRITE-N	1	mg/L	LT	0.05	LT	0.2	LT	0.2	LT	0.2	LT	0.2
SELENIUM	0.05	mg/L	LT	0.005	LT	0.01	LT	0.01	LT	0.01	LT	0.01
SODIUM[b]	20	mg/L	LT	5	EQ	5.1	EQ	5.4	EQ	5.2	EQ	5.7
THALLIUM	0.002	mg/L	LT	0.002	LT	0.002	LT	0.002	LT	0.002	LT	0.002
TOTAL NITRATE/NITRITE	10	mg/L	LT	0.05	LT	0.5	LT	0.5	LT	0.5	LT	0.5
Secondary and Physical Constituents												
CHLORIDE	250	mg/L	LT	20	LT	20	LT	20	LT	20	LT	20
COLOR	15	CU		15	LT	15	LT	15	LT	15	LT	15
CONDUCTIVITY	700	Umhos/cm		130	EQ	130	EQ	140	EQ	140	EQ	120
HARDNESS	NC	mg/L		46	EQ	54	EQ	58	EQ	58	EQ	57
IRON	0.3	mg/L		0.12	EQ	0.1	EQ	0.13	LT	0.1	EQ	0.67
MANGANESE	0.05	mg/L		0.053	EQ	0.055	EQ	0.06	EQ	0.05	EQ	0.049
pH	6 to 9	pH Units		6.8	EQ	7.7	EQ	7	EQ	7.2		NA
SILVER	0.1	mg/L	LT	0.1	LT	0.1	LT	0.1	LT	0.1	LT	0.1
SULFATE	250	mg/L		11	LT	50	LT	50	LT	50	LT	50
TDS-TOTAL DISSOLVED SOLIDS	500	mg/L		NA	LT	100	LT	100	EQ	120	LT	100
TURBIDITY	NC	NTU		0.78	EQ	0.69	EQ	0.25	EQ	0.17	EQ	1.9
ZINC	5	mg/L	LT	0.2	LT	0.2	LT	0.2	LT	0.2	EQ	3.1

Notes:
Data from Washington State Department of Health Sentry Database (https://fortress.wa.gov/doh/eh/portal/odw/si/FindWaterQuality.aspx)
Shaded cells exceed Maximum Contaminant Level
EQ - equals
LT - less than
NC - no criteria
NA - not analyzed
a - action level
b - advisory level

Table 5: KCWD 97 Well No. 5 Inorganic Groundwater Quality

Analyte Name	Maximum Contaminant Level	Units	August 12, 2013		August 20, 2015		October 24, 2016	
			Result Range	Result	Result Range	Result	Result Range	Result
Primary Constituents								
ANTIMONY	0.006	mg/L	LT	0.006	LT	0.006	LT	0.006
BARIUM	2	mg/L	LT	0.4	LT	0.4	LT	0.4
BERYLLIUM	0.004	mg/L	LT	0.0008	LT	0.0008	LT	0.0008
CADMIUM	0.005	mg/L	LT	0.002	LT	0.002	LT	0.002
CHROMIUM	0.1	mg/L	LT	0.02	LT	0.02	LT	0.02
COPPER[a]	1.3	mg/L	LT	0.02	LT	0.02	LT	0.02
CYANIDE	0.2	mg/L	LT	0.01	LT	0.01	LT	0.01
FLUORIDE	4	mg/L	LT	0.5	LT	0.5	EQ	0.19
LEAD[a]	0.015	mg/L	LT	0.001	LT	0.001	LT	0.001
MERCURY	0.002	mg/L	LT	0.0004	LT	0.0004	LT	0.0004
NICKEL	0.1	mg/L	LT	0.1	LT	0.1	LT	0.1
NITRATE-N	10	mg/L	LT	0.2	LT	0.2	LT	0.2
NITRITE-N	1	mg/L	LT	0.2	LT	0.2	LT	0.2
SELENIUM	0.05	mg/L	LT	0.01	LT	0.01	LT	0.01
SODIUM[b]	20	mg/L	EQ	7.2	EQ	7.3	EQ	7.8
THALLIUM	0.002	mg/L	LT	0.002	LT	0.002	LT	0.002
TOTAL NITRATE/NITRITE	10	mg/L	LT	0.5	LT	0.5	LT	0.5
Secondary and Physical Constituents								
CHLORIDE	250	mg/L	LT	20	LT	20	LT	20
COLOR	15	CU	LT	15	LT	15	LT	15
CONDUCTIVITY	700	Umhos/cm	EQ	120	EQ	120	EQ	110
HARDNESS	NC	mg/L	EQ	44	EQ	44	EQ	44
IRON	0.3	mg/L	EQ	0.6	EQ	0.65	EQ	0.82
MANGANESE	0.05	mg/L	EQ	0.044	EQ	0.043	EQ	0.04
pH	6 to 9	pH Units	EQ	7.4	EQ	7		na
SILVER	0.1	mg/L	LT	0.1	LT	0.1	LT	0.1
SULFATE	250	mg/L	LT	50	LT	50	LT	50
TDS-TOTAL DISSOLVED SOLIDS	500	mg/L	LT	100	EQ	100	LT	100
TURBIDITY	NC	NTU	EQ	0.33	EQ	0.45	EQ	0.72
ZINC	5	mg/L	LT	0.2	LT	0.2	EQ	0.58

Notes:

Data from Washington State Department of Health Sentry Database (https://fortress.wa.gov/doh/eh/portal/odw/si/FindWaterQuality.aspx)

Shaded cells exceed Maximum Contaminant Level

EQ - equals

LT - less than

NC - no criteria

NA - not analyzed

a - action level

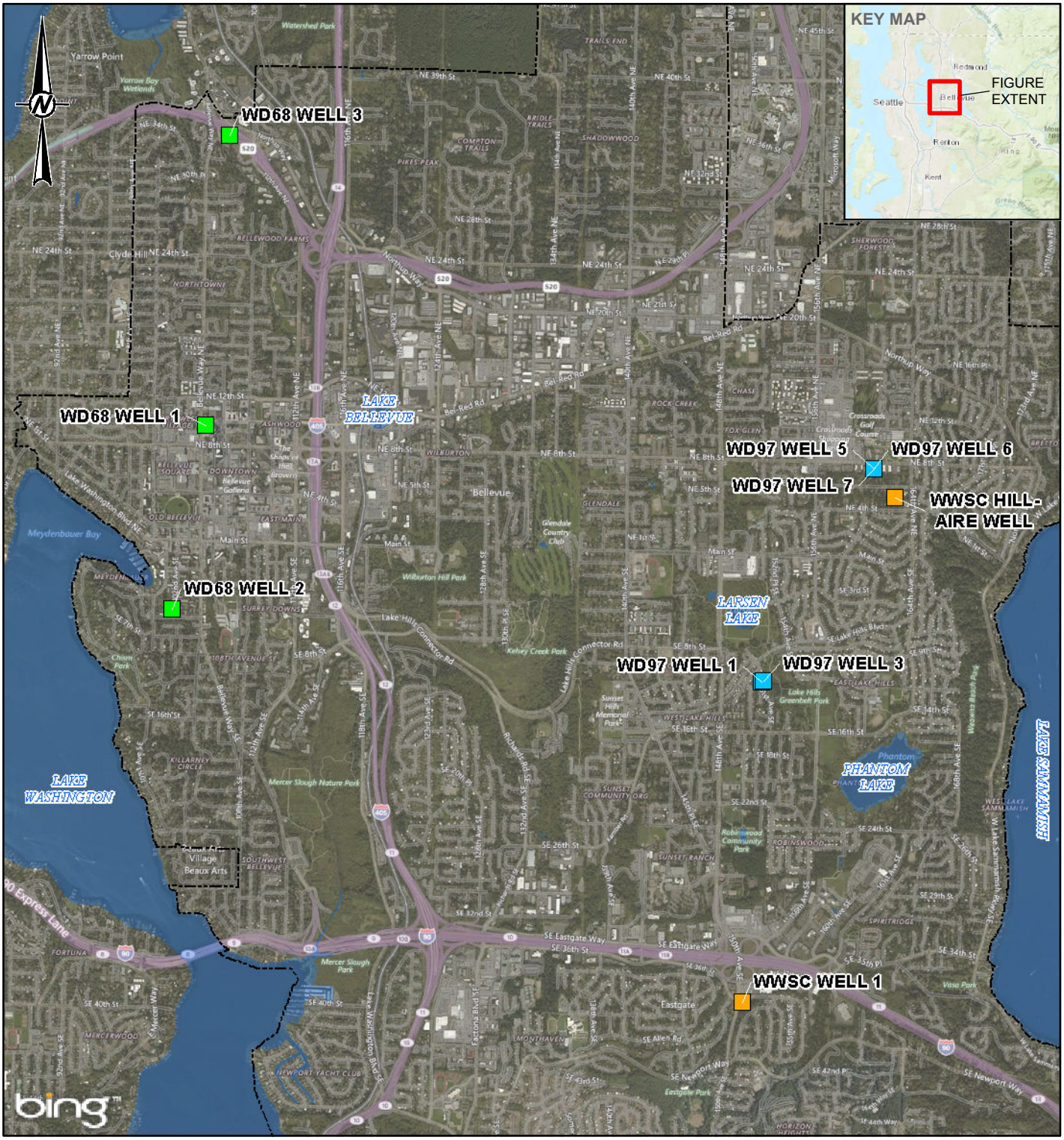
b - advisory level

Table 6: KCWD 97 Well No. 7 Inorganic Groundwater Quality

Analyte Name	Maximum Contaminant Level	Units	May 27, 2014	
			Result Range	Result
Primary Constituents				
ANTIMONY	0.006	mg/L	LT	0.006
BARIUM	2	mg/L	LT	0.4
BERYLLIUM	0.004	mg/L	LT	0.0008
CADMIUM	0.005	mg/L	LT	0.002
CHROMIUM	0.1	mg/L	LT	0.02
COPPER[a]	1.3	mg/L	LT	0.02
CYANIDE	0.2	mg/L	LT	0.01
FLUORIDE	4	mg/L	LT	0.5
LEAD[a]	0.015	mg/L	LT	0.001
MERCURY	0.002	mg/L	LT	0.0004
NICKEL	0.1	mg/L	LT	0.1
NITRATE-N	10	mg/L	LT	0.2
NITRITE-N	1	mg/L	LT	0.2
SELENIUM	0.05	mg/L	LT	0.01
SODIUM[b]	20	mg/L	EQ	7.4
THALLIUM	0.002	mg/L	LT	0.002
TOTAL NITRATE/NITRITE	10	mg/L	LT	0.5
Secondary and Physical Constituents				
CHLORIDE	250	mg/L	LT	20
COLOR	15	CU	LT	15
CONDUCTIVITY	700	Umhos/cm	EQ	120
HARDNESS	NC	mg/L	EQ	47
IRON	0.3	mg/L	EQ	0.58
MANGANESE	0.05	mg/L	EQ	0.048
pH	6 to 9	pH Units	EQ	6.6
SILVER	0.1	mg/L	LT	0.1
SULFATE	250	mg/L	LT	50
TDS-TOTAL DISSOLVED SOLIDS	500	mg/L	EQ	100
TURBIDITY	NC	NTU	EQ	0.68
ZINC	5	mg/L	LT	0.2

Notes:
Data from Washington State Department of Health Sentry Database - (https://fortress.wa.gov/doh/eh/portal/odw/si/FindWaterQuality.aspx)
Shaded cells exceed Maximum Contaminant Level
EQ - equals
LT - less than
NC - no criteria
NA - not analyzed
a - action level
b - advisory level

FIGURE



LEGEND

- KING COUNTY WATER DISTRICT 68 WELL
- KING COUNTY WATER DISTRICT 97 WELL
- WASHINGTON WATER SERVICE COMPANY WELL
- BELLEVUE CITY LIMITS
- LAKE

0 2,000 4,000 8,000

Feet

REFERENCE(S)

1. TROOST GEOSCIENCES (WELL LOCATIONS, CITY LIMITS)
2. COORDINATE SYSTEM: NAD 1983 STATE PLANE WASHINGTON NORTH (FT)
3. SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, DELORME, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), SWISSTOPO, MAPMYINDIA, © OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY

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CLIENT
STANTEC

PROJECT
CITY OF BELLEVUE EMERGENCY WATER SUPPLY MASTER PLAN

TITLE
WELL LOCATION MAP

CONSULTANT
Golder Associates

YYYY-MM-DD	2018-01-17
DESIGNED	BVJ
PREPARED	BVJ
REVIEWED	MK
APPROVED	MK

PROJECT NO.	PHASE	REV.	FIGURE
1775477	3.1	0	1

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

PATH: G:\Stantec\City of Bellevue\98 PROJECTS\1775477 WaterRightsMasterPlan\3.1\02 PRODUCTION\MXD\FIGURES\Rev0\1775477 3.1 001 F1 Rev0 WellLocations.mxd

ATTACHMENT A
WELL LOGS

KCWD 68 Well #3 Decommissioning Log

DEPARTMENT OF ECOLOGY
State of Washington

WATER WELL REPORT

Original & 1st copy – Ecology, 2nd copy – owner, 3rd copy – driller

Construction/Decommission *("x" in circle)*

☐ Construction

☒ Decommission *ORIGINAL INSTALLATION*

Notice of Intent Number N/A

PROPOSED USE: ☐ Domestic ☐ Industrial ☐ Municipal ☐ DeWater ☐ Irrigation ☐ Test Well ☐ Other _____

TYPE OF WORK: Owner's number of well (if more than one) _____

☐ New well ☐ Reconditioned *Method:* ☐ Dug ☐ Bored ☐ Driven ☐ Deepened ☐ Cable ☐ Rotary ☐ Jetted

DIMENSIONS: Diameter of well 12 inches, drilled 182 ft.
Depth of completed well 182 ft.

CONSTRUCTION DETAILS

Casing Installed: ☒ Welded 12" Diam. from 0 ft. to 182 ft.
☐ Liner installed _____" Diam. from _____ ft. to _____ ft.
☐ Threaded _____" Diam. From _____ ft. to _____ ft.

Perforations: ☒ Yes ☐ No

Type of perforator used NA

SIZE of perfs .25 in. by 3 in. and no. of perfs 3 from 40 ft. to 182 ft.

Screens: ☐ Yes ☐ No ☐ K-Pac Location _____

Manufacturer's Name _____

Type _____ Model No. _____

Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Gravel/Filter packed: ☐ Yes ☐ No Size of gravel/sand _____

Materials placed from _____ ft. to _____ ft.

Surface Seal: ☐ Yes ☐ No To what depth? _____ ft.

Material used in seal _____

Did any strata contain unusable water? ☐ Yes ☐ No

Type of water? _____ Depth of strata _____

Method of sealing strata off _____

PUMP: Manufacturer's Name _____

Type: _____ H.P. _____

WATER LEVELS: Land-surface elevation above mean sea level _____ ft.

Static level _____ ft. below top of well Date _____

Artesian pressure _____ lbs. per square inch Date _____

Artesian water is controlled by _____ (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level

Was a pump test made? ☐ Yes ☐ No If yes, by whom? _____

Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.

Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.

Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test _____

Bailer test _____ gal./min. with _____ ft. drawdown after _____ hrs.

Airtest _____ gal./min. with stem set at _____ ft. for _____ hrs.

Artesian flow 150 g.p.m. Date 10/2/12

Temperature of water _____ Was a chemical analysis made? ☐ Yes ☒ No

CURRENT

Notice of Intent No. AE19194

Unique Ecology Well ID Tag No. N/A

Water Right Permit No. N/A

Property Owner Name WSDOT

Well Street Address NE Northup Way & 520

City Bellevue County King-17

Location SE 1/4-1/4 NW 1/4 Sec 20 Twn 25N R 5E **(s, t, r Still REQUIRED)** EWM ☒ Or WWM ☐

Lat/Long Lat Deg na Lat Min/Sec na
Long Deg na Long Min/Sec na

Tax Parcel No. (Required) N/A

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
Water Well was decommissioned		
by pumping Neat Cement via 3"		
pipe from the bottom of the		
hole to land surface.		
Pumped at a rate of 300-2000		
psi. A total of 8-9 yards of		
cement was pumped into the		
well from the bottom to the		
top.	0	180

Start Date 10/2/12 Completed Date 10/2/12

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee Name (Print) Chris V. Gregory	Drilling Company Gregory Drilling Inc.
Driller/Engineer/Trainee Signature	Address 17609 NE 70th St.
Driller or trainee License No. 2534	City, State, Zip Redmond , WA, 98052
IF TRAINEE: Driller's License No:	Contractor's Registration No. GREGODI110JP Date 10/2/12
Driller's Signature:	

ECY 050-1-20 (Rev 02/10) *If you need this document in an alternate format, please call the Water Resources Program at 360-407-6872. Persons with hearing loss can call 711 for Washington Relay Service. Persons with a speech disability can call 877-833-6341.*

KCWD 97 Well No. 1
(page 1 of 2)

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION AND DEVELOPMENT

WELL LOG No Appli.#4058 Cert. 2539-A

Date July 30, 1955

Record by Howard T. Harstad

Source driller's record

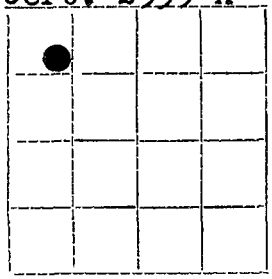

Diagram of Section

24N/5E-2D
File number

Location State of WASHINGTON

County King

Area

Map

NW ¼ NW ¼ sec 2 T 24N, R 5 E ~~W~~

Drilling Co Howard T. Harstad

Address Seattle, Wash.

Method of Drilling Date Aug. 15, 1955

Owner King Co. Water Dist. #97

Address Bellevue, Wash.

Land surface, datum ft above / below

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary in parentheses If material water-bearing, so state and record static level if reported Give depths in feet below land-surface datum unless otherwise indicated Correlate with stratigraphic column if feasible Following log of materials, list all casings perforations screens etc.)		
	~~Nxxxxxxxxxxxxxxxxxxxx~~ (See back for well log)		
	Dim. 160'x12"		
	SWL: 102 ft.		
	DD: 140 ft.		
	Yield: 420 g.p.m.		
	Temp. 52°		
	CASING:		
	12".I.D. steel 44# casing from 0 to 130 ft.		
	Perforations:		
	wire wound silicon bronze 0.040" screen from 130 to 160 ft.		

Turn up Sheet of sheets

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KCWD 97 Well No. 1
(page 2 of 2)

WELL LOG—Continued No / -

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	———	
	Hardpan	20	20
	Coarse sand, waterbearing	22	42
	Blue clay	42	84
	Fine sand- some water	3	87
	Impervious clay	26	113
	Coarse gravel & rocks water bearing	22	135
	Coarse sand, gravel & rocks, water bearing	21	154
	Consolidated clay	2	156
	Coarse sand & gravel water bearing	4	160

S F No 7448—12-54—3M 62108

KCWD 97 Well No. 3 (page 1 of 2)

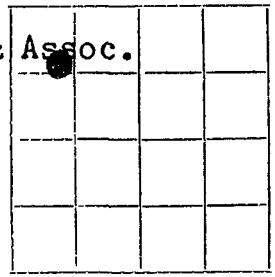
STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION AND DEVELOPMENT

WELL LOG No Appli. 4201

Date Feb. 16 , 19 56

Record by Howard T. Haarstad & Assoc.

Source driller's record



Location State of WASHINGTON

County King

Lot 8, Blk. 5 of Evergreen Add. #2 to Eastgate Hills

¼ ¼ sec 2 T 24 N, R 5 E

Drilling Co Howard T. Haarstad & Assoc.

Address Seattle

Method of Drilling Date Mar. 1 , 19 56

Owner King Co. Water Dist. #97

Address Seattle, Wash.

Land surface, datum ft above / below

24N/5E-2D.
File number

Correlation	Material	Thickness (feet)	Depth (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary in parentheses If material water-bearing so state and record static level if reported Give depths in feet below land surface datum unless otherwise indicated Correlate with stratigraphic column, if feasible Following log of materials list all casings perforations, screens, etc)		
	Sand & clay	38	38
	Water bearing sand	5	43
	Silt & clay	25	68
	Clay	16	84
	Silt clay	28	112
	Hardpan (cement sand & gravel)	8	120
	Silt & gravel (water bearing)	30	150
	Sand & gravel "	9	159
	Hardpan (clay & sand)	16	175
	Coarse tofine sand (water bearing)	48	223
	Silt and clay	6	229

Turn up Sheet of sheets

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WELL LOG —Continued No /

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	KCWD 97 Well No. 3 (page 2 of 2) Depth forward	———	
	PUMP TEST		
	Dim. 220'x18x12"		
	SWL: 102 ft.		
	DD: 93 ft.		
	Yield: 900 g.p.m.		
	CASING:		
	Outside-18" diam. 59#/ft steel		
	from 0 to 187 ft.		
	Inside- 12" diam. 44#/ft steel		
	from 0 to 220 ft.		
	PERFORATIONS:		
	Red Brass 0.030" from 195 to 215 ft.		
	" " 0.020" " 215 to 220 ft.		

S F No 7448—12-54—3M 40108

KCWD 97 Well No. 7
(page 1 of 2)

STATE OF WASHINGTO
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

WELL LOG No A.6350

Date 8-1, 1962

Record by well driller

Source driller's record

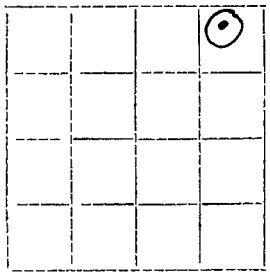

Diagram of Section

25/15E/35A
File number

Location State of WASHINGTON

County King

Area

Map

¼ ¼ sec 35 ~~2~~ T ~~24~~ 25 N, R 5 E ~~WX~~

Drilling Co Harstad Associates

Address Seattle, Wash.

Method of Drilling Date June 14, 1962

Owner King Co. Water Dist. #97

Address 16049 N.E. 8th St., Bellevue, Wash.

Land surface, datum ft above / below

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary in parentheses. If material water bearing so state and record static level if reported. Give depths in feet below land surface datum unless otherwise indicated. Correlate with stratigraphic column if feasible. Following log of materials list all casings, perforations, screens, etc.)		
	Top soil	2	2
	Gravel sandy clay brown	~~10~~	~~12~~
	Gravel sandy clay gray	63	75
	Hardpan	10	85
	Sand & gravel brown	49	134
	Brown clay & sand	54	188
	Water bearing sand	5	193
	Gravel sandy clay w/org.	5	198
	Hardpan	14	212
	Sand gravel & clay	4	216
	Coarse gravel- dry	11	227
	Gravel sand & blue clay	5	232
	Water bearing sand	5	237
	Sand & gray clay	11	248
	Sand & lumps of brown clay	4	252
	Sand gravel & clay	1	253
	Coarse rock & small amt. sand	17	270

Turn up (over) Sheet of sheets

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WELL LOG —Continued No / -

KCWD 97 Well No. 7
(page 2 of 2)

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	———	270
	Coarse gravel & sand	27	297
	Cemented gravel	3	300
	PUMP TEST:		
	Dim. 12"x299'		
	SWL: 170 ft. (6-14-62)		
	DD: 38 ft.		
	Yield; 590 g.p.m.		
	Type & size of pump: Turbine		
	Type & size of motor: U.S.Part winding; 1700 rpm. 440 volts		
	CASING:		
	12" diam. std. steel casing from 0 to 275 ft.		
	PERFORATIONS:		
	12" well screen 60 mesh from 275 to 284 ft.		
	12" well screen 40 mesh from 284 to 299 ft.		

S P No 7449—OS—6-61—2M

KCWD 68 Well No. 1
(page 1 of 2)

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

No Appli. #182
Cert. #518A

Date July 25, 1946
Record by W. R. Hill
Source Driller record

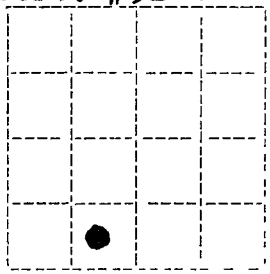
DIAGRAM OF SECTION

Location State of WASHINGTON
County King
Area
Map
SE ¼ SW ¼ sec 29 T 25 N, R 5 E W

Drilling Co N. C. Jannsen Drilling Co.
Address P. O. Box 3185; Seattle 14, Wn.
Method of Drilling Date Aug. 2 1946
Owner King County Water Dist. #68
Address Bellevue, Washington
Land surface, datum ft above / below

25N/5E-29P
File number

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Sand	0	20
	Sand & large boulders	10	30
	Fine sand & small gravel	30	60
	Hard packed sand & gravel	10	70
	Rock & hard gravel	13	83
	Sand & gravel	15	98
	Sandy clay	24	122
	Sand	48	170
	Hard packed gravel	9	179
	Gravel	8	187
	Clay	60	247
	Sand	15	262
	Small gravel	16	278
	Clay	13	291
	Small gravel	59	350
	(over)		

(Transcribe driller's terminology literally but paraphrase as necessary in parentheses If material water bearing so state and record static level if reported Give depths in feet below land surface datum unless otherwise indicated Correlate with stratigraphic column if feasible Follow ing log of materials list all casings perforations screens etc)

Turn up

Sheet of sheets

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KCWD 68 Well No. 1
(page 2 of 2)

WELL LOG —Continued No_____/_____-_____

Corre-	Material	Thickness (feet)	Depth (feet)
	Depth forward	———	
	Sandy clay	60	410
	Sand	40	450
	Clay	10	460
	Sandy clay	80	540
	Sand	10	550
	Loose gravel	16	566
	Hard sandstone	8	574
	Gravel	10	584
	Clay	12	596
	Gravel	25	621
	Clay	19	640
	Fine sand	10	650
	Hard packed sand & gravel	10	660
	Clay	30	690
	Fine sand & gravel	20	710
	Clay	216	926
	Sandy clay	49	975
	Sticky clay	19	994
	Sand with streaks of hard shale	26	1020
	Sand & small gravel with streaks of shale	95	1115
	Sandy clay	10	1125
	Pump test:		
	Dim: 1125' x 24"; SWL: 120'; D.D. 100';		
	Yield: 600 g.p.m.; Casing: 18" dia.		
	from 0 to 641'; 24" dia. from 0 to 170';		
	12" dia. from 641 to 1125'.		
	Perforations: perforated - shutter from		
	247-370; 530-621; 974-1115.		

KCWD 68 Well No.2
(page 1 of 2)

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

No Appli. #490
Cert. #360A

Date July 1, 19 47

Record by F. C. Yett

Source Driller record

Location State of WASHINGTON

County King

Area

Map

SW ¼ SW ¼ sec 32 T 25 N, R 5 E W

DIAGRAM OF SECTION

Drilling Co N. C. Jannsen Drilling & Mfg. Co.

Address 9407 E. Marginal Way; Seattle

Method of Drilling Date July 1 1947

Owner King Co. Water Dist. #68

Address Bellevue, Washington

Land surface, datum ft above / below

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Topsoil	10	10
	Sandy clay	10	20
	Hard pan w/streaks gravel	60	80
	Sand	70	150
	Coarse sand	20	170
	Fine sand	80	250
	Coarse sand	10	260
	Sand medium	30	290
	Sand	10	300
	Coarse sand	10	310
	Sand	10	320
	Sand & clay	10	330
	Sand & gravel	10	340
	Coarse gravel	25	365
	Blue clay	13	378
	(over)		

(Transcribe driller's terminology literally but paraphrase as necessary in parentheses If material water bearing so state and record static level if reported Give depths in feet below land surface datum unless otherwise indicated Correlate with stratigraphic column if feasible Following log of materials list all casings perforations screens etc)

Turn up

Sheet of sh

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WELL LOG —Continued No_____/_____-___

KCWD 68 Well No.2
(page 2 of 2)

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	———	
	Sand & gravel	68	458
	Coarse sand	5	463
	Sand hard packed	22	485
	" " "	37	522
	Clay & sand (dry)	534	1056
	Pump test:		
	Dim: 1056' x 24"		
	SWL: 0 ARTESIAN 60 g.p.m.		
	D.D. 57'		
	Yield: 900 g.p.m.		
	Casing: 24" dia. from 0 to 32'		
	12" dia. from 0 to 485'		
	Perforations: 8 rows per foot 1/4" x 3" horizontal beveled from 270 to 475 ft.		

KCWD 68 Well No. 3
(page 1 of 2)

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

WELL LOG

No Appli. #582
Cert. #521A

Date August, 1947
Record by F. C. Yett
Source Driller record

Location State of WASHINGTON
County King
Area
Map

SE ¼ NW ¼ sec 20 T 25 N, R 5 E W

DIAGRAM OF SECTION

Drilling Co N. C. Jannsen Drilling & Mfg. Co.
Address 9407 E. Marginal Way; Seattle, Wash.
Method of Drilling Date August 1947
Owner King County Water District #68
Address Bellevue, Washington
Land surface, datum ft above / below

25N/5E-20F
File number

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Clay	5	5
	Sand	10	15
	Coarse sand	17	32
	Clay	8	40
	Sand	10	50
	Sand & gravel	15	65
	Gravel	20	85
	Coarse sand	46	131
	Coarse sand & gravel	45	176
	Gravel	52	228
	Clay	16	244
	Pump test:		
	Dim: 244' x 24"		
	SWL: 0'		
	(over)		

(Transcribe driller's terminology literally but paraphrase as necessary in parentheses If material water bearing so state and record static level if reported Give depths in feet below land surface datum unless otherwise indicated Correlate with stratigraphic column if feasible Follow ing log of materials list all casings perforations screens etc)

Turn up

Sheet of sheets

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WELL LOG —Continued No._____/_____-_____

KCWD 68 Well No. 3
(page 2 of 2)

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	———	
	D.D. 75'		
	Yield 712 g.p.m.		
	Casing: 24" dia. from 0	to 48'	
	12" dia. from 0	to 244'	
	Perforations: perforated ¼" x 3"		
	horizontal beveled 8 rows	per ft.	
	from 60' to 244'.		

S F 7449 46 RI MINGTON INC 20 20 745-2 46

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WWSC Hill Aire Well

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION AND DEVELOPMENT

WELL LOG

No Appli. #1214
Permit #1077

Date not completed, 19

Record by E. F. Axelson

Source well driller's record

Location State of WASHINGTON

County King

Area

~~Map~~ Lot 4 Block 2

¼ ¼ sec 35 T 25 N, R 5 E ~~W~~

Diagram of Section

Drilling Co

Address

Method of Drilling drilled Date , 19

Owner Washington Water Service Co. Inc.

Address Bellevue, Washington

Land surface, datum ft above / below

25N/5E-35A
File number

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary in parentheses If material water-bearing so state and record static level if reported Give depths in feet below land-surface datum unless otherwise indicated Correlate with stratigraphic column, if feasible Following log of materials list all casings perforations, screens, etc)		
	Surface soil	5	5
	Hard pan	65	70
	Gravel & sand-some clay	85	155
	Gravel, sand & water	15	170
	Sand & water	13	183
Pump Test:			
	Dim: 183' x 8"		
	SWL: 155'		
	Dd: - Yield: 150 g.p.m. (permit)		
	Perfor: screen test from 183 to 193'		
	Pump: not decided		

Turn up Sheet of sheets

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WWSC Well No. 1

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

Well #2
WELL LOG

No Appl. #3251
Permit #3043

Date February , 19 54

Record by M.S. Campbell

Source well driller's record

Location State of WASHINGTON

County King

Area

Map

SW ¼ SW ¼ sec 11 T 24 N, R 5 E ~~W~~

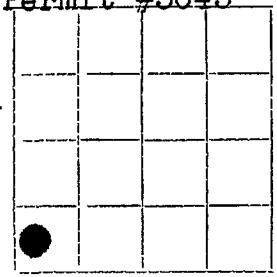

Diagram of Section

24N/5E-11N

File number

Drilling Co

Address

Method of Drilling drilled Date Feb. 23 , 19 54

Owner Washington Water Service Co. Inc.

Address Bellevue, Washington

Land surface, datum ft above / below

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary, in parentheses If material water-bearing so state and record static level if reported Give depths in feet below land-surface datum unless otherwise indicated Correlate with stratigraphic column, if feasible Following log of materials list all casings perforations, screens, etc)		
	Unconsolidated Hardpan	10	10
	Hardpan & gravel, sand	20	30
	Hardpan & coarse gravel	6	36
	Gravel in hardpan; sand	4	40
	Loose sand & gravel	10	50
	Coarse gravel in hardpan	8	58
	Coarse gravel; water	4	62
	Hardpan & coarse gravel	4	66
	Gravel & sand. Bailed down	6	72
	Coarse grains in hardpan	4	76
	Medium sand, some sediment	3	79
	Medium sand; some gravel	10	89
	Coarse sand	13	102
	Blue clay	3	105
Pump Test:			
	Dim: 86' x 12" & 8"		

Turn up (over) Sheet of sheets

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

WELL LOG —Continued No / -

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	———	
	SWL: 51'		
	Dd: 96'		
	Yield: 120 g.p.m.		
	Recovery data: 30 sec - 65'		
	2 min 30 sec - 51'		
	Casing: 12" from 0 to 86'		
	8" from 0 to 93'		
	Perfor: 0.060" from 93 to 98'		
	0.040" from 98 to 103'		
	Pump: 125 GPM at 320' TDH Deep Well Turbine		
	Motor: Electric 15 HP		

S F No 7440—12-54—3M 42108

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

ATTACHMENT B
PHOTOGRAPHS

Project Title: City of Bellevue Emergency Water Supply Master Plan

PHOTOGRAPH 1 KCWD 97 Well No. 3 (Samena) wellhead	
PHOTOGRAPH 2 KCWD 97 Well No. 3 (Samena) site	

PHOTOGRAPH 3 KCWD 97 Well No. 5 (Crossroads) – housed in vault with manhole	
PHOTOGRAPH 4 KCWD 97 Well No. 6 (Crossroads) – housed in vault with manhole	

PHOTOGRAPH 5

KCWD 97 Well No. 7
(Crossroads)

PHOTOGRAPH 6 KCWD 97 Well No. 7 (Crossroads) wellhead	
PHOTOGRAPH 7 KCWD 97 Well No. 1 (Samena) Well Vault (no pump installed)	

PHOTOGRAPH 8 KCWD 68 Well No. 2 Site Location	
PHOTOGRAPH 9 KCWD 68 Well No. 3 Decommissioning	

PHOTOGRAPH 10 Hill-Aire Well	
PHOTOGRAPH 11 Hill-Aire Well Pumping	

Appendix B. Aquifer Characterization and Well Yield Assessment

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TECHNICAL MEMORANDUM

DATE September 18, 2019 **Project No.** 1775477.3.1

TO Thomas Bell-Games PE, HDR Inc.
Laurie Fulton PE, Stantec

CC Doug Lane PE, City of Bellevue

FROM Michael Klisch LHG and David Banton LHG **EMAIL mklisch@golder.com**

CITY OF BELLEVUE WATER EMERGENCY WATER SUPPLY PLAN - AQUIFER CHARACTERIZATION AND WELL YIELD ASSESSMENT

1.0 INTRODUCTION

This technical memorandum provides a characterization of the aquifer that the City of Bellevue (City) wells are completed in and an assessment of the potential yield from one well or several wells completed at one wellfield site in the aquifer. The City wells include former King County Water District (KCWD) 97 Wells No. 1, 3, 5, 6, and 7, KCWD 68 Wells No. 1, 2, and 3, and Washington Water Service Company (WWSC) Well No. 1 and Hill-Aire Well (Figure 1). The Water Districts were taken over by the City as the City grew (Golder Associates Inc. 2018). KCWD 97 Wells No. 3, 5, 6, and 7 were designated as emergency wells by the Washington State Department of Health in 2010. KCWD 97 Wells No. 5, 6, and 7 are located on NE 8th Street in the Crossroads area, and KCWD Wells No. 1 and 3 (also referred to as the Samena Wells) are located on 151st Avenue SE. The remaining wells have been designated as reserve wells in the City's Water System Plan (City of Bellevue 2016).

This assessment was based on the following:

- Information provided by the City including well logs, consultant reports, water quality reports, and water district records.
- City of Bellevue Groundwater Mapping Project completed by Troost (2015).
- Water resource evaluations prepared by the Washington State Department of Ecology (Ecology) and the US Geological Survey (USGS).
- Well logs on file with Ecology.

Information on the City wells is presented in Golder Associates Inc. technical memorandum titled City of Bellevue Water Rights Master Plan – Well Condition Assessment (Golder 2018). The locations of the wells are shown on Figure 1.

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1.1 Scope of Work

This memorandum was prepared to address part of Subtask 3.1 Existing Conditions in the scope of work for the City of Bellevue Water Rights Master Plan to document aquifer characterization and potential well yield. An additional memorandum (City of Bellevue Emergency Water Supply Plan - Aquifer-Stream Delineation and Assessment) has been prepared to assess groundwater-surface interaction as part of Subtask 3.1 Golder 2019). The existing conditions at the City wells were documented in Golder's technical memorandum on well conditions (2018) as part of Task 3.1.

2.0 AQUIFER CHARACTERIZATION

This section presents a characterization of the aquifer(s) that the City wells are completed in, including geologic units, aquifer materials, hydrogeologic units and thickness, hydraulic properties and boundaries, recharge and discharge, and other water supply wells that are completed in the same aquifer.

2.1 Geological Setting

The geological units in the Bellevue area include a thick sequence of glacial and interglacial unconsolidated sediments overlying sedimentary or volcanic bedrock. Figure 3 shows a surficial geologic map in the Bellevue area. The City wells are all located on the Interlake Drift Plain (Leisch et al. 1963), a glacial till-mantled upland between Lake Washington and Lake Sammamish (Figure 1) that extends north from the Newport Hills area to at least the King-Snohomish County line. The till upland is underlain by at least 1,100 feet glacial and interglacial sediments based on KCWD 68 Well No. 1, which did not intersect bedrock to a depth of 1,125 feet. Bedrock is only exposed at the ground surface in the Newport Hills area south of I-90.

A generalized geological and hydrogeological stratigraphic column is summarized on Table 1. The thicknesses of the units are variable across the area. The uppermost glacial units include Vashon-age recessional outwash, till, and advance outwash. The Vashon-age glacial materials may be up to 350 feet thick. The Vashon glacial materials are overlain by alluvial and colluvial materials, peat, and lacustrine deposits.

Older glacial and interglacial materials underlie the Vashon glacial deposits. The Unnamed Sand (Leisch et al. 1963) underlies the Vashon Advance Outwash and is difficult to distinguish from the overlying advance outwash because of similar lithology (fine to coarse stratified sand with silt). The Unnamed Sand is underlain by a clay unit (Upper Clay) and an Unnamed Gravel. Based on cross-section A-A' presented by Leisch et al. (1963), the Upper Clay and Unnamed Gravel are undifferentiated below the Interlake drift Plain. The lowermost unconsolidated units include a thick sequence of clay (Lower Clay Unit) and undifferentiated unconsolidated sediments including sand, silt, gravel, clay, till, and volcanic ash.

2.2 Aquifer Units

A generalized stratigraphic column of geological units and corresponding aquifer units in the Bellevue area is summarized in Table 1. A shallow unconfined aquifer occurs in shallow coarse-grained materials (recessional outwash and alluvium) overlying the till where these materials are saturated. The underlying till forms an aquitard. The advance outwash, underlying Unnamed Sand, and Unnamed Gravel form unconfined to confined aquifers (hydrogeological units Qva and A3 of Troost 2015) that are difficult to distinguish from one another depending on lithology and whether the Upper Clay is present.

Hydrogeological unit A4 (Troost 2015) includes both confined aquifers and aquitards that are not well defined because of a lack of deep well information.

Table 2 summarizes the aquifer units and completion depths for the KCWD 97 wells. The five KCWD 97 wells are interpreted to be completed in a confined, sand and gravel aquifer that appears to be the A3 hydrogeologic unit by Troost (2015). In the Crossroads area (Wells No. 5, 6 and 7), the A3 aquifer is about 40 to 50 feet thick and occurs at a depth of about 250 to 300 below ground surface (bgs), or an elevation of about 150 to 200 feet (NAVD88). In the Samena area, (Wells No. 1 and 3), the confined sand and gravel aquifer (A3) is thicker (about 80 to 100 feet thick) and is present between about 120 to 220 feet below ground (including some non-water bearing interbeds), or an elevation of about 64 to 167 feet (GeoEngineers 2014a, 2014b).

The sand and gravel aquifer that all of the KCWD 97 wells are completed in is interpreted to be the pre-Vashon Unnamed Gravel described in Leisch et al. (1963) and appears to correlate with pre-Vashon permeable materials described by Troost (2015) and designated as hydrogeologic unit A3 (Troost 2015). The A3 hydrogeologic unit is overlain by Vashon recessional outwash, advance outwash (Qva Hydrogeologic Unit), Vashon Till, which forms an aquitard, and shallow unconfined aquifers in recessional outwash and alluvium. The Qva hydrogeological unit and the underlying A3 hydrogeological unit are difficult to distinguish because of the similarity of geological materials and may form a continuous aquifer where the Upper Clay Unit is not present.

The Unnamed Gravel consists of up to 200 feet of sand and gravel and forms a productive aquifer in parts of the Bellevue area as shown on Figure 2. Well yields range from about 50 to over 600 gallons per minute (gpm) based on information on well logs. Groundwater in the aquifer has a hydraulic head of about 120 feet above the base of the aquifer, or a depth to water of about 170 feet below ground in KCWD 97 Wells No. 5, 6, and 7, and 104 feet below ground in KCWD 97 Wells 1 and 3. The groundwater elevation is about 278 feet mean sea level (msl) in KCWD 97 Wells 5, 6, and 7, and 183 feet msl in KCWD 97 Wells 1 and 3.

Groundwater in the Unnamed Gravel occurs under confined to unconfined conditions depending in the aquifer thickness and depth to water. In the area of the KCWD 97 wells, the aquifer is confined.

The Unnamed Gravel aquifer is overlain by up to 350 feet of Vashon glacial deposits (recessional outwash, till, and advance outwash) and undifferentiated Vashon and pre-Vashon fine-grained materials (Unit C2 of Troost 2015; Table 1). The fine-grained units (till and undifferentiated fine-grained units) form an overlying confining layer for the A3 unit. The aquifer is underlain by undifferentiated Vashon and pre-Vashon geologic units that form both aquifers and confining units (hydrogeologic unit A4 of Troost 2015). The thickness of the A4 unit is not known.

The extent of the A3 hydrogeologic unit in areas away from the Crossroads and Samena well locations was interpreted using the geological descriptions on well logs on file with the Washington State Department of Ecology (2017). The wells are summarized on Table 3. In many cases, separation of the Qva and A3 hydrogeologic units was difficult based on the well log descriptions and the two units are combined. Figure 2 shows the location of wells used in the evaluation and the locations of three hydrogeological cross-sections, and Figures 4, 5, and 6 show the hydrogeological cross sections through the aquifer units. Well logs used to develop the cross-sections are included in Attachment A.

Geological cross-section A-A' (Figure 4) indicates the A3 aquifer extends from north of the Newport Hills (well 54 on the cross-section) northwards to the Overlake area where it appears to have been intersected in well 52. Based on the geological description of materials intersected in Well 42, it is uncertain if the well intersected the A3 unit or is completed in overlying Qva materials.

Geological cross-section B-B' (Figure 5) indicates the thickness of the A3 unit is variable. The valleys of Kelsey Creek and Richards Creek are incised into the advance outwash and A3 units, resulting in a decrease in thickness of the A3 unit to about 30 to 50 feet. The aquifer appears to be present between the Newport Hills and Richards Creek and north of Kelsey Creek, however it is difficult to distinguish the A3 unit from the Qva unit based on the descriptions of the geologic materials on the well logs.

The KCWD 68 and WWSC wells appear to be completed in the deeper A4 aquifer unit rather than the A3 aquifer unit the KCWD 97 wells are completed in based on the depths of the wells and the geological descriptions on the well logs (geological cross-section C-C'; Figure 6). The two WWSC wells are shallow wells with depths of 183 feet (Hill-Aire) and 105 feet (Well No. 1; Table 2) and appear to be completed in the Qva (hydrogeologic units Qva, Qva1, or Qva2 as defined by Troost) as shown on Figure 3.

KCWD 68 Wells No. 1 and 2 are greater than 1,000 feet deep; the completion intervals of these wells extend to an elevation of about 425 feet below sea level (Well No. 2) and 950 feet below sea level (Well No. 1) and are open to several aquifer units (Figure 6). These wells are likely completed in pre-Vashon permeable materials and combined permeable and low permeability materials (hydrogeologic units A3 and A4, respectively, of Troost 2015). KCWD 68 Well No.3 may also be completed in hydrogeologic units A3 and/or A4, the well completion extended to about 50 feet below sea level.

2.3 Aquifer Recharge and Discharge

Groundwater recharge occurs through infiltration of precipitation through the till capping the Interlake Drift Plain to the Qva underlying the till and through "windows" in the till where the till has been eroded. Recharge to the deeper A3 and A4 hydrogeological units underlying the Qva occurs via downward leakage from the overlying Qva which is about 100 to 180 feet thick in most areas. There are no site-specific estimates of recharge to the Qva, A3, or A4 aquifers in the Bellevue area. The U.S. Geological Survey (Bauer and Mastin 1996) provided estimates of groundwater recharge in till-mantled areas in King County similar to the Interlake Drift Plain ranging from about 7.4 to 13.6 inches per year. This estimate is for groundwater recharge to the Qva underlying the till. Recharge to the deeper hydrogeological units underlying the Qva will be less because some of the recharge to the Qva will be discharged to surface water. Some recharge may also be provided by downward leakage from lakes on the drift plain such as Phantom Lake or areas where groundwater is present in recessional outwash overlying the till.

The Interlake Drift Plain is bounded on the east and west by Lake Sammamish and Lake Washington, respectively. The north side is bounded by the Sammamish River Valley where the river flows westward into Lake Washington. The southern boundary is formed by bedrock exposed in the Newport Hills. Groundwater discharge from the A3 and Qva hydrogeologic units occurs where these units are exposed along the margins of the drift plain as seeps and springs, and as seepage to the Lake Sammamish and Lake Washington and the Sammamish River. Groundwater discharge also occurs to the valleys of Kelsey Creek and Richards Creek within the drift plain where the aquifer is exposed in the margins of the stream valleys (Figure 3).

2.4 Aquifer Hydraulic Properties

The hydraulic properties of the A3 hydrogeologic unit were estimated from short-term (several hours duration) pumping tests completed in KCWD 97 Wells No. 3, 5, 6, and 7 (GeoEngineers 2014a, 2014b). The drawdown and recovery data from each test were used to estimate the aquifer transmissivity. The results of the test analyses indicated a transmissivity of about 6,600 feet squared per day (ft^2/d) for the A3 hydrogeological unit

screened by Wells No. 5, 6, and 7, and a similar transmissivity of about 7,400 ft^2/d for the A3 hydrogeological unit screened by Well No. 3 (Table 1).

No pumping test data are available for the other wells (KCWD 97 Well No. 1, KCWD 68, Wells No. 1, 2 and 3, and the WWSC Hill-Aire Well and Well No. 1). Therefore, the transmissivity of the A3 unit (KCWD 97 Well No.1), A4 unit (KCWD 68 Wells No. 1, 2, and 3) and the Qva (WWSC Hill Aire Well and Well No. 1) was estimated by an indirect method based on data presented on well logs on file with Ecology. The transmissivity was estimated using the pumping rate and drawdown data (specific capacity) presented on the well logs and the following empirical approximation (Driscoll 1986):

$$T = \frac{Q}{s} \times 267.3$$

Where: T is transmissivity (ft^2/d)
Q is the pumping rate (gpm)
s is the drawdown at the end of the test (feet)

Using this method, the estimated transmissivities for the hydrogeologic units are:

- Qva: 350 ft^2/d (WWSC Well No. 1, no data for Hill Aire Well)
- A3: 800 ft^2/d (KCWD 97 Well No. 1)
- A4: 1,340 to 4,220 ft^2/d (KCWD 68 Wells No. 1, 2, and 3)

This method may underestimate the transmissivity because the drawdown reported on the well log includes some unknown component of drawdown resulting from well losses in addition to the drawdown in the aquifer. The estimated transmissivities from the specific capacities are also not directly comparable to the results of transmissivities estimated from the 2014 pumping tests because the pumping durations were not specified on the well logs.

The short-term pumping tests completed in KCWD 97 Wells No. 5 and 6 completed in the A3 hydrogeologic unit suggested that one or more lower-permeability aquifer boundaries may be present, or the aquifer transmissivity may decrease away from the wells (GeoEngineers 2014b). The presence of lower-permeability aquifer boundaries in the A3 aquifer, or whether leakage to the A3 and A4 hydrogeologic units may occur from overlying hydrogeologic units (Qva and Vashon Till), would need to be confirmed with longer-duration pumping tests.

3.0 WELL YIELD ASSESSMENT

An assessment was made of the potential yield from either one new well or four new wells to evaluate the capacity of a well or wellfield to deliver water in an emergency situation of up to 100 days. The assessment was made for wells completed in the A3 hydrogeologic unit in the Crossroads area. This location was chosen because:

- The hydrogeological properties of the A3 aquifer including aquifer thickness and depth and depth to water are known based on KCWD 97 Wells No. 1, 2, and 3.
- Pumping tests were completed on three wells (KCWD 97 Wells No. 1, 2, and 3) in the Crossroads area providing aquifer transmissivity information.

- The existing KCWD 97 Wells No. 5, 6, and 7 in this area are recognized by Ecology as emergency wells with valid water rights.

The assessment was made using analytical methods in a spreadsheet well hydraulics model. The results should be considered preliminary until further drilling and longer-term testing have been completed.

3.1 Assumptions

The following assumptions were used for the analyses:

- The well or wells are constructed similar to the KCWD 97 Crossroads wells. The wells are drilled to an approximate depth of 300 feet (base of the A3 hydrogeological unit) and completed with 20 feet of stainless steel, wire-wrap well screen from about 275 to 295 feet below ground and an engineered filter pack sized for the formation materials.
- The depth to groundwater is about 175 feet bgs in late winter and spring – high groundwater level based on groundwater levels measured in KCWD 97 Wells No. 5, 6, and 7 in December 2014 (GeoEngineers 2014a, 2014b). The seasonal groundwater level fluctuation in the aquifer is uncertain; the depth to water in Well No. 7 was measured at a similar depth of about 175 feet below ground in June 2014 (GeoEngineers 2014a). Because seasonal fluctuation is uncertain, the groundwater level was assumed to vary by 10 feet seasonally, i.e. the depth to water decreases to 185 feet bgs in late summer).
- There is no interference drawdown from pumping of other water supply or irrigation wells in the Crossroads area. This assumption is based on a review of well logs in the vicinity of the KCWD 97 wells, indicating the majority of wells were either monitoring wells or heat-exchange wells.
- The total available drawdown in the wells is 75 to 85 feet. This is based on a pump intake depth of 270 feet below ground, 10 feet of pump submergence and seasonal high and low depths to groundwater. This results in a maximum pumping water level ranging from 250 to 260 feet bgs.
- The transmissivity of the A3 hydrogeological unit is 6,600 ft^2/d. This transmissivity is based on pumping tests of the Crossroads Wells by GeoEngineers (2014a, 2014b).
- The aquifer storativity is estimated to be 1x10-3 (dimensionless). This value is estimated based on the geological materials in the A3 hydrogeological unit and the confined to semi-confined nature of the A3 unit.
- The aquifer is confined, homogeneous, and extensive, and is not bounded with any lower-permeability boundaries which would increase the estimated drawdown. The estimated drawdown does not include any recharge or leakage from overlying hydrogeologic units which would decrease the estimated drawdown.
- The pumping rate for a single well is between 500 and 850 gpm (0.72 to 1.22 million gallons per day [MGD]) based on the water rights for the KCWD 97 Crossroads and Samena wells (Golder 2018). The pumping rate for four wells in a wellfield is 650 gpm per well (the approximate average of the instantaneous water rights for the KCWD 97 Crossroads and Samena Wells), or a total wellfield capacity of 2,600 gpm (3.74 MGD).
- The wells are continuously pumped for 7, 30, and 100 days to simulate short-term to extended emergency conditions.

The Cooper-Jacob (1946) method was used to estimate drawdown in a single well and each well in the 4-well wellfield using a spreadsheet aquifer hydraulics model. The Cooper-Jacob equation is:

$$s = \frac{2.3Q}{4\pi T} \, log \frac{2.25Tt}{r^2 S}$$

Where:
- s is the drawdown in the well (ft)
- Q is the pumping rate (ft^3/d)
- T is the aquifer transmissivity (ft^2/d)
- S is the aquifer storativity (-)
- t is the pumping time (days)

Additional drawdown was added to the model results at each pumping well to represent drawdown resulting from well losses. Well losses are the additional head losses in the well associated with well construction, well screen slot size, filter pack gradation, incomplete development, and wellbore skin effects. Well losses result in drawdown in a pumping well that is greater than that predicted using the Cooper-Jacob method. Well losses were assumed to result in an additional 25% drawdown in each pumping well.

3.1.1 Single Well

Figure 7 shows the estimated drawdown in a single well (i.e. no other nearby pumping wells that could result in interference drawdown) for continuous pumping at rates varying from 500 to 850 gpm after 100 days of pumping. The drawdown in the well is estimated to range from 32.6 feet (500 gpm) to 55.24 feet (850 gpm) after 100 days of pumping. The estimated drawdown will be less for shorter pumping durations.

A sensitivity analysis was performed to evaluate the sensitivity of the drawdown at a pumping rate of 600 gpm for 100 days to changes in the aquifer hydraulic properties from the baseline condition shown on Figure 7. The aquifer transmissivity was varied from 5,000 ft^2/d to 7,400 ft^2/d and the storativity was decreased to 5 x 10-5 and increased to 5 x10-3. Table 4 summarizes the baseline condition and the parameters that were varied for the sensitivity analysis and the estimated drawdown resulting from varying the aquifer hydraulic properties. Figure 8 shows the results of the sensitivity analysis.

The results of the single-well sensitivity analysis are summarized as follows (Table 4 and Figure 8):

- Scenario 1 is the base case for pumping at 600 gpm for 100 days with an aquifer transmissivity of 6,600 ft^2/d and an aquifer storativity of 1 x 10-3. The estimated drawdown after 100 days of pumping is 39.1 feet.
- The drawdown is most sensitive to changes in aquifer transmissivity. If the aquifer transmissivity is 5,000 ft^2/d (Scenario 2), the estimated drawdown at a pumping rate of 600 gpm is 51 feet after 100 days, or about 11.9 feet greater than the base case. A higher transmissivity (7,400 ft^2/d; Scenario 3), results in an estimated drawdown of 35.1 feet after 100 days of pumping at 600 gpm, or about 4.1 feet less than the base case.
- The drawdown is less sensitive to aquifer storativity. Using a transmissivity of 6,600 ft^2/d, if the storativity is decreased to 5x10-5 (Scenario 4), the estimated drawdown increases to 44.3 feet after 100 days of

pumping, or about 5.2 feet more than the base case. If the storativity is increased to 5 x 10-3, the estimated drawdown decreases to 36.3 feet, or about 2.8 feet less than the base case.

3.1.2 Four Well Wellfield

The drawdown in an individual well in a wellfield is dependent on the well pumping rates, the aquifer hydraulic properties (and boundary conditions) and the distance between wells (leading to interference drawdown). This wellfield analysis assumes four wells with identical construction and capacity that are located at the corners of a square-shaped wellfield, with the sides of the square ranging from 400 to 1,200 feet in length.

The assumptions for the wellfield analysis are similar to those presented for the single well analysis, including a 25% factor for additional drawdown to account for well losses.

The results of the wellfield analyses are summarized on Table 5 and shown on Figure 9. As shown on Table 5 and Figure 9, the predicted interference drawdown and total drawdown in each well increases with increasing pumping duration and decreasing distance between wells. The predicted drawdown in all wells is less than the available drawdown for the wellfield geometries except for 100 days of pumping when well spacing is 400 feet or 800 feet.

A sensitivity analysis was performed to evaluate the sensitivity of the drawdown at a pumping rate of 650 gpm for 100 days to changes in the aquifer hydraulic properties from the baseline condition shown on Figure 9. Similar to the single well sensitivity analysis, the aquifer transmissivity was varied from 5,000 ft^2/d to 7,400 ft^2/d and the storativity was decreased to 5 x 10-5 and increased to 5 x10-3. Table 6 summarizes the baseline condition and the parameters that were varied for the sensitivity analysis and the estimated drawdown resulting from varying the aquifer hydraulic properties. Figure 10 shows the results of the sensitivity analysis for 100 days of pumping.

The results of the wellfield sensitivity analysis are summarized as follows (Table 6 and Figure 10):

- Scenario 1 is the base case for pumping four wells at 650 gpm for 100 days with an aquifer transmissivity of 6,600 ft^2/d and an aquifer storativity of 1 x 10-3. The estimated drawdown after 100 days of pumping ranges from 72.7 to 82.6 feet for well spacings of 400 to 1,200 feet.
- If the aquifer transmissivity is 5,000 ft^2/d (Scenario 2), the estimated drawdown at a pumping rate of 650 gpm after 100 days ranges from 93.6 to 106.7 feet for well spacings of 400 to 1,200 feet, or about 20.9 to 24.1 feet greater than the base case. A higher transmissivity (7,400 ft^2/d; Scenario 3), results in an estimated drawdown of 65.5 to 74.4 feet after 100 days of pumping at 650 gpm, or about 7.2 to 8.3 feet less than the base case for well spacings of 400 to 1,200 feet.
- Using a transmissivity of 6,600 ft^2/d, if the storativity is decreased to 5x10-5 (Scenario 4), the estimated drawdown increases to 91.9 to 101.8 feet for well spacings of 40 to 1,200 feet after 100 days of pumping, or about 19.2 feet more than the base case. If the storativity is increased to 5 x 10-3, the estimated drawdown decreases to 62.4 to 72.3 feet for well spacings of 400 to 1,200 feet, or about 10.3 feet less than the base case.

4.0 SUMMARY

4.1 Aquifer Conditions

The following summarizes the aquifer conditions for the aquifers the City wells are completed in:

- The City of Bellevue wells are located on the Interlake Drift Plain. The Interlake Drift Plain is a till-mantled upland bounded on the east by Lake Sammamish and on the west by Lake Washington. The southern boundary is formed by bedrock of the Newport Hills, and the northern boundary is formed by the Sammamish River Valley as the river flows to the west to Lake Washington.
- The following hydrogeological units underlie the till:
  - Vashon Advance Outwash - sand, gravel, and silt forming an aquifer
  - C2 confining unit
  - A3 Hydrogeologic unit – sand, gravel and silt forming an aquifer
  - A4 Hydrogeologic Unit – series of glacial and non-glacial deposits forming aquifers and confining units
- The KCWD 97 wells appear to be completed in the A3 hydrogeologic unit which appears to be relatively continuous in the area of the drift plain except in the valleys of Kelsey Creek and Richards Creek where it appears to be partly eroded.
- The KCWD 68 wells appear to be completed in the A3 and/or the deeper A4 hydrogeological unit.
- The WWSC wells appear to be completed in the Vashon Advance outwash aquifer.
- The A3 and A4 aquifers are recharged by downward leakage of precipitation recharge to the Qva and seepage from lakes and groundwater in recessional outwash. Recharge to the A3 and A4 aquifers is less than the recharge to the Qva because of groundwater discharge from the Qva to surface water. Groundwater discharge from the A3 and A4 aquifers occurs where the aquifer is exposed on the margins of the drift plain along Lake Sammamish and Lake Washington, and along the incised valleys of Kelsey Creek and Richards Creek in the interior of the drift plain.
- The A3 aquifer is moderately permeable based on the results of short-term pumping tests completed in four of the KCWD 97 wells. Short-term pumping tests suggested lower-permeability aquifer boundaries or a lateral decrease in aquifer transmissivity may be present but would need to be confirmed with longer pumping tests.
- The permeability of the Qva and A4 aquifers appears to be lower than the A3 aquifer based on an indirect method to estimate the permeability. Pumping tests would be needed to confirm the permeability of these units.

4.2 Well and Wellfield Capacity

The following summarizes the assumptions and results of the single well and 4-well wellfield capacity evaluation using the analytical model:

- New wells are assumed to be constructed similar to KCWD 97 Wells No. 5, 6, and 7 with stainless steel, wire-wrap well screens and an engineered filter pack and are properly developed to maximize well efficiency.

- The aquifer hydraulic properties are assumed to be similar to the properties determined during the 2014 testing of KCWD 97 Wells No. 3, 5, 6, and 7 and the aquifer is assumed to be confined, homogeneous, and extensive.
- The well capacity evaluation predicts pumping of 500 to 850 gpm (0.72 to 1.22 MGD) from a single well results in an estimated drawdown of about 32.6 to 55.4 feet after 100 days of continuous pumping assuming well losses of 25% and no interference drawdown from other non-City water supply wells. Less drawdown occurs for shorter pumping durations. The estimated drawdown is less than the estimated available drawdown of 75 to 85 feet (based on similar aquifer thickness and depth to water as KCWD 97 Wells No. 5, 6, and 7 at the Crossroads site).
- The well capacity evaluation predicts the drawdown resulting from pumping of 4 wells in a box-shaped wellfield at individual pumping rates of 650 gpm results in about 72.7 to 82.6 feet of drawdown after 100 days of continuous pumping depending on the well spacing. The estimated drawdown after 100 days of pumping is less than the estimated available summer drawdown of 75 feet except for a well spacing of 400 or 800 feet. Less drawdown occurs for shorter pumping durations and increasing distance between wells. The estimated drawdown assumes no interference drawdown from other non-City water supply wells.
- The estimated drawdown in the wells predicted by the analytical model is sensitive to the aquifer transmissivity and storativity (single well) and aquifer transmissivity and storativity and well spacing for a wellfield. Lower transmissivity and/or lower storativity results in greater drawdown, and drawdown decreases with increasing distance between wells in a wellfield.
- The predicted drawdown in the emergency supply wells has implications for facility design and potential environmental and geotechnical impacts during pumping:
  - The pumping rate and drawdown in the wells will determine the total dynamic head and pump and motor size for the well design. There are no regulatory constraints on drawdown in a well.
  - Pumping of a single well or wellfield will result in a decrease in groundwater levels in the aquifer. The magnitude and spatial extent will depend on the aquifer hydraulic properties, pumping rates, and durations. Pumping could result in interference drawdown, or lowering of groundwater levels, in other nearby wells. Depending on the magnitude of interference drawdown and construction of other wells, the interference drawdown could result in impairment of senior water rights or exempt wells (or inability to pump at the water right capacity). Based on our review of well logs on file with Ecology, most wells in the vicinity of the City's emergency wells appear to be heat-exchange or monitoring wells rather than water supply or domestic wells. Therefore, the potential for interference drawdown and impairment appears to be low because the emergency wells would be operated on a short-term basis.
  - Drawdown in the confined A3 Aquifer resulting from pumping of an emergency well or wellfield could result in downward leakage and lowered groundwater levels in shallow aquifer(s) in hydraulic continuity with surface water bodies. This could lead to stream depletion depending on the thickness and permeability of the confining unit overlying the aquifer and pumping rates and duration. A preliminary evaluation of potential stream depletion was presented in Golder's technical memorandum on aquifer-stream delineation (Golder 2019).

- Under certain geotechnical conditions, pumping and the resulting depressurization of the aquifer and overlying units can result in settlement (subsidence). While the likelihood for settlement appears to be minor, the potential for pumping-induced settlement should be evaluated if the City decides to proceed with development of an emergency groundwater supply.

4.3 Emergency Groundwater Supply Development

- The well capacity analysis suggests that one or more wells could be developed in the A3 hydrogeological unit to serve as an emergency supply. The pumping rates in the wells will be dependent on the aquifer hydraulic properties and aquifer thickness, available drawdown, proximity to other pumping wells, and well performance.

- Assuming the City's emergency demand is 9 MGD, the existing KCWD 97 Wells No. 3, 5, 6, and 7 that are designated as emergency supply wells do not have the capacity to meet this demand. These wells have a combined instantaneous water right capacity of about 3.74 MGD. Short-term pumping tests suggested Wells No. 3, 5, 6, and 7 could be operated at the water right capacity for only a few days (Golder 2018). Therefore, about 8 to 13 individual (dispersed) wells completed in the A3 Aquifer could be required to meet emergency demand. Based on the wellfield analysis, three, (non-interfering) 4-well wellfields could be required to meet the emergency demand.

4.4 Recommendations

- Additional hydrogeological investigations including test well drilling, step-pumping tests, and longer-duration pumping tests are recommended to confirm these preliminary estimates of well and wellfield capacity, and to provide an assessment of whether the A3 Aquifer is capable of meeting the City's emergency supply needs of up to 9 MGD.

- We also recommend the groundwater supply potential of deeper aquifers (for example the A4 Aquifer) should be investigated.

- We recommend that a numerical groundwater flow model is developed to evaluate potential well locations, well capacity and drawdown, and potential impacts to the hydrogeological system (such as interference drawdown on other wells, leakage from overlying hydrogeological units, and to surface water) resulting from development of an emergency groundwater supply.

Golder Associates Inc.

Michael P. Klisch 09/18/19

Michael Klisch, LHG
Senior Project Hydrogeologist

David Banton, LHG, RG
Principal Hydrogeologist

MK/DB/ks

TABLES

Table 1: Geologic and Hydrogeologic Units

Table 2: City of Bellevue Well Information

Table 3: Wells Used in Aquifer Evaluation

Table 4: Summary of Single Well Sensitivity Analysis

Table 5: Summary of Wellfield Analyses

Table 6: Summary of Wellfield Sensitivity Analyses

FIGURES

Figure 1: Drinking Water Well Location Map

Figure 2: Cross-Section Location Map

Figure 3: Surficial Geologic Map

Figure 4: Geologic Cross-Section A-A’

Figure 5: Geologic Cross-Section B-B’

Figure 6: Geologic Cross-Section C-C’

Figure 7: Estimated Drawdown - Single Well 100 Days Pumping

Figure 8: Estimated Drawdown - Sensitivity Single Well 100 Days Pumping

Figure 9: Wellfield Evaluation – Estimated Drawdown 4 Wells Pumping 7 to 100 Days

Figure 10: Wellfield Evaluation – Sensitivity Analysis 4 Wells Pumping 100 Days

ATTACHMENTS

Attachment A Cross-Section Well Logs

5.0 REFERENCES

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Tables

Table 1: Geologic and Hydrogeologic Units

Geologic Unit[1]	Thickness (Feet)[1]	Hydrogeologic Unit Description[2]	Hydrogeologic Unit Identification[2]	Hydrogeological Unit and Description	Aquifer Type
Modifed Areas	Fill 0 to 50 feet	Fill	S1	Fill materials of all types	Shallow Unconfined
Undifferentiated Sedimentary Deposits	Up to 340 feet[3]	Alluvium	S2	Alluvial and lacustrine deposits	
Peat	3 to 50 feet	Peat	S3	Peat and wetland deposits	
Undifferentiated Sedimentary Deposits	Up to 340 feet[3]	Colluvium	S4	Colluvium and landslide deposits	
Vashon Recessional Stratified Drift and Delta Gravels	Up to 100 feet	Vashon Recesssional Outwash	S5	Recessional channel, delta, and lacustrine deposits, sand, gravel and silt	
Undifferentiated Sedimentary Deposits	Up to 340 feet[3]	Undifferentiated	S6	Undifferentiated units	
Vashon Till	Up to 150 feet	Vashon Till	P	Dense silt, clay, sand, and gravel.	Shallow Perched
Vashon Advance Outwash and Unnamed Sand	Advance Outwash - Up to 100 feet, Unnamed Sand Up to 200 feet	Vashon Advance Outwash (confined)	Qva1	Fine to coarse sand, difficult to distinguish from A3	Intermediate
		Vashon Advance Outwash (unconfined)	Qva2	Fine to coarse sand, difficult to distinguish from A3	Intermediate
		Vashon Advance Outwash (undifferentiated)	Qva	Fine to coarse sand, difficult to distinguish from A3	Intermediate
Upper Clay Unit	Up to 200 feet	Vashon/Pre-Vashon Silt and	C2	Silt and clay	Intermediate to Deep
Unnamed Gravel	Up to 200 feet	Pre-Vashon Permeable	A3	Sand and gravel	Deep
Unnamed Gravel, Undifferentiated Clay, Lower Clay Unit, Older Unconsolidated Units	Over 450 feet	Combined	A4	Sand, gravel, silt, clay	Intermediate to Deep
Marine Sedimentary Rocks, Puget Group, Volcanic Rocks, Continental and Marine Sedimentary Rocks	2,000 to 8,000 feet depending on unit	Bedrock	Bx	Sandstone and volcanic rock	Bedrock

Notes:

1. from Leisch and other (1963)
2. From Troost (2015)
3. Total thickness of all undifferentiated units including alluvium, colluvium, and undifferentiated materials

Table 2: City of Bellevue Well Information

Well Number	Location	Date Drilled	Depth Drilled (feet bgs)	Diameter (inches)	Completion Interval (feet bgs)	Aquifer interval (feet bgs)	Completion Interval Geology	Aquifer Unit[a]
KCWD 97 Well No. 1	Samena	1955	160	12	130 to 160	135-154	Sand and Gravel	A3
KCWD 97 Well No. 3		1956	229	12	195 to 220	120-223	Coarse to Fine Sand	A3
KCWD 97 Well No. 5	Crossroads	1959	293	8	263 to 293	252 to 297	Coarse Sand and Gravel	A3
KCWD 97 Well No. 6		1959	302	16	282 to 302	No Log	Coarse Sand and Gravel	A3
KCWD 97 Well No. 7		1963	300	12	275 to 299	No Log	Coarse Sand and Gravel	A3
KCWD 68 Well No. 1	KCWD 68	1946	1,125	12	247 to 370	247-350	Sand, Gravel, Clay	A3/A4?
					530 to 621	550-621	Sand, Gravel, Clay	A4
					974 to 1,115	994-1,115	Sand, Clay	A4
KCWD 68 Well No. 2		1947	1,056	12	270 to 475	170-463	Sand, Gravel, Clay	A3/A4?
KCWD 68 Well No. 3		1947	244	12	60 to 244	50-228	Sand and Gravel	Qva/A3
WWSC Well No. 1	WWSC	1954	105	8	93 to 103	79 -102	Sand	Qva
WWSC Hill-Aire		Unknown	183	8	183 to 193?	155-183	Sand and Gravel	Qva

Notes:
bgs - below ground surface
gpm - gallons per minute
See Figure 1 for well locations
a. Troost 2015

Table 3: Wells Used in Aquifer Evaluation

Map Number[1]	Well Owner Name	Well Depth (feet)	Location[2]	Aquifer Extent (feet bgs)	Inferred Aquifer Units(s)[3]	Well Type[4]
1	AMY & IVAN ALPEZA	200	T24/R5E-4SE	No geologic log		W
2	Baker Main LLC	210	T25/R5E-32SWNE	80-210	Qva/A3	R
3	BANK OF AMERICA | HART CROWSER	201.5	T25/R5E-32NENW	65-201	Qva/A3	R
4	Bellevue College	300	T24/R5E-10NESE	90-300	Qva/A3	R
5	BELLEVUE PUMP ST	204	T25/R5E-32SWSW	82-210	Qva/A3	R
6	BELLEVUE SCHOOL DIST	320	T24/R5E-12NWNW	135-320	Qva/A3	R
7	BELLEVUE SCHOOL DIST 405	300	T24/R5E-12NWNW	147-300	Qva/A3	R
8	BELLEVUE SCHOOL DIST 405	300	T25/R5E-21SWNE	130-300	Qva/A3	R
9	Bellevue School District	300	T24/R5E-8NWNE	150-300	Qva/A3	R
10	Bellevue School District	300	T25/R5E-34NENE	75-300	Qva/A3	R
11	Bellevue School District	300	T25/R5E-25SESE	160-300	Qva/A3	R
12	Bellevue School District	300	T24/R5E-2NESE	90-300	Qva/A3	R
13	Bellevue School District | Earthheat	350	T25/R5E-33NWNE	120-350	Qva/A3	R
14	Bellevue School District 405	300	T25/R5E-26NENE	153-300	Qva/A3	R
15	Bellevue School District Operations Dept	300	T25/R5E-34NENE	148-300	Qva/A3	R
16	Bellevue School District Operations Dept	300	T25/R5E-33NWNW	110-300	Qva/A3	R
17	Bellevue School District Operations Dept	300	T25/R5E-34SENW	110-300	Qva/A3	R
18	Cherry Crest Elementary | Geo Loop Tec	300	T25/R5E-21SWNE	160-300	Qva/A3	R
19	CITY OF BELLEVUE	200	T25/R5E-32SESE	?-200	Qva	R
20	City Of Bellevue	200	T24/R5E-5SENE	96-200	Qva	R
21	City Of Bellevue/Parks & Community	300	T25/R5E-26SESW	100-300	Qva/A3	R
22	CITY OF KIRKLAND	200	T25/R5E-17SENE	119-200	Qva/A3	W
23	CORPS OF ENGINEERS	319	T25/R5E-35SENE	60-319	Qva/A3	W
24	Daniel Damon	200	T25/R5E-25NESE	120-200	Qva	R
25	DARYL BRENNER	220	T25/R5E-35NESE	165-220	Qva	W
26	DAVID AND PAMELA JOHNSTON	300	T25/R5E-21NWNE	96-300	Qva/A3	R
27	DAVID AND PAMELA JOHNSTON	300	T25/R5E-21NWNE	96-300	Qva/A3	R
28	DWIGHT MARTIN	326	T25/R5E-14SWSW	108-330	Qva/A3	W
29	EASTGATE HOMES INC	243	T25/R5E-26SENW	135-250	Qva/A3	W
30	Edson	300	T24/R5E-5SWSE	225-300	A3/A4	R
31	F. J. K. INC.	275	T25/R5E-14SESE	256-275?	Qva/A3	W
32	Gregg Smith	300	T25/R5E-15SWSW	130-300	Qva/A3	R
33	Harv Bhela	285	T25/R5E-15SWNE	122-285	Qva/A3	R
34	Imagine Housing	310	T25/R5E-20NENW	60-280	Qva/A3	R
35	James G Roush	330	T25/R5E-24SESW	80-330	A3/A4	R
36	KEITH RIFFLE / C.D.S. ENTERPRISES	232	T25/R5E-22NWSW	179-241	Qva	W
37	KING COUNTY	348	T24/R5E-12SWSW	135-331	A3/A4	R
38	King County Water Treatment	230	T24/R5E-8NWSE	50-160	Qva	R
39	KIRTLEY-COLE ASSOC.	200	T25/R5E-23SENE	120-200?	Qva	W
40	LONGHOUSE | RICHARD GARFIELD	300	T25/R5E-15SWSW	76-215	Qva	R
41	PUGET SOUND ENERGY	210	T24/R5E-4SENW	120-210	Qva	R
42	Puget Sound Energy	211	T25/R5E-32SENE	175-211	Qva	R
43	Puget Sound Energy	215	T25/R5E-15NENE	76-215	Qva	R
44	PUGET SOUND ENERGY | COSSPIO CO INC	210	T25/R5E-30NENE	?-210	Qva	R
45	Rick Young	200	T24/R5E-9NENW	135-200	Qva	R
46	Ron Ferguson	320	T25/R5E-30SENW	185-320	Qva/A3	W
47	Scott Clayhold | Earthheat	300	T24/R5E-8SESW	110-300	A4?	R
48	TAM O'SHANTER C/O JACK HART	215	T25/R6E-30NWSE	115-148?	A4?	W
49	TAM O'SHANTER INC.	210	T25/R6E-30	203-210	A4?	W
50	T-Mobile/SWSG	350	T25/R5E-27SWNW	327-350	A4?	R
51	TONY BOZANICH	220	T25/R5E-25	No geologic log		W
52	UNITED CONTROL CORP	357	T25/R5E-23NWSW	48-192	Qva/A3/A4	W
53	WSDOT | CH2M Hill	200	T24/R5E-8SENE	0-200?	A3/A4	R
54	Bellevue College | GeoEngineers~ Inc	350	T24/R5E-10NESE	90-350	Qva/A3	R
55	Glendale Golf Club	397	T25/R5E-34SWNW	264-270	A4?	W

Notes:

1. See Figures 2 and 3 for well locations.
2. Location from well log database to nearest 1/4 - 1/4 section unless otherwise noted.
3. Qva -Vashon Advance Outwash, A3, A4 - A3 and A4 hydrogeological units (Troost 2015)
4. Well Type: W - Water, R - Resource Protection including geothemal heat pump, cathodic protection, grounding, and geotechnical borings.

Data from Washington State Department of Ecology Well Log Database (https://fortress.wa.gov/ecy/waterresources/map/WCLSWebMap/default.aspx)

Table 4: Summary of Single Well Sensitivity Analysis

Scenario	Transmissivity (ft^2/d)	Storativity (dimensionless)	Predicted Drawdown (feet)	Total Drawdown (feet)	Comment
1	6,600	1.0E-03	39.1	-	Base Case
2	5,000	1.0E-03	51.0	11.9	Low Transmissivity
3	7,400	1.0E-03	35.1	-4.1	High Transmissivity
4	6,600	5.0E-05	44.3	5.2	Low Storativity
5	6,600	5.0E-03	36.3	-2.8	High Storativity

Notes:

1. Well losses assumed to be 25%
2. Analysis for 100 days of pumping at 600 gpm

See Figure 8 for plot of sensitivity analysis

Table 5: Summary of Wellfield Analyses

Wellfield Layout	Pumping Duration (days)	Number of Wells	Well Spacing (feet)	Individual Well Pumping Rate (gpm)	Aquifer Transmissivity (ft^2/d)	Aquifer Storativity (ft^2/d)	Drawdown in One Well (no interference drawdown) (feet)	Well Losses (feet)[1]	Interference Drawdown from Three Other Wells (feet)	Total Drawdown (feet)	Pumping Water Level - Winter[3] (feet bgs)	Pumping Water Level - Summer[4] (feet bgs)
Box	7	4	400	650	6,600	1.0E-03	29.9	7.5	28.2	65.6	240.6	250.6
			800	650	6,600	1.0E-03	29.9	7.5	22.0	59.3	234.3	244.3
			1,200	650	6,600	1.0E-03	29.9	7.5	18.3	55.7	230.7	240.7
Box	30	4	400	650	6,600	1.0E-03	32.1	8.0	34.8	74.9	249.9	259.9
			800	650	6,600	1.0E-03	32.1	8.0	28.5	68.7	243.7	253.7
			1,200	650	6,600	1.0E-03	32.1	8.0	24.9	65.0	240.0	250.0
Box	100	4	400	650	6,600	1.0E-03	33.9	8.5	40.3	82.6	257.6	267.6
			800	650	6,600	1.0E-03	33.9	8.5	34.0	76.4	251.4	261.4
			1,200	650	6,600	1.0E-03	33.9	8.5	30.3	72.7	247.7	257.7

Notes:

1. Well losses assumed to be 25%
2. Analysis for 7 to 100 days of pumping
3. Assumes non-pumping depth to water of 175 feet bgs
4. Assumes non-pumping depth to water of 185 feet bgs
5. Shaded cells exceeds maximum drawdown of 75 feet and pumping water level of 260 feet bgs for summer conditions

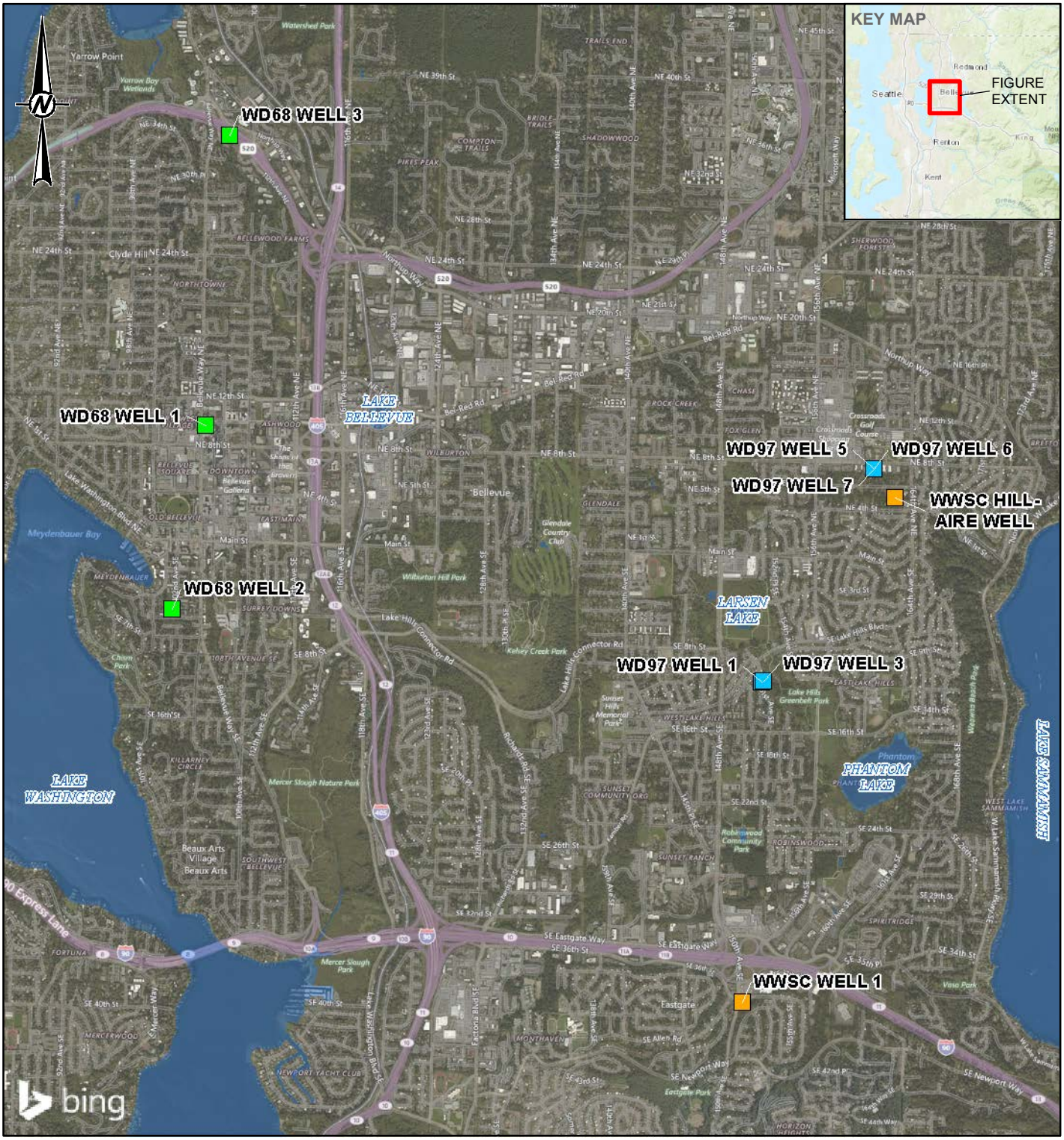
Table 6: Summary of Wellfield Sensitivity Analyses

Scenario	Pumping Duration (days)	Number of Wells	Well Spacing (feet)	Individual Well Pumping Rate (gpm)	Aquifer Transmissivity (ft^2/d)	Aquifer Storativity (ft^2/d)	Drawdown in One Well (no interference drawdown) (feet)	Well Losses (feet)[1]	Interference Drawdown from Three Other Wells (feet)	Total Drawdown (feet)	Change in Drawdown from Base Case Scenario 1 (feet)	Comment
1	100	4	400	650	6,600	1.0E-03	33.9	8.5	40.3	82.6	-	Base Case
			800	650	6,600	1.0E-03	33.9	8.5	34.0	76.4	-	
			1,200	650	6,600	1.0E-03	33.9	8.5	30.3	72.7	-	
2	100	4	400	650	5,000	1.0E-03	44.2	11.1	51.5	106.7	24.1	Low Transmissivity
			800	650	5,000	1.0E-03	44.2	11.1	43.2	98.5	22.1	
			1,200	650	5,000	1.0E-03	44.2	11.1	38.4	93.6	20.9	
3	100	4	400	650	7,400	1.0E-03	30.4	7.6	36.4	74.4	-8.3	High Transmissivity
			800	650	7,400	1.0E-03	30.4	7.6	30.8	68.8	-7.6	
			1,200	650	7,400	1.0E-03	30.4	7.6	27.5	65.5	-7.2	
4	100	4	400	650	6,600	5.0E-05	38.4	9.6	53.8	101.8	19.2	Low Storativity
			800	650	6,600	5.0E-05	38.4	9.6	47.5	95.6	19.2	
			1,200	650	6,600	5.0E-05	38.4	9.6	43.9	91.9	19.2	
5	100	4	400	650	6,600	5.0E-03	31.5	7.9	33.0	72.3	-10.3	High Storativity
			800	650	6,600	5.0E-03	31.5	7.9	26.7	66.1	-10.3	
			1,200	650	6,600	5.0E-03	31.5	7.9	23.0	62.4	-10.3	

Notes:
1. Well losses assumed to be 25%
2. Analysis for 100 days of pumping at 650 gpm

See Figure 10 for plot of sensitivity analysis

Figures



LEGEND

- KING COUNTY WATER DISTRICT 68 WELL
- KING COUNTY WATER DISTRICT 97 WELL
- WASHINGTON WATER SERVICE COMPANY WELL
- LAKE

0 2,000 4,000 8,000

Feet

REFERENCE(S)

1. TROOST GEOSCIENCES (WELL LOCATIONS, CITY LIMITS)
2. COORDINATE SYSTEM: NAD 1983 STATE PLANE WASHINGTON NORTH (FT)
3. SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, DELORME, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), SWISSTOPO, MAPMYINDIA, © OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY

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CLIENT
STANTEC

PROJECT
CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN

TITLE
CITY OF BELLEVUE WATER SUPPLY WELL LOCATION MAP

CONSULTANT
GOLDER

YYYY-MM-DD	2018-08-28
DESIGNED	BVJ
PREPARED	HJ
REVIEWED	MK
APPROVED	MK

PROJECT NO.	PHASE	REV.	FIGURE
1775477	3.1	A	1

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

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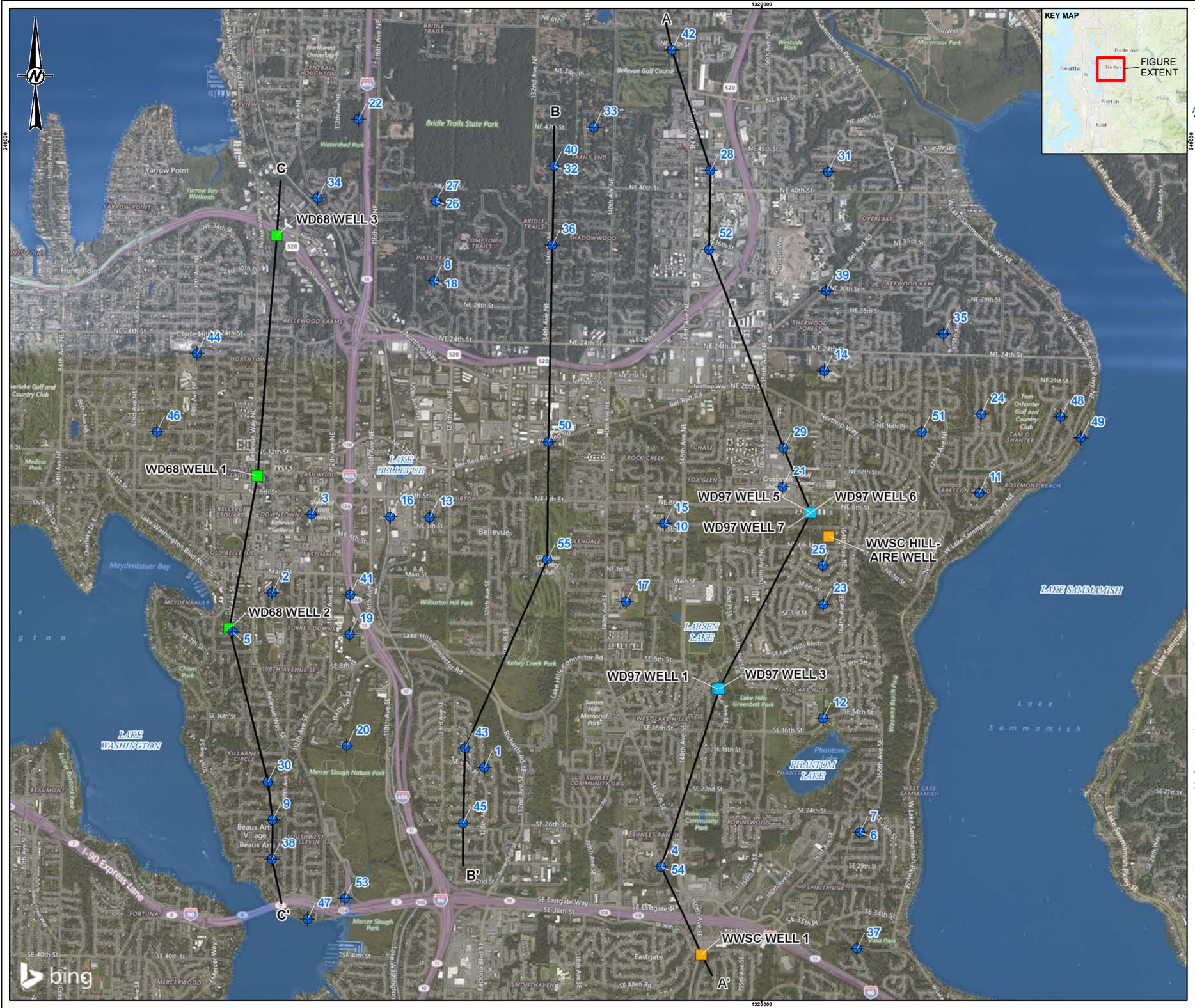

0 3,250 6,500

1 INCH = 3,250 FEET FEET

NOTE(S)

1. WELLS LOCATED TO NEAREST ¼ - ¼ SECTION IN DATABASE.

REFERENCE(S)

1. TROOST GEOSCIENCES (WELL LOCATIONS, CITY LIMITS)
2. GOLDER (GEOLOGIC CROSS SECTION)
3. WASHINGTON DEPARTMENT OF ECOLOGY (WELL LOCATIONS)
4. COORDINATE SYSTEM: NAD 1983 STATE PLANE WASHINGTON NORTH (FT)
5. SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, DELORME, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), SWISSTOPO, MAPMYINDIA, © OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY

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PROJECT
CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN

TITLE
CROSS-SECTION LOCATION MAP

CONSULTANT
GOLDER

YYYY-MM-DD	2019-09-17
DESIGNED	BVJ
PREPARED	HJ
REVIEWED	MK
APPROVED	MK

PROJECT NO.	PHASE	REV.	FIGURE
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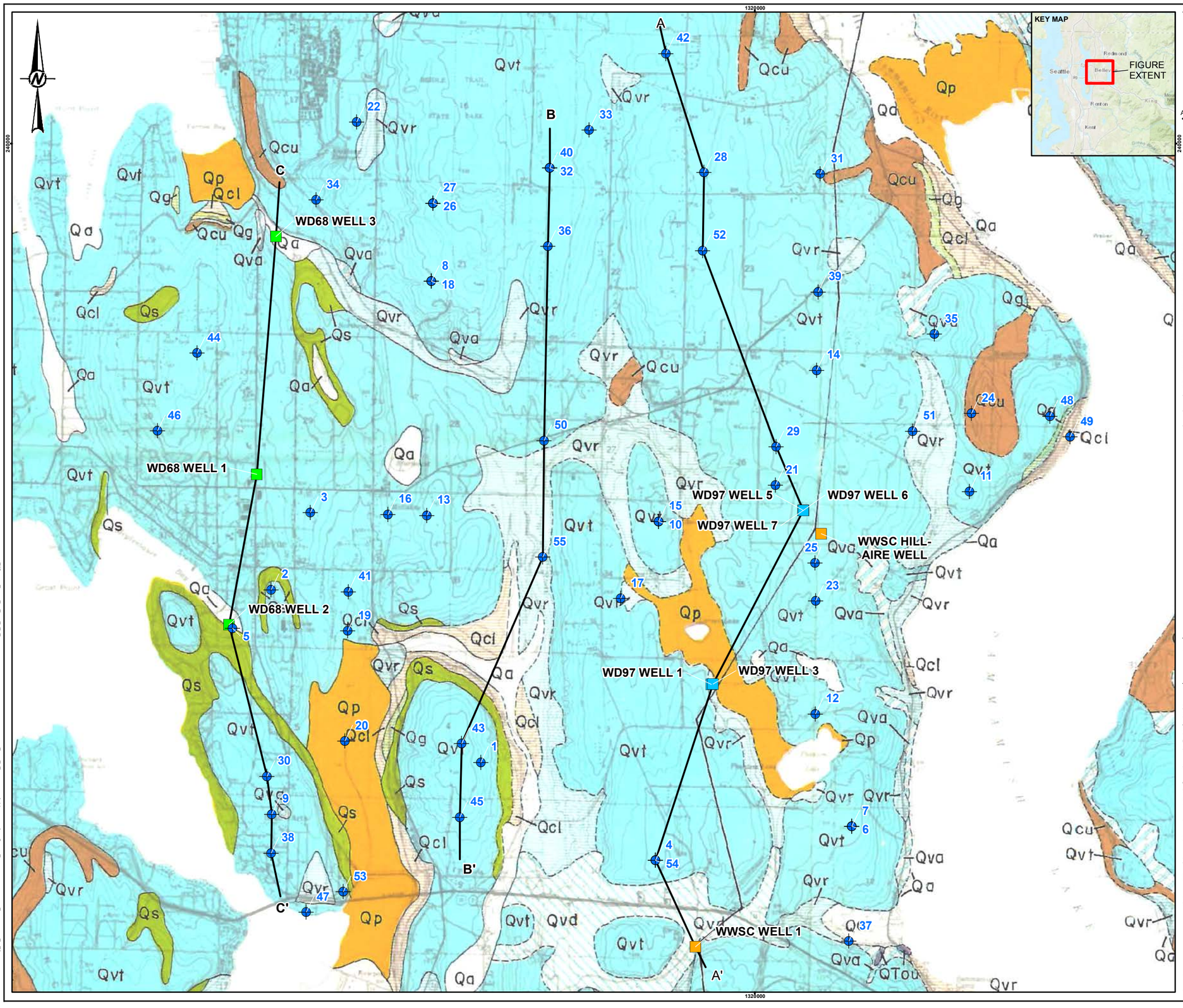


LEGEND

- WELL LOCATION (WA DOE)
- KING COUNTY WATER DISTRICT 68 WELL
- KING COUNTY WATER DISTRICT 97 WELL
- WASHINGTON WATER SERVICE COMPANY WELL
- A A' GEOLOGIC CROSS-SECTION LOCATION

GEOLOGIC UNIT DESCRIPTIONS:

ma – MODIFIED LAND AND FILL
Qa – UNDIFFERENTIATED QUATERNARY SEDIMENTARY DEPOSITS
Qp – PEAT
Qvr – VASHON RECESSIONAL OUTWASH
Qvd - VASHON RECESSIONAL OUTWASH DELTA
Qvt – VASHON TILL
Qva – VASHON ADVANCE OUTWASH
Qs – UNNAMED SAND
Qcu – UPPER CLAY UNIT
Qg – UNNAMED GRAVEL
Qc - UNDIFFERENTIATED CLAY
Qcl – LOWER CLAY UNIT
QTou – OLDER UNCONSOLIDATED DEPOSITS
Tom – MARINE SEDIMENTARY ROCKS
Tp – PUGET GROUP SEDIMENTARY ROCKS
Tv – VOLCANIC ROCKS

0 3,250 6,500
1 INCH = 3,250 FEET FEET

NOTE(S)
1. WELLS LOCATED TO NEAREST ¼ - ¼ SECTION IN DATABASE.

REFERENCE(S)
1. TROOST GEOSCIENCES (WELL LOCATIONS, CITY LIMITS)
2. GOLDER (GEOLOGIC CROSS SECTION)
3. WASHINGTON DEPARTMENT OF ECOLOGY (WELL LOCATIONS)
4. WASHINGTON DIVISION OF WATER RESOURCES (GEOLOGY MAP)
5. COORDINATE SYSTEM: NAD 1983 STATE PLANE WASHINGTON NORTH (FT)
6. SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, DELORME, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), SWISSTOPO, MAPMYINDIA, © OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY

CLIENT
STANTEC

PROJECT
CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN

TITLE
SURFICIAL GEOLOGIC MAP

CONSULTANT
GOLDER

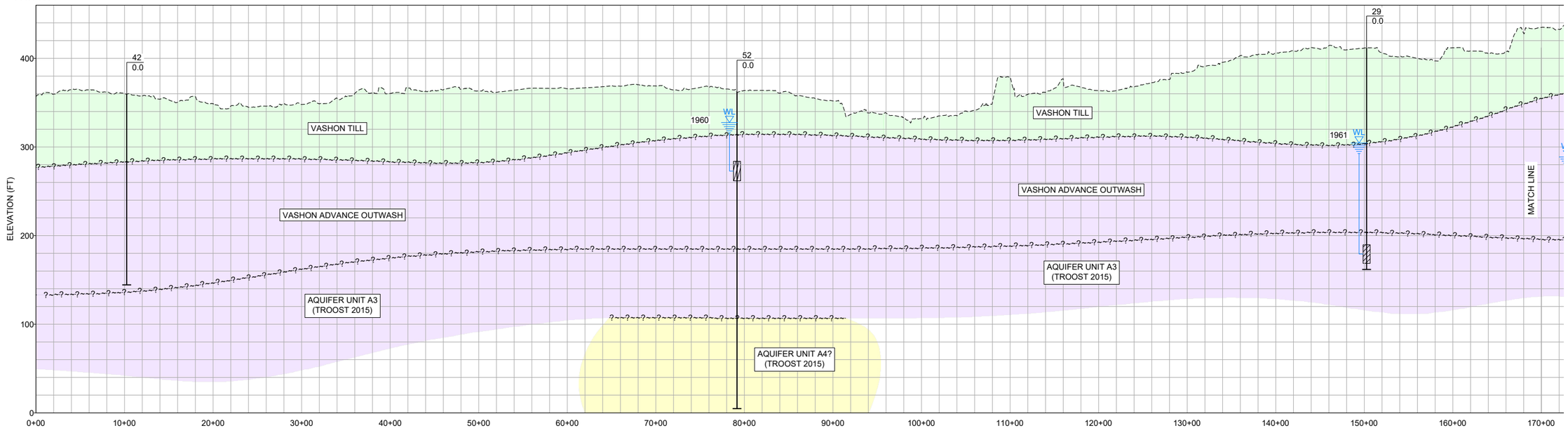
YYYY-MM-DD	2019-09-17
DESIGNED	BVJ
PREPARED	HJ
REVIEWED	MK
APPROVED	MK

PROJECT NO.	PHASE	REV.	FIGURE
1775477	3.1	0	3

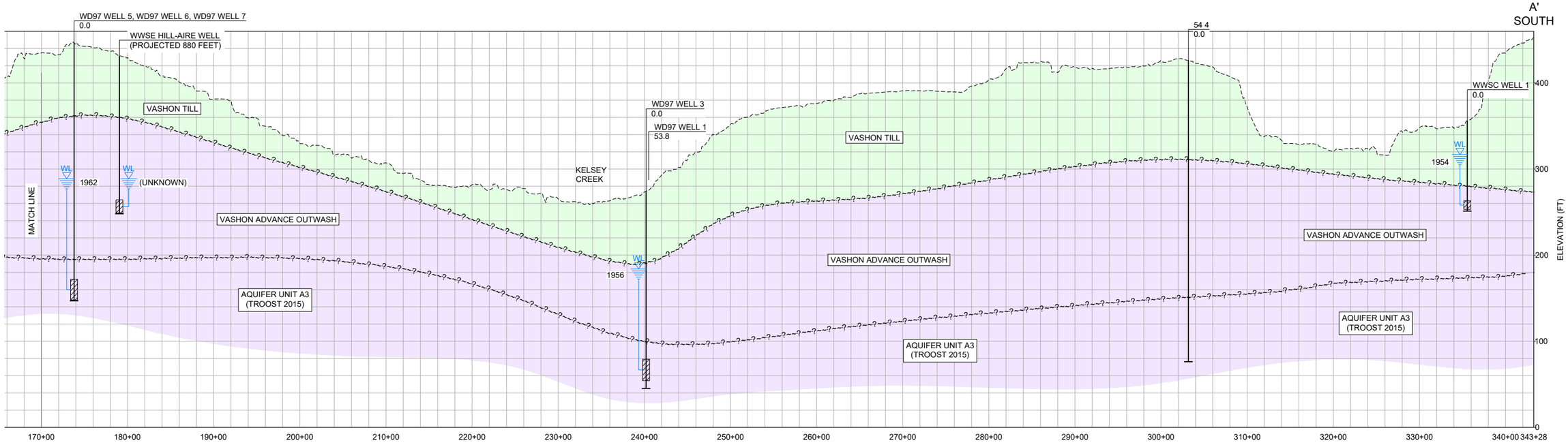
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM ANSI B

PATH: G:\Stantec\City_of_Bellevue\99_PROJECTS\1775477_EmergencyWaterSupplyPlan\Phase_3_1\02_PRODUCTION\MXD\FIGURES\Rev\A\1775477_3_1_004_F3_Rev0_Geology_XSection.mxd PRINTED ON: 2019-09-17 AT: 10:23:19 AM

A
NORTH



A'
SOUTH



NOTE(S)
1. SEE FIGURE 5 FOR LEGEND.

0 600 1200
1" = 600' VERT. FEET

0 600 1200
1" = 600' HORIZ. FEET

CLIENT
STANTEC

CONSULTANT
GOLDER

PROJECT
CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN

TITLE
GEOLOGIC CROSS-SECTION A-A'

YYYY-MM-DD	2019-06-16
DESIGNED	-
PREPARED	REDMOND
REVIEWED	MK
APPROVED	MK

PROJECT NO.	PHASE	REV.	FIGURE
1775477	3.1	A	4

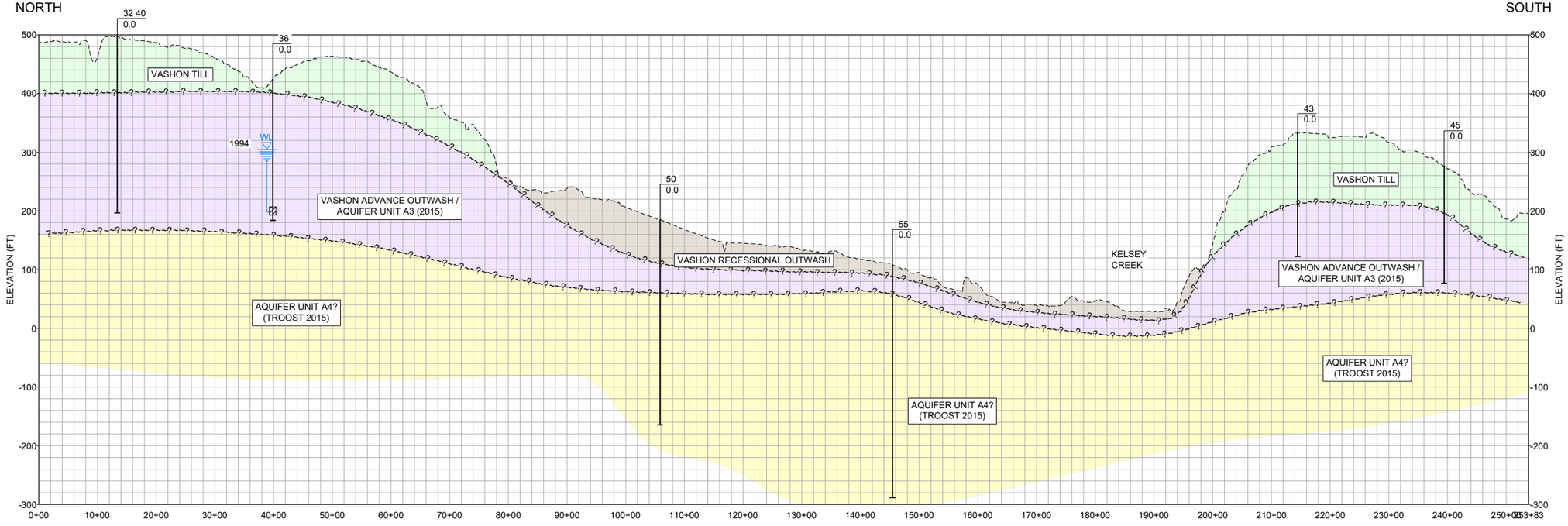
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D

0 1in

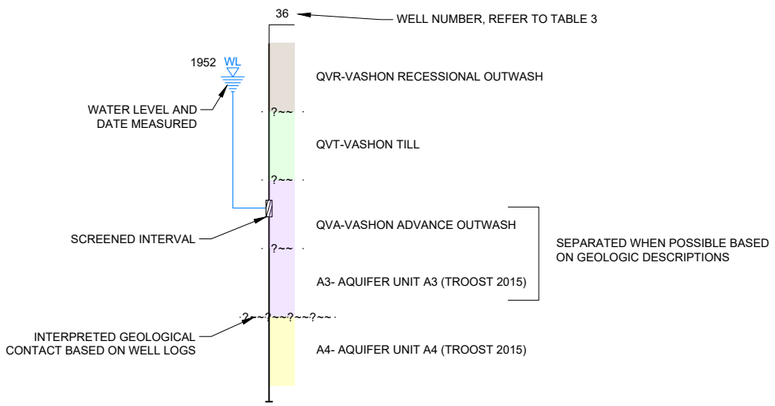
Path: \\redmond.golder.gds\data\geomatics\Stantec\City_of_Bellevue\99_PROJECTS\1775477_WaterRightsMasterPlan\3.1\02_PRODUCTION\DWGs\ | File Name: 1775477-3.1-001.dwg | Last Edited By: trybar Date: 2019-09-17 Time:9:33:15 AM | Printed By: TRybar Date: 2019-09-17 Time:9:37:01 AM

B
NORTH

B'
SOUTH



LEGEND



0 600 1200
1" = 600' VERT. FEET

0 1000 2000
1" = 1000' HORIZ. FEET

CLIENT
STANTEC

CONSULTANT
GOLDER

YYYY-MM-DD	2019-06-16
DESIGNED	-
PREPARED	REDMOND
REVIEWED	MK
APPROVED	MK

PROJECT
CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN

TITLE
GEOLOGIC CROSS-SECTION B-B'

PROJECT NO.	PHASE	REV.	FIGURE
1775477	3.1	A	5

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D

0 1in

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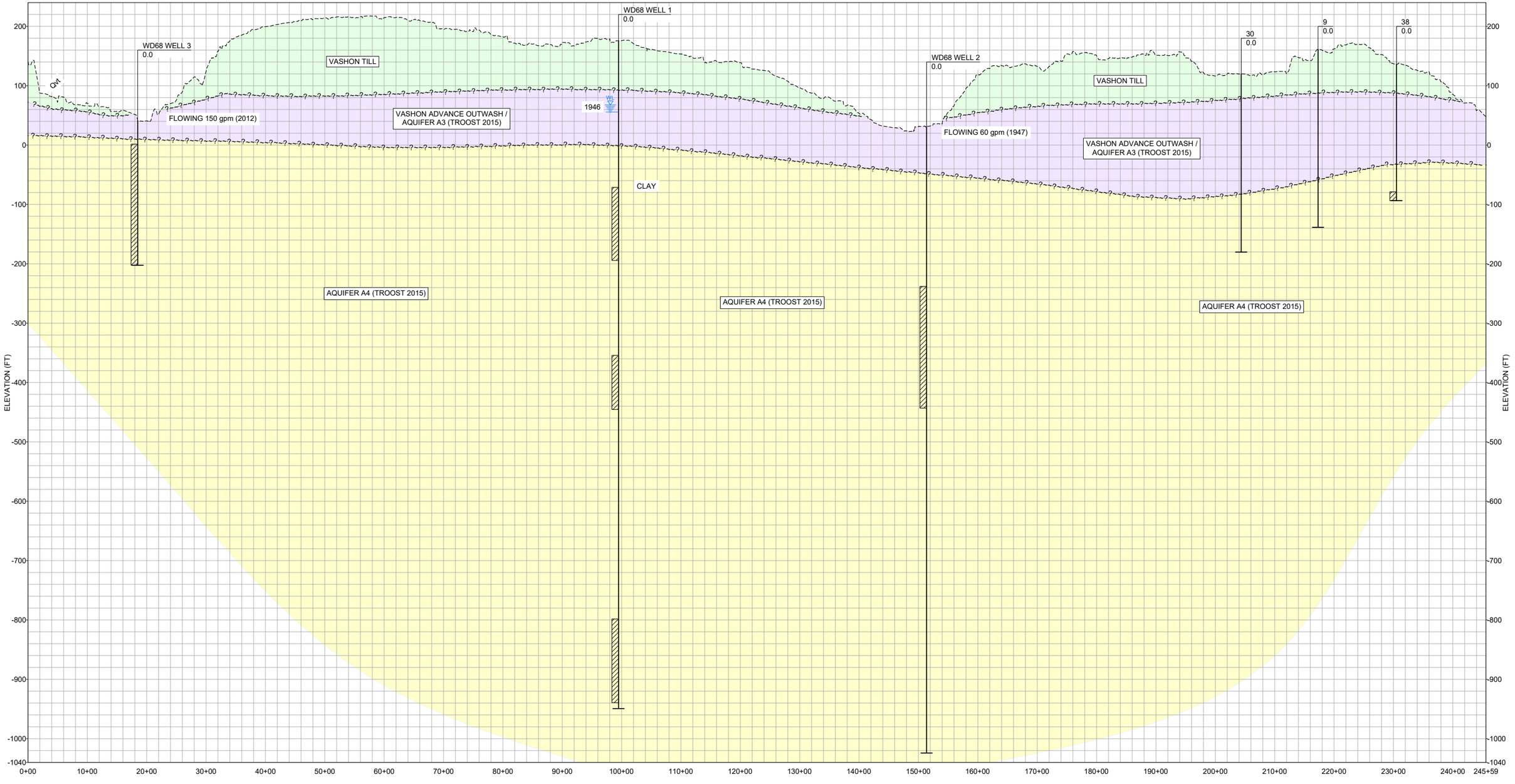
C
NORTH

C'
SOUTH



NOTE(S)

1. SEE FIGURE 5 FOR LEGEND.

0 80 160
1" = 80' VERT. FEET

0 800 1600
1" = 800' HORIZ. FEET

CLIENT
STANTEC

CONSULTANT
GOLDER

YYYY-MM-DD	2019-06-16
DESIGNED	-
PREPARED	REDMOND
REVIEWED	MK
APPROVED	MK

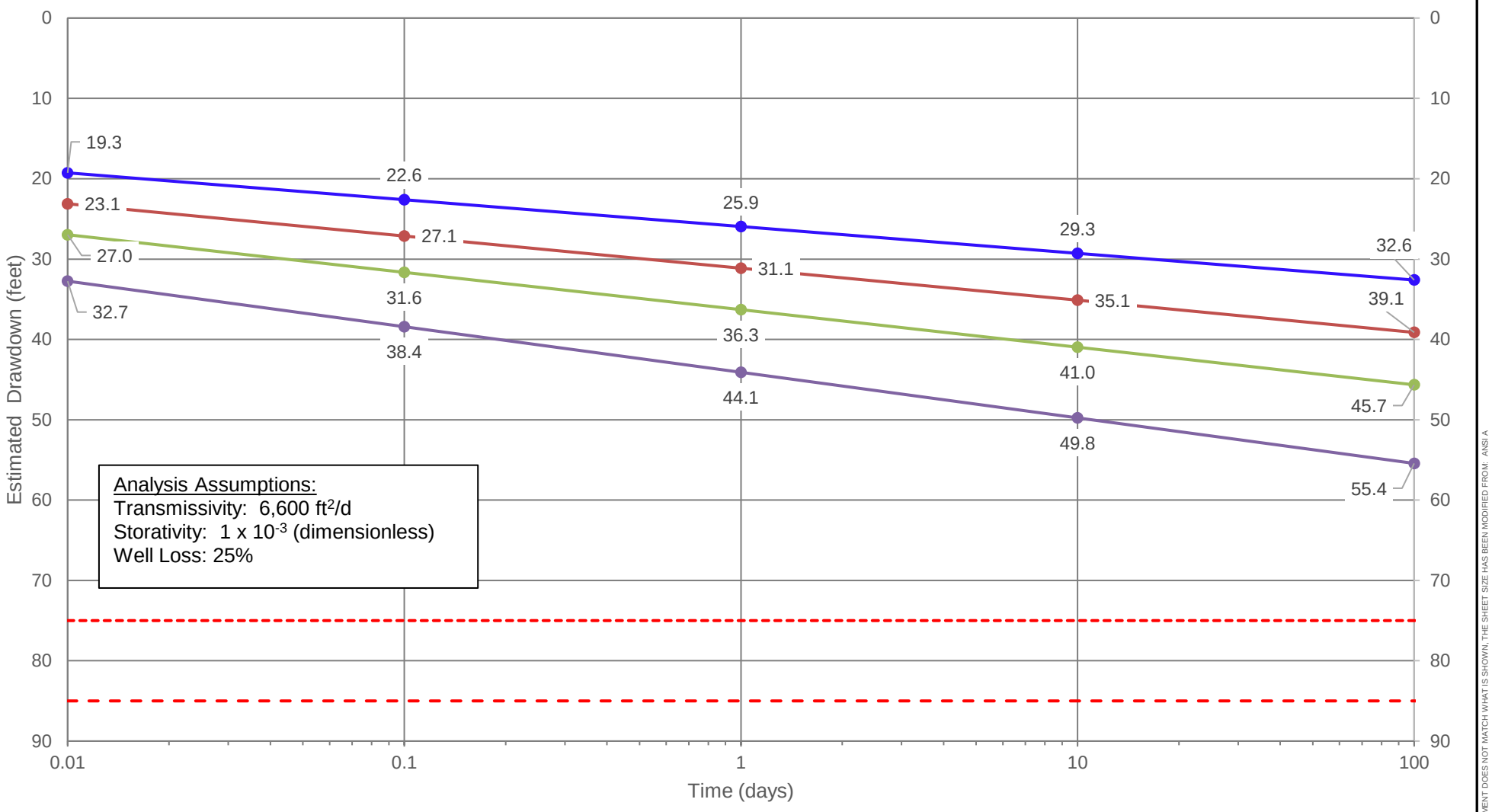
PROJECT
CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN

TITLE
GEOLOGIC CROSS-SECTION C-C'

PROJECT NO.	PHASE	REV.	FIGURE
1775477	3.1	A	6

0 1 in
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI D

Path: \\redmond.golder.gds\data\geomatics\Stantec\City_of_Bellevue\99_PROJECTS\1775477_WaterRightsMasterPlan\3.1\02_PRODUCTION\DWG\ | File Name: 1775477-3.1-002.dwg | Last Edited By: trybar Date: 2019-09-16 Time:11:08:17 AM | Printed By: TRybar Date: 2019-09-17 Time:9:37:31 AM



LEGEND

- 500 gpm
- 600 gpm
- 700 gpm
- 850 gpm
- Available Drawdown - High Groundwater Level
- Available Drawdown - Low Groundwater Level

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CONSULTANT
GOLDER

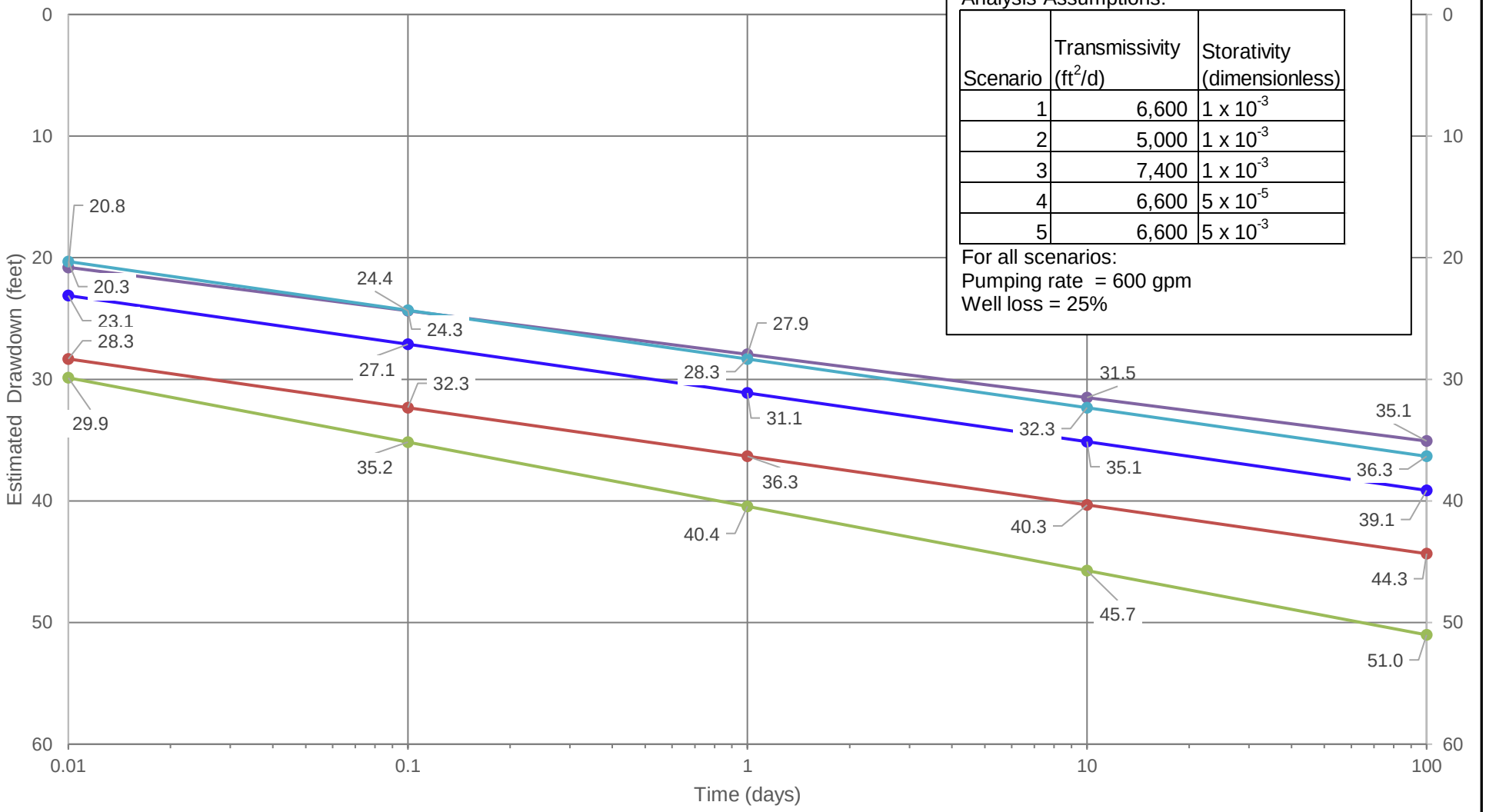
YYYY-MM-DD	2019-09-16
DESIGNED	---
PREPARED	MPK
REVIEWED	EA
APPROVED	DB

PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
ESTMATED DRAWDOWN
SINGLE WELL
100 DAYS PUMPING

PROJECT NO.	CONTROL	REV.	FIGURE
1775477.3.1		A	7

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0



Analysis Assumptions:

Scenario	Transmissivity (ft^2/d)	Storativity (dimensionless)
1	6,600	1×10^{-3}
2	5,000	1×10^{-3}
3	7,400	1×10^{-3}
4	6,600	5×10^{-5}
5	6,600	5×10^{-3}

For all scenarios:
Pumping rate = 600 gpm
Well loss = 25%

LEGEND
- Scenario 1 (baseline)
- Scenario 3 (high T)
- Scenario 4 (low S)
- Scenario 5 (high S)
- Scenario 2 (low T)

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CONSULTANT
GOLDER

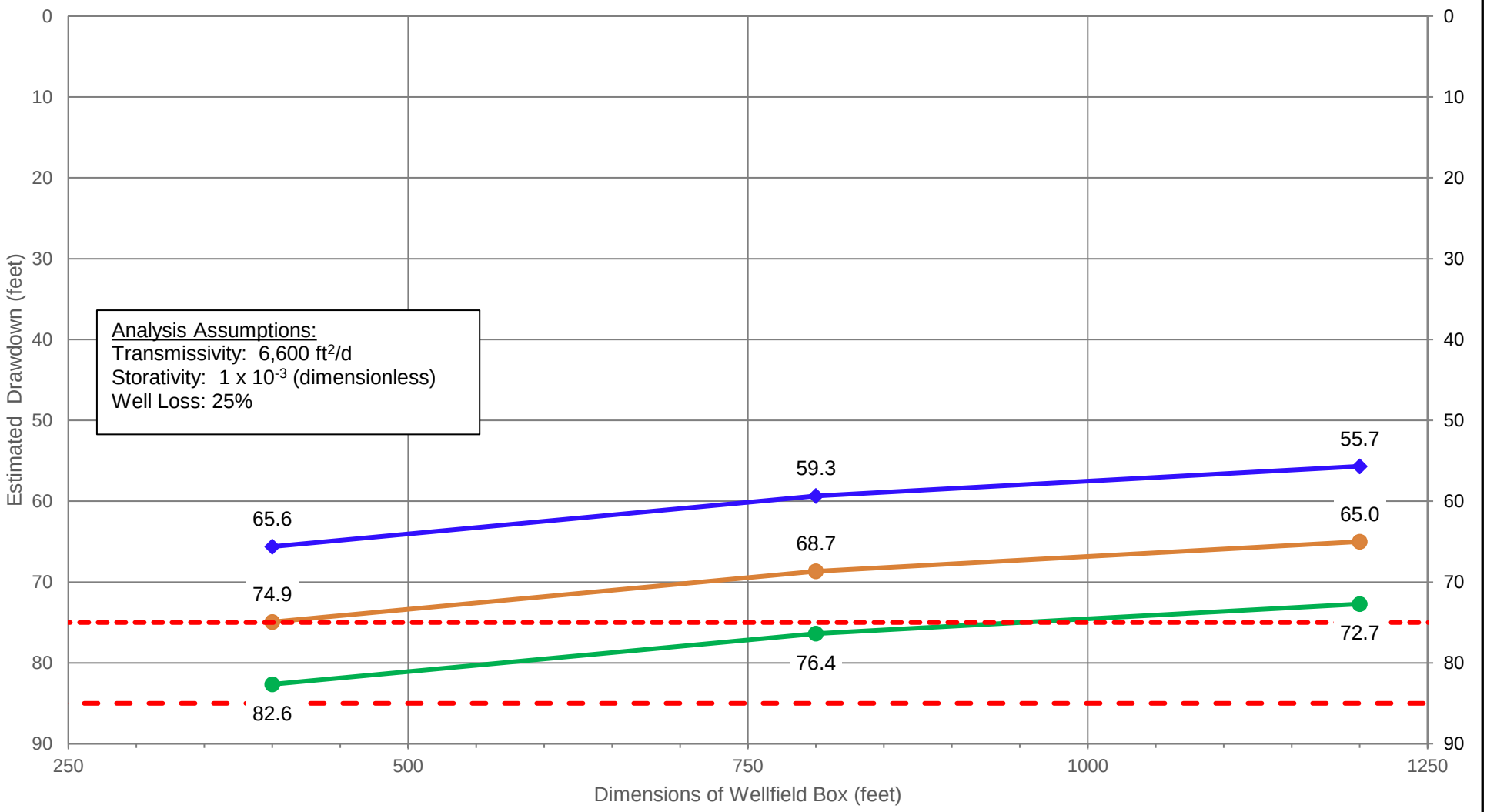
YYYY-MM-DD	2019-09-16
DESIGNED	---
PREPARED	MPK
REVIEWED	EA
APPROVED	DB

PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
ESTMATED DRAWDOWN SENSITIVITY
SINGLE WELL
100 DAYS PUMPING

PROJECT NO.	CONTROL	REV.	FIGURE
1775477.3.1		A	8

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0



Note: 4 wells in square box-shaped wellfield, each well pumps 650 gpm

LEGEND
- 7 Days Pumping
- 30 Days Pumping
- 100 Days Pumping
- Available Drawdown - Low Groundwater Level
- Available Drawdown - High Groundwater Level

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GOLDER

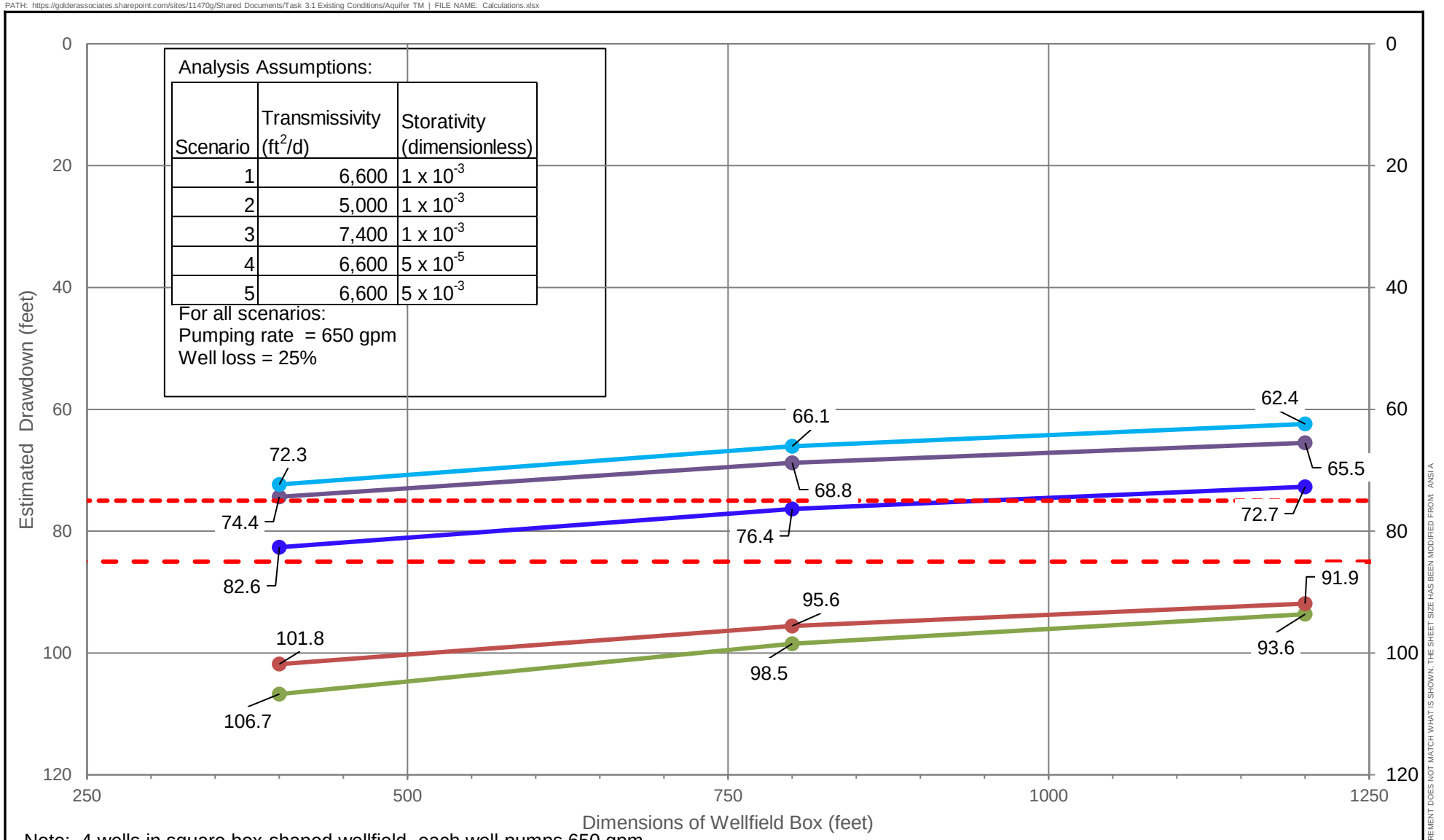
YYYY-MM-DD	2019-09-16
DESIGNED	---
PREPARED	MPK
REVIEWED	EA
APPROVED	DB

PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
WELLFIELD EVALUATION
ESTIMATED DRAWDOWN
4 WELLS PUMPING 7 TO 100 DAYS

PROJECT NO.	CONTROL	REV.	FIGURE
1775477.3.1		A	9

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0



Note: 4 wells in square box-shaped wellfield, each well pumps 650 gpm

LEGEND
- Scenario 1 (baseline)
- Scenario 2 (low T)
- Scenario 2 (high T)
- Scenario 4 (Low S)
- Scenarion 5 (high S)
- Available Drawdown - Low Groundwater Level
- Available Drawdown - High Groundwater Level

CLIENT
STANTEC

CONSULTANT
GOLDER

YYYY-MM-DD	2019-09-16
DESIGNED	---
PREPARED	MPK
REVIEWED	EA
APPROVED	DB

PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
WELLFIELD EVALUATION
SENSITIVITY ANALYSIS
4 WELLS PUMPING 100 DAYS

PROJECT NO.	CONTROL	REV.	FIGURE
1775477.3.1		A	10

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0

ATTACHMENT A

Cross-Section Well Logs

#4

Please print, sign and return by mail to Department of Ecology

RESOURCE PROTECTION WELL REPORT

CURRENT Notice of Intent No. G301071

(SUBMIT ONE WELL REPORT PER WELL INSTALLED)

Construction/Decommission *(select one)*

☒ Construction

☐ Decommission *ORIGINAL INSTALLATION Notice of Intent Number* _____

Consulting Firm GEO Loop Tec

Unique Ecology Well ID Tag No. BIT 153

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee Name (Print) Kris Panchen

Driller/Engineer /Trainee Signature _____

Driller or Trainee License No. 3028

If trainee, licensed driller's Signature and License No. _____

Type of Well *(select one)*

☒ Resource Protection

☐ Geotech Soil Boring

Property Owner Bellevue College

Site Address 3000 Landerholm Circle SE

City Bellevue County King

Location SE 1/4-1/4 NE 1/4 Sec 10 Twn 24 R 05E Select One ☒ EWM ☐ WWM

Lat/Long (s, t, r still REQUIRED) Lat Deg _____ Lat Min/Sec _____ Long Deg _____ Long Min/Sec _____

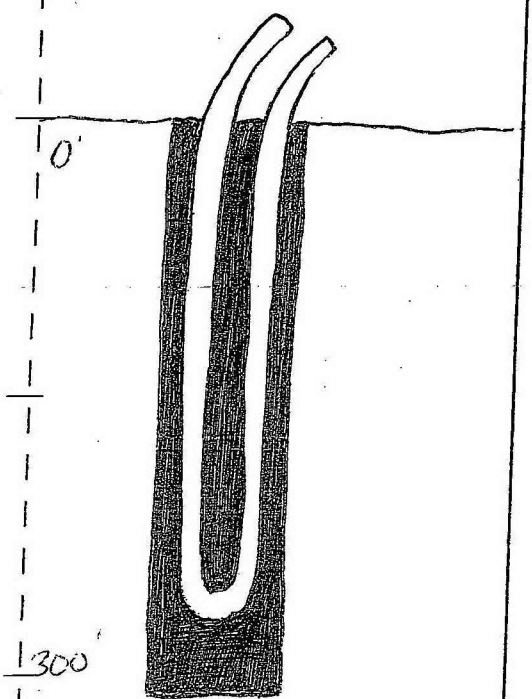
Tax Parcel No. 102405-9008

Cased or Uncased Diameter 6" Static Level _____

Work/Decommission Start Date 12/3/2014

Work/Decommission Completed Date 12/3/2014

Construction/Design



Well Data

Install 1" closed ground loop.

Place thermally enhanced grout from 300' to 0'

Bore #- 53

Formation Description

0-80 Sand/gravel

80-90 Sand/gravel/silt

90-115 Gravel/Sand-Brown

115-125 Course Sand & gravel Blue/white

125-184 Sand/gravel w/ some silt

184-200 Sand/Silt

200-215 Sand/Silt/gravel

215-243 Sand/gravel

243-275 Sand/Silt w/ some gravel

275-287 Sand/Silt/ gravel

287-300 Large gravel caving w/ some silt

RECEIVED

JAN 20 2015

DEPT OF ECOLOGY

NWRO - WR

ECY 050-12 (Rev. 2/03) SCALE: 1"=__ Page___of___ Ecology is an Equal Opportunity Employer.

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report

#54

401578

24-5E-10 lt

Please print, sign and return to the Department of Ecology

RESOURCE PROTECTION WELL REPORT

CURRENT Notice of Intent No. GE00174

(SUBMIT ONE WELL REPORT PER WELL INSTALLED)

Construction/Decommission *("x" in box)*

☒ Construction
☐ Decommission

ORIGINAL INSTALLATION Notice of Intent Number:
8/18/10

Consulting Firm N/A

Unique Ecology Well IDTag No. BBT-614

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee
Name (Print Last, First Name) Gregory , Chris
Driller/Engineer /Trainee Signature
Driller or Trainee License No. 2534

If trainee, licensed driller's Signature and License Number:

Type of Well *("x in box)*

☒ ~~Resource Protection~~ GEOTHERMAL
☐ Geotech Soil Boring

Property Owner Bellevue College

Site Address 3000 Landerholm Circle SE

City Bellevue County King

Location se1/4-1/4 ne1/4 Sec 10 Twn 24 R 05e

EWM ☒ or WWM ☐

Lat/Long (s, t, r still REQUIRED) Lat Deg ____ Min ____ Sec ____
Long Deg ____ Min ____ Sec ____

Tax Parcel No. N/A

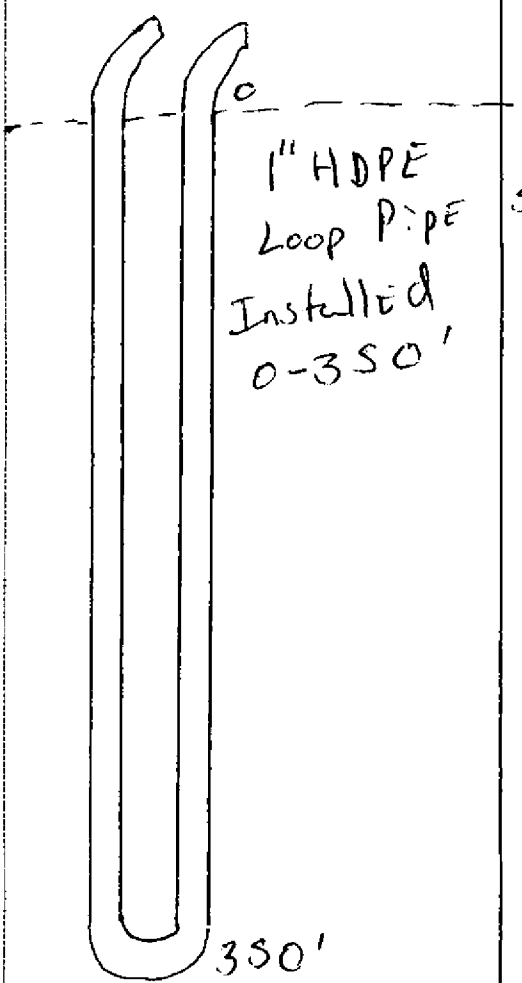
Cased or Uncased Diameter 6"

Static Level N/A

Work/Decommission Start Date 8/18/10

Work/Decommission Completed Date 8/20/10

Construction Design



Well Data

0-5' BENTONITE chips - 3 sacks

5'-350' Thermal Grout
15 - Baratherm
60 - Sand

Formation Description

0-80 Sand/Gravel
80-90 Sand/Gravel/Silt
90-115 Gravel/Sand - Brown
115-125 Gravel/Course Sand Blue/White
125-184 Gravel/Sand some silt
184-200 Sand/Silt
200-215 Sand/Silt/Gravel
215-243 Sand/Gravel
243-275 Sand/Silt some Gravel
275-287 Sand/Silt Gravels
287-300 Large Gravel Caving
303-350 Silt/Gravel

RECEIVED
JAN 19 2011
Department of Ecology - Northwest Regional Office

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

#29

STATE OF WASHINGTOI
DEPARTMENT OF CONSERVATION AND DEVELOPMI NT

WELL LOG No A.5961, P.5605

Date 8-11, 1961

Record by well driller

Source driller's record

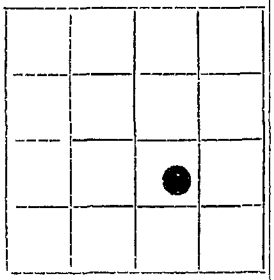


Diagram of Section

25/5-16K
File number

Location State of WASHINGTON

County King

Area

Map

SE¼NW ¼SE ¼ sec 26 T 25 N, R 5 E W

Drilling Co H.O. Meyer Drilling Co.

Address 6424 Lk.Wash. Blvd. N.E. Kirkland

Method of Drilling Date May & June 1961

Owner Eastgate Homes Inc.

Address 14217 Lake Hills Blvd. Bellevue

Land surface, datum ft above / below

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Top soil	2	2
	Hardpan	19	21
	Layer water bearing mat.	2	23
	Hardpan	13	36
	Hardpan & water	1	37
	Hardpan	13	50
	Sandy clay	19	69
	Dry sand	25	94
	Hardpan	14	108
	Sandy clay	12	120
	Brown silt	15	135
	Gravel, sand, water	22	157
	Hardpan	1	158
	Brown sandy clay	50	208
	Blue sand	4	212
	Brown sand, coarse	27	239
	Green sand	3	242
	Blue sand	8	250

(Transcribe driller s terminology literally but paraphrase as necessary in parentheses If material water bearing so state and record static level if reported Give depths in feet below land surface datum unless otherwise indicated Correlate with stratigraphic column if feasible Following log of materials list all casings perforations screens etc)

Turn up (over) Sheet of sheets

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

WELL LOG—Continued | No / -

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	———	
	PUMP TEST		
	Dim. 8"x243'		
	SWL 119'4"		
	DD 93'		
	Yield 185 g.p.m.		
	Type & size of pump Jacuzzi, Submersible		
	Type & size of motor or engine		20 h.p.
	CASING		
	8" diam. from 0 to 223 ft.		
	PERFORATIONS		
	2# 14's, 10' from 222 to 232 ft.		
	2# 20's 10' " 232 to 243 ft.		

S F No 74-8—12 54—3M 40108

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

KCWD 97 Well No. 1

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION AND DEVELOPMENT

WELL LOG No Appli.#4058 Cert. 2539-A

Date July 30, 1955

Record by Howard T. Harstad

Source driller's record

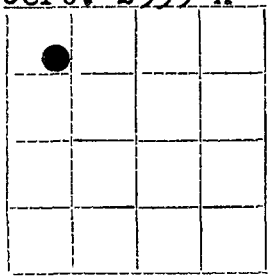


Diagram of Section

Location State of WASHINGTON

County King

Area

Map

NW ¼ NW ¼ sec 2 T 24N, R 5 E ~~W~~

Drilling Co Howard T. Harstad

Address Seattle, Wash.

Method of Drilling Date Aug. 15, 1955

Owner King Co. Water Dist. #97

Address Bellevue, Wash.

Land surface, datum ft above / below

24N/5E-2J

File number

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	(Transcribe driller s terminology literally but paraphrase as necessary in parentheses If material water-bearing so state and record static level if reported Give depths in feet below land-surface datum unless otherwise indicated Correlate with stratigraphic column if feasible Following log of materials, list all casings perforations screens etc)		
	~~Nxxxxxxxxxxxxxxxxxxxx~~ (See back for well log)		
	Dim. 160'x12"		
	SWL: 102 ft.		
	DD: 140 ft.		
	Yield: 420 g.p.m.		
	Temp. 52°		
	CASING:		
	12".I.D. steel 44# casing from 0 to 130 ft.		
	Perforations:		
	wire wound silicon bronze 0.040" screen from 130 to 160 ft.		

Turn up Sheet of sheets

t of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

WELL LOG—Continued No / -

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	———	
	Hardpan	20	20
	Coarse sand, waterbearing	22	42
	Blue clay	42	84
	Fine sand- some water	3	87
	Impervious clay	26	113
	Coarse gravel & rocks water bearing	22	135
	Coarse sand, gravel & rocks, water bearing	21	154
	Consolidated clay	2	156
	Coarse sand & gravel water bearing	4	160

S F No 7448—12-54—3M 62108

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

KWDW 97 Well No. 3

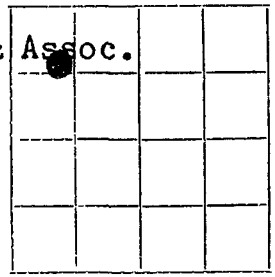
STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

WELL LOG No Appli. 4201

Date Feb. 16 , 19 56

Record by Howard T. Haarstad & Assoc.

Source driller's record



24N/5E-22D
File number

Location State of WASHINGTON

County King

~~xxxx~~ Lot 8, Blk. 5 of

~~xxx~~ Evergreen Add. #2

to Eastgate Hills

¼ ¼ sec 2 T 24 N, R 5 E ~~xx~~

Drilling Co Howard T. Haarstad & Assoc.

Address Seattle

Method of Drilling Date Mar. 1 , 19 56

Owner King Co. Water Dist. #97

Address Seattle, Wash.

Land surface, datum ft above / below

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary in parentheses If material water-bearing so state and record static level if reported Give depths in feet below land surface datum unless otherwise indicated Correlate with stratigraphic column, if feasible Following log of materials list all casings perforations, screens, etc)		
	Sand & clay	38	38
	Water bearing sand	5	43
	Silt & clay	25	68
	Clay	16	84
	Silt clay	28	112
	Hardpan (cement sand & gravel)	8	120
	Silt & gravel (water bearing)	30	150
	Sand & gravel "	9	159
	Hardpan (clay & sand)	16	175
	Coarse to fine sand (water bearing)	48	223
	Silt and clay	6	229

Turn up Sheet of sheets

Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

WELL LOG —Continued No / -

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	———	
	PUMP TEST		
	Dim. 220'x18x12"		
	SWL: 102 ft.		
	DD: 93 ft.		
	Yield: 900 g.p.m.		
	CASING:		
	Outside-18" diam. 59#/ft steel		
	from 0 to 187 ft.		
	Inside- 12" diam. 44#/ft steel		
	from 0 to 220 ft.		
	PERFORATIONS:		
	Red Brass 0.030" from 195 to 215 ft.		
	" " 0.020" " 215 to 220 ft.		

S F No 7448—12-54—3M 40108

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

KCWD 97 Well No. 7

STATE OF WASHINGTO
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

No A.6350

Date 8-1, 1962
Record by well driller
Source driller's record

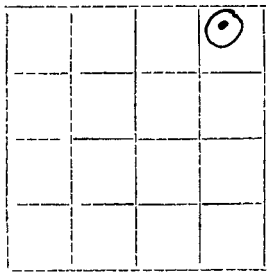


Diagram of Section

25/15E/35A
File number

Location State of WASHINGTO
County King
Area
Map
¼ ¼ sec ~~2~~ 35 T ~~24~~ 25 N, R 5 E ~~W~~

Drilling Co Harstad Associates
Address Seattle, Wash.
Method of Drilling Date June 14, 1962
Owner King Co. Water Dist. #97
Address 16049 N.E. 8th St., Bellevue, Wash.
Land surface, datum ft above / below

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary in parentheses If material water bearing so state and record static level if reported Give depths in feet below land surface datum unless otherwise indicated Correlate with stratigraphic column if feasible Following log of materials list all casings perforations screens etc)		
	Top soil	2	2
	Gravel sandy clay brown	~~10~~ 10	~~12~~ 12
	Gravel sandy clay gray	63	75
	Hardpan	10	85
	Sand & gravel brown	49	134
	Brown clay & sand	54	188
	Water bearing sand	5	193
	Gravel sandy clay w/org.	5	198
	Hardpan	14	212
	Sand gravel & clay	4	216
	Coarse gravel- dry	11	227
	Gravel sand & blue clay	5	232
	Water bearing sand	5	237
	Sand & gray clay	11	248
	Sand & lumps of brown clay	4	252
	Sand gravel & clay	1	253
	Coarse rock & small amt. sand	17	~~270~~ 270

Turn up (over) Sheet of sheets

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

WELL LOG—Continued No / -

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	———	270
	Coarse gravel & sand	27	297
	Cemented gravel	3	300
	PUMP TEST:		
	Dim. 12"x299'		
	SWL: 170 ft. (6-14-62)		
	DD: 38 ft.		
	Yield; 590 g.p.m.		
	Type & size of pump: Turbine		
	Type & size of motor: U.S.Part winding; 1700 rpm. 440 volts		
	CASING:		
	12" diam. std. steel casing from 0 to 275 ft.		
	RERFORATIONS:		
	12" well screen 60 mesh from 275 to 284 ft.		
	12" well screen 40 mesh from 284 to 299 ft.		

S P No 7449—OS—6-61—2M

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

#28

ENTERED

WATER WELL REPORT

STATE OF WASHINGTON

File Original and First Copy with Department of Ecology
Second Copy — Owner's Copy
Third Copy — Driller's Copy

Start Card No. W055016
UNIQUE WELL I.D. # AAZ 736
Water Right Permit No. 25-6E-14N

(1) OWNER: Name Dwight Martin Address 4518 243rd Ave N.E. Redmond WA 98053

(2) LOCATION OF WELL: County King S½ of SW 1/4 SW 1/4 Sec 14 T. 25 N., R 6E W.M.

(2a) STREET ADDRESS OF WELL (or nearest address) 44XX 244th Ave N.E. Redmond

(3) PROPOSED USE: [X] Domestic [ ] Industrial [ ] Municipal [ ] Irrigation [ ] Test Well [ ] Other [ ] DeWater

(4) TYPE OF WORK: Owner's number of well (If more than one) _____
Abandoned [ ] New well [X] Method: Dug [ ] Bored [ ]
Deepened [ ] Cable [X] Driven [ ]
Reconditioned [ ] Rotary [ ] Jetted [ ]

(5) DIMENSIONS: Diameter of well 6 inches.
Drilled 330 feet. Depth of completed well 326 ft.

(6) CONSTRUCTION DETAILS:
Casing installed: 6" Diam. from +2 ft. to 312 ft.
Welded [X] Liner installed [ ] Threaded [ ]
_____" Diam. from _____ ft. to _____ ft.
_____" Diam. from _____ ft. to _____ ft.

Perforations: Yes [ ] No [X]
Type of perforator used _____
SIZE of perforations _____ in. by _____ in.
_____ perforations from _____ ft. to _____ ft.
_____ perforations from _____ ft. to _____ ft.
_____ perforations from _____ ft. to _____ ft.

Screens: Yes [X] No [ ]
Manufacturer's Name Johnson
Type Stainless Steel Model No. _____
Diam. 5" Slot size .06 from 314 ft. to 326 ft.
Diam. ____ Slot size _____ from _____ ft. to _____ ft.

Gravel packed: Yes [ ] No [X] Size of gravel _____
Gravel placed from _____ ft. to _____ ft.

Surface seal: Yes [X] No [ ] To what depth? 18' ft.
Material used in seal Bentonite
Did any strata contain unusable water? Yes [ ] No [X]
Type of water? _____ Depth of strata _____
Method of sealing strata off _____

(7) PUMP: Manufacturer's Name Goulds
Type: Submersible H.P. 1

(8) WATER LEVELS: Land-surface elevation above mean sea level _____ ft.
Static level 270 ft. below top of well Date 5-26-99
Artesian pressure _____ lbs. per square inch Date _____
Artesian water is controlled by _____ (Cap, valve, etc.)

(9) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? Yes [X] No [ ] If yes, by whom? Aqua Flo
Yield: 8 gal./min. with less than 39 ft. drawdown after 1 hrs.
" " " "
" " " "

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test 5-26-99
Bailer test _____ gal./min. with _____ ft. drawdown after _____ hrs.
Airtest _____ gal./min. with stem set at _____ ft. for _____ hrs.
Artesian flow _____ g.p.m. Date _____
Temperature of water _____ Was a chemical analysis made? Yes [X] No [ ]

(10) WELL LOG or ABANDONMENT PROCEDURE DESCRIPTION

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information.

MATERIAL	FROM	TO
Top Soil	0	1
Sand + Gravel	1	8
Green Clay	8	55
Gravel with Clay	55	57
Green Clay	57	108
Dry Gravel	108	110
Sandy Green Clay	110	165
Sand	165	170
Gray Clay	170	300
Heaving Gray Sand	300	330
Gray Clay	330	

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JUN 11 1999
DEPT OF ECOLOGY

Work Started 3-22 19 99 Completed 5-26 19 99

WELL CONSTRUCTOR CERTIFICATION:

I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

NAME AQUA FLO, INC. (PERSON, FIRM, OR CORPORATION) (TYPE OR PRINT)
Address 1413 Meridian E. Edgewood 98371
(Signed) _____ (WELL DRILLER) License No. 2481
Contractor's Registration No. AQUAFI*099QG Date 6-3 19 99

(USE ADDITIONAL SHEETS IF NECESSARY)

ECL 050-1-20 (2/93)

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

450996

Please print, sign and return to the Department of Ecology

RESOURCE PROTECTION WELL REPORT

CURRENT Notice of Intent No. GE00349

(SUBMIT ONE WELL REPORT PER WELL INSTALLED)

Construction/Decommission *("x" in box)*

☒ Construction
☐ Decommission

ORIGINAL INSTALLATION Notice of Intent Number:

Consulting Firm PSE

Unique Ecology Well IDTag No. BHF-973

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee
Name (Print Last, First Name) Arfman, John
Driller/Engineer /Trainee Signature
Driller or Trainee License No. 2673

If trainee, licensed driller's Signature and License Number:

Type of Well *("x in box)*

☒ Resource Protection
☐ Geotech Soil Boring

Property Owner Puget Sound Energy

Site Address 148 th & 55 th st

City Bellevue County King

Location NE1/4-1/4 NE1/4 Sec 15 Twn 25N R 5E

EWM ☒ or WWM ☐

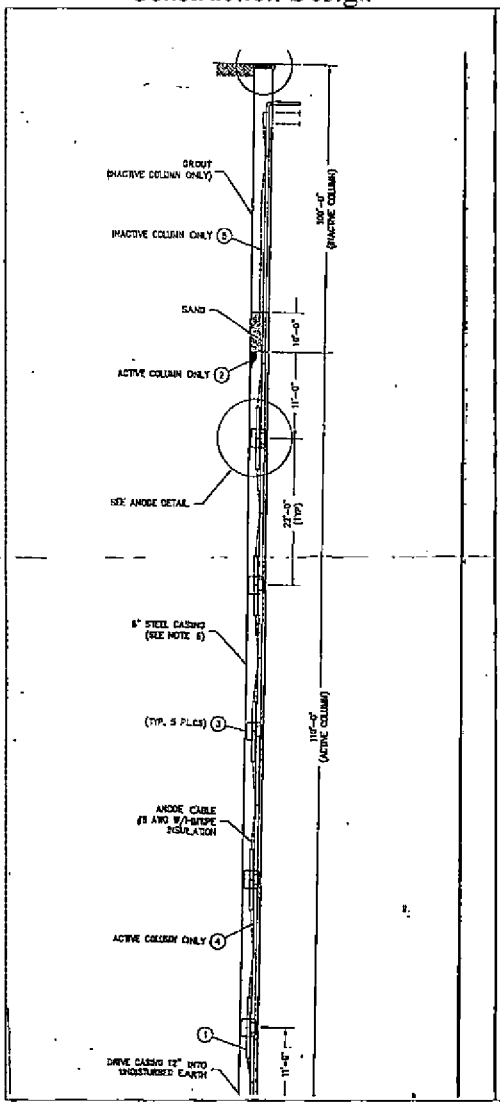
Lat/Long (s, t, r still REQUIRED) Lat Deg ____ Min ____ Sec ____
Long Deg ____ Min ____ Sec ____

Tax Parcel No.

Cased or Uncased Diameter 6 Static Level 22

Work/Decommission Start Date 5-22-12

Work/Decommission Completed Date 5-30-12

Construction Design	Well Data	Formation Description
	0-110 High solids bentonite grout 110-215 backfill with conductive material with tremmie pipe from the surface	0-15 till and cobbles 15-49 brown sand and gravels 49-76 grey soft clay 76-215 fine grey sand- active

RECEIVED
JUN 05 2012
WA State Department of Ecology (SWRO)

SCALE: 1"= ____ PAGE ____ OF ____

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#52

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION AND DEVELOPMENT

WELL LOG Well #1 No Apply.#5591

Date 5-27 1960

Record by well driller

Source well driller's record

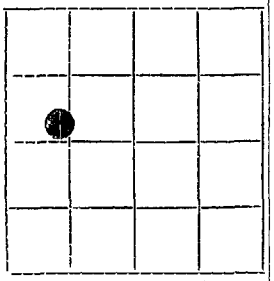

Diagram of Section

File number 22-22127

Location State of WASHINGTON

County King

Area Tract 3, Overlake Industrial Park

Map

¼ ¼ sec 23 T 25 N, R 5 E ~~W~~

Drilling Co H.O. Meyer Drilling Co.

Address 6424 L.W. Blvd. N.E., Kirkland, Wn.

Method of Drilling Date 2-8 , 1960

Owner United Control Corporation

Address 4540 Union Bay Place, Seattle 5

Land surface datum ft above / below

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary in parentheses. If material water bearing so state and record static level if reported. Give depths in feet below land surface datum unless otherwise indicated. Correlate with stratigraphic column if feasible. Following log of materials list all casings perforations screens etc.)		
	Top soil	3	3
	Hardpan	20	23
	"	25	48
	Coarse sand & some gravel	5	53
	~~Sand & gravel medium~~	~~11~~	~~64~~
	~~Sand all w/b~~	6	70
	Sand with occasional gr.	19	89
	Sand & gravel	5	94
	Coarse bluesand	5	99
	Compact silt some layers of gravel	31	130
	~~" " " "~~	~~12~~	~~142~~
	~~Silt between layers clay~~	~~20~~	~~162~~
	Compact silt	15	177
	Sand & gravel, water	2	179
	Silt	13	192
	~~Hard blue clay~~ (over)	~~8~~	~~200~~

Turn up Sheet of sheets

Ecology does NOT Warranty the Data and/or the Information on this Well Report.

WELL LOG —Continued No / -

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	———	200
	Sand & sed.	2	202
	Compact blue clay	53	255
	Softer blue clay	10	265
	Blue clay	19	284
	Layer of rock or compact sand - grey	4	288
	Soft & brown in color	4	292
	Grey shaley clay	65	357
	PUMP TEST		
	Dim. 8"x357'		
	SWL. 46 ft.		
	DD. 45 ft.		
	Yield 132 g.p.m.		
	Water Temp. 48°		
	CASING. 8" diam. from 0 to 100 ft.		
	Shoe at 78 ft.		
	PERFORATIONS		
	22 ft. of 8" #30 slot Cook screen from 78 to 100 ft.		

S F No 7449—12 54—3M 40108

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

WWSC Hill Aire

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

WELL LOG

No Appli. #1214
Permit #1077

Date not completed, 19

Record by E. F. Axelson

Source well driller's record

Location State of WASHINGTON

County King

Area

~~XXX~~ Lot 4 Block 2

¼ ¼ sec 35 T 25 N, R 5 E ~~XX~~

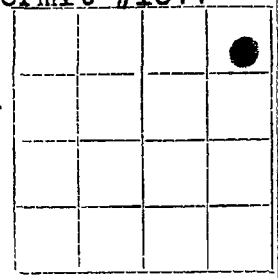

Diagram of Section

Drilling Co

Address

Method of Drilling drilled Date , 19

Owner Washington Water Service Co. Inc.

Address Bellevue, Washington

Land surface, datum ft above / below

25N/5E-35A
File number

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary in parentheses If material water-bearing so state and record static level if reported Give depths in feet below land-surface datum unless otherwise indicated Correlate with stratigraphic column, if feasible Following log of materials list all casings perforations, screens, etc)		
	Surface soil	5	5
	Hard pan	65	70
	Gravel & sand-some clay	85	155
	Gravel, sand & water	15	170
	Sand & water	13	183
Pump Test:			
	Dim: 183' x 8"		
	SWL: 155'		
	Dd: - Yield: 150 g.p.m. (permit)		
	Perfor: screen test from 183 to 193'		
	Pump: not decided		

Turn up Sheet of sheets

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WWSC Well No. 1

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

WELL LOG

No Appl. #3251
Permit #3043

Date February , 19 54

Record by M.S. Campbell

Source well driller's record

Location State of WASHINGTON

County King

Area

Map

SW ¼ SW ¼ sec 11 T 24 N, R 5 E W

Diagram of Section

Drilling Co

Address

Method of Drilling drilled Date Feb. 23 , 19 54

Owner Washington Water Service Co. Inc.

Address Bellevue, Washington

Land surface, datum ft above / below

24N/5E-11N

File number

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary, in parentheses If material water-bearing so state and record static level if reported Give depths in feet below land-surface datum unless otherwise indicated Correlate with stratigraphic column, if feasible Following log of materials list all casings perforations, screens, etc)		
	Unconsolidated Hardpan	10	10
	Hardpan & gravel, sand	20	30
	Hardpan & coarse gravel	6	36
	Gravel in hardpan; sand	4	40
	Loose sand & gravel	10	50
	Coarse gravel in hardpan	8	58
	Coarse gravel; water	4	62
	Hardpan & coarse gravel	4	66
	Gravel & sand. Bailed down	6	72
	Coarse grains in hardpan	4	76
	Medium sand, some sediment	3	79
	Medium sand; some gravel	10	89
	Coarse sand	13	102
	Blue clay	3	105
	Pump Test:		
	Dim: 86' x 12" & 8"		

Turn up (over) Sheet of sheets

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WELL LOG —Continued No / -

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	———	
	SWL: 51'		
	Dd: 96'		
	Yield: 120 g.p.m.		
	Recovery data: 30 sec - 65'		
	2 min 30 sec - 51'		
	Casing: 12" from 0 to 86'		
	8" from 0 to 93'		
	Perfor: 0.060" from 93 to 98'		
	0.040" from 98 to 103'		
	Pump: 125 GPM at 320' TDH Deep Well Turbine		
	Motor: Electric 15 HP		

S F No 7440—12-54—3M 42108

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

#55

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION AND DEVELOPMENT

WELL LOG Trial Well #1 No Appli. 4877

Date , 19

Record by

Source well driller's record

Location State of WASHINGTON

County King

Area

Map

¼ ¼ sec 34 T 25 N, R 5 E XX

Diagram of Section

Drilling Co

Address

Method of Drilling Date , 19

Owner Glendale Country Club

Address near Kelsey Creek, Bellevue

Land surface datum ft above below

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary in parentheses If material water bearing so state and record static level if reported Give depths in feet below land surface datum unless otherwise indicated Correlate with stratigraphic column if feasible Following log of materials list all casings perforations screens etc)		
	Gravelly sand	20	20
	Hardpan	6	26
	Clay, hardpan	7	33
	Blue gray sand & gravel with water	12	45
	Blue hardpan	3	48
	Hardpan & clay (water @ 51 ft.)	24	72
	Mucky sand & gravel	18	90
	Blue clay w/silt, sand, gravel	43	133
	Blue clay	56	189
	Clay, gravel	4	193
	Blue clay	2	195
	Gravel, w/some clay,	53	248
	blue clay w/gravel	10	258
	Blue clay	6	264
	Blue clay w/gravel		

Turn up (over) Sheet of sheets

25 5E 34E
File number

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

WELL LOG —Continued | No / -

CORRELATION	MATERIAL		THICKNESS (feet)	DEPTH (feet)
		Depth forward	———	264
	Gravel, sand, watdr w/clay streaks		6	270
	Gravel in clay, tough clay		15	285
	Clay		12	397

S F No 7448—12 54—3M 40108

* D O C U M E N T *

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

Please print, sign and return by mail to Department of Ecology

#40

RESOURCE PROTECTION WELL REPORT

(SUBMIT ONE WELL REPORT PER WELL INSTALLED)

CURRENT Notice of Intent No. G016213

Construction/Decommission *(select one)* 265705

☑ Construction

☐ Decommission *ORIGINAL INSTALLATION Notice of Intent Number* _____

Consulting Firm _____

Unique Ecology Well ID

Tag No. _____

Type of Well *(select one)*

☐ Resource Protection

☑ [redacted] GEO-THERMAL

Property Owner LONGHOUSE

Site Address 4018 134th Ave

City Bellevue **County** King

Location SW 1/4-1/4 SW 1/4 **Sec** 15 **Twn** 25 N **R** 5 Select One ☑ E/W ☐ W/W

Lat/Long (s, t, r still REQUIRED) Lat Deg _____ Lat Min/Sec _____ Long Deg _____ Long Min/Sec _____

Tax Parcel No. _____

Cased or Uncased Diameter 6" **Static Level** _____

Work/Decommission Start Date March 9/07

Work/Decommission Completed Date March 9/07

WELL CONSTRUCTION CERTIFICATION: *I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.*

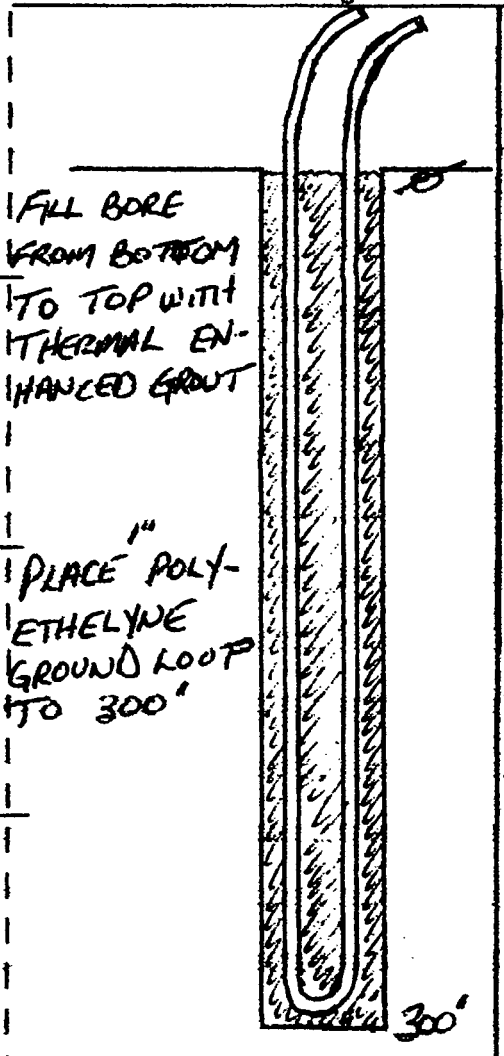
☑ Driller ☐ Engineer ☐ Trainee **Name (Print)** CURTIS GOSLING

Driller/Engineer /Trainee Signature [signature]

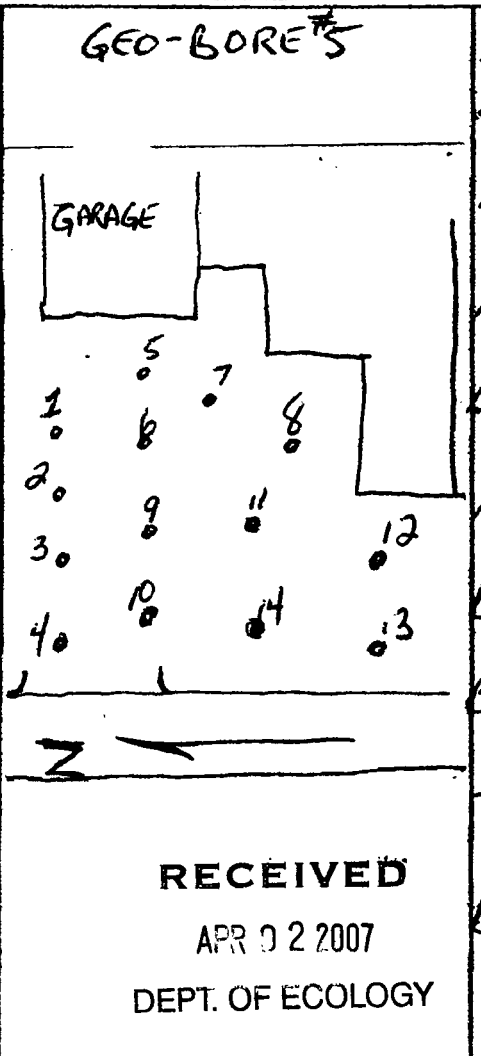
Driller or Trainee License No. 2659

If trainee, licensed driller's Signature and License No. _____

Construction/Design



Well Data



Formation Description

Brown sand + gravel 0-11
sandy brown clay + gravel 11-40
sandy tan clay + gravel 40-68
sandy brown clay + gravel 68-135
sandy blue/brown clay 135-145
sandy blue clay 145-165
Brown till 165-235
Brown till w/basalt 235-240
Tan till 240-270
Blue till 270-300

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APR 02 2007
DEPT. OF ECOLOGY

ECY 050-12 (Rev. 2/03)

SCALE: 1"= __ Page 5 of 14

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JUN 11 2007
DEPT. OF ECOLOGY

Ecology is an Equal Opportunity Employer.

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

#43

272495

24.5E-4K

URCE PROTECTION WELL REPORT Notice of Intent No. 4007711

NE WELL REPORT PER WELL INSTALLED)

Construction/Decommission *("x" in circle)*

- (X) Construction
- ( ) Decommission *Original Construction Notice of Intent Number* _____

Type of Well *("x" in circle)*

- ( ) Resource Protection
- ( ) Geotech Soil Boring

Property Owner Puget Sound Energy

Unique Ecology Well ID Tag No. N/A

Consulting Firm Puget Sound Energy

Driller or Trainee Name Clay E Griffith

Driller or Trainee Signature Clay E Griffith

Driller or Trainee License No 1850

If trainee, licensed driller's Signature and License no. _____

Site Address SE 20th Place

City Bellevue County: King

Location NW 1/4- 1/4 SE 1/4 Sec 4 Twn 24N R 5E EWM or WWM *circle one*

Lat/Long (s, t, r still REQUIRED) Lat Deg _____ Lat Min/Sec _____ Long Deg _____ Long Min/Sec _____

Tax Parcel No. N/A

Cased or Uncased Diameter _____ Static Level _____

Work/Decommission Start Date 6/26/07

Work/Decommission Completed Date 7/11/07

Construction/Design	Well Data	Formation Description
0 1" pipe. riser Coke Breeze. 200 210	0-100 Bentonite chips 100-200 Coke Breeze. 4 Anodes 140' 160' 180' 200'	0-120 Clay 120-165 Gravel 165-210 Dense Coarse Sand

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AUG 13 2007
DEPT. OF ECOLOGY

Scale 1"= _____

#36

NTERED

25/5/22F

WATER WELL REPORT

STATE OF WASHINGTON

Start Card No. W18040

UNIQUE WELL I.D. # ABM016

Water Right Permit No. _____

(1) OWNER: Name Keith Riffle/C.D.S. Enterprises Address 2301 N. Castle Way, Lynnwood WA

(2) LOCATION OF WELL: County King SW 1/4 NW 1/4 Sec 22 T. 25 N., R 5 W.M.

(2a) STREET ADDRESS OF WELL (or nearest address) 2400 - 134th Ave NE, Bellevue WA

(3) PROPOSED USE: [X] Domestic [ ] Industrial [ ] Municipal [ ] Irrigation [ ] Test Well [ ] Other [ ] DeWater

(4) TYPE OF WORK: Owner's number of well (if more than one) _____

Abandoned [ ] New well [X] Method: Dug [ ] Bored [ ] Deepened [ ] Cable [ ] Driven [ ] Reconditioned [ ] Rotary [X] Jetted [ ]

(5) DIMENSIONS: Diameter of well 6 inches. Drilled 241 feet. Depth of completed well 232 ft.

(6) CONSTRUCTION DETAILS:

Casing Installed: 6 " Diam. from 0 ft. to 222 ft.
Welded [ ] Liner installed [ ] Threaded [ ] _____ " Diam. from _____ ft. to _____ ft.

Perforations: Yes [ ] No [X]
Type of perforator used _____
SIZE of perforations _____ in. by _____ in.
_____ perforations from _____ ft. to _____ ft.
_____ perforations from _____ ft. to _____ ft.
_____ perforations from _____ ft. to _____ ft.

Screens: Yes [X] No [ ]
Manufacturer's Name HOWARD SMITH
Type STAINLESS STEEL Model No. _____
Diam. 6 Slot size .010 from 222 ft. to 232 ft.
Diam. ____ Slot size _____ from _____ ft. to _____ ft.

Gravel packed: Yes [ ] No [X] Size of gravel _____
Gravel placed from _____ ft. to _____ ft.

Surface seal: Yes [X] No [ ] To what depth? 18 ft.
Material used in seal BENTONITE
Did any strata contain unusable water? Yes [ ] No [X]
Type of water? _____ Depth of strata _____
Method of sealing strata off _____

(7) PUMP: Manufacturer's Name NO PUMP INSTALLED
Type: _____ H.P. _____

(8) WATER LEVELS: Land-surface elevation above mean sea level 100 ft.
Static level 140.5 ft. below top of well Date 10-11-94
Artesian pressure _____ lbs. per square inch Date _____
Artesian water is controlled by _____ (Cap, valve, etc.)

(9) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? Yes [ ] No [X] If yes, by whom? _____
Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
" " " "
" " " "

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test _____
Bailer test _____ gal./min. with _____ ft. drawdown after _____ hrs.
Airtest 34.5 gal./min. with stem set at 228 ft. for 2 hrs.
Artesian flow _____ g.p.m. Date _____
Temperature of water _____ Was a chemical analysis made? Yes [ ] No [ ]

(10) WELL LOG or ABANDONMENT PROCEDURE DESCRIPTION

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information.

MATERIAL	FROM	TO
BROWN SANDY LOAM	0	6
GRAY SAND & GRAVEL	7	10
BROWN SANDY CLAY	11	24
TAN SAND & GRAVEL LOOSE	25	168
GRAY SANDY CLAY	169	179
TAN SAND & GRAVEL	179	194
TAN SAND WATER BEARING	195	241

RECEIVED
OCT 14 1994
DEPT. OF ECOLOGY

Work Started 10-6 19. Completed 10-11 1994

WELL CONSTRUCTOR CERTIFICATION:

I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

NAME S.R. STALEY DRILLING (PERSON, FIRM, OR CORPORATION) (TYPE OR PRINT)

Address P.O. BOX 687 STANWOOD WA.

(Signed) W.K. Staley (WELL DRILLER) License No. 1904

Contractor's Registration No. STEVERIPF Date 10-12 1994

(USE ADDITIONAL SHEETS IF NECESSARY)

ECL 050-1-20 (2/93)

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

#32

Please print, sign and return by mail to Department of Ecology

E PROTECTION WELL REPORT

CURRENT Notice of Intent No. G 301092

(SUBMIT ONE WELL REPORT PER WELL INSTALLED)

Construction/Decommission *(select one)*

☒ Construction

☐ Decommission *ORIGINAL INSTALLATION Notice of Intent Number* _____

Type of Well *(select one)*

☒ Resource Protection

☐ Geotech Soil Boring

Consulting Firm GEO Loop Tec

Property Owner Smith

Site Address 13250 NE 40th St

Unique Ecology Well ID Tag No. BIT 705

City Bellevue County King

Location SW 1/4-1/4 SW 1/4 Sec 15 Twn 25N R 05E Select One ☒ EWM ☐ WWM

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

Lat/Long (s, t, r still REQUIRED) Lat Deg _____ Lat Min/Sec _____

Long Deg _____ Long Min/Sec _____

☒ Driller ☐ Engineer ☐ Trainee Name (Print) Kris Pancheri

Driller/Engineer /Trainee Signature _____

Driller or Trainee License No. 3025

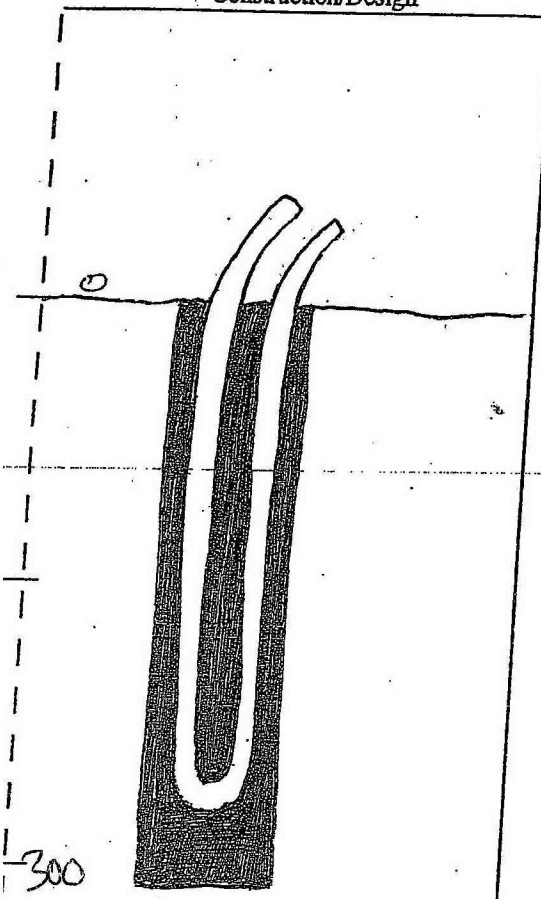
Tax Parcel No. 1525059122

Cased or Uncased Diameter 6" Static Level _____

Work/Decommission Start Date 4/20/16

Work/Decommission Completed Date 4/20/16

If trainee, licensed driller's Signature and License No. _____

Construction/Design	Well Data	Formation Description
	Install 1" closed ground loop. Place thermally enhanced grout from 300' to 0'. Bore #2	0-15 Brown Sand gravel 15-95 Brown Sand gravel 95-130 Brown Clay w/ Sand and gravel 130-210 Brown Sand & gravel 210-300 Brown Sand soft

Department of Ecology

APR 26 2016

Water Resources Program

CY 050-12 (Rev. 2/03)

SCALE: 1"=__ Page___of___

Ecology is an Equal Opportunity Employer.

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report

#50

478453

WATER WELL REPORT

Original & 1st copy – Ecology, 2nd copy – owner, 3rd copy – driller

DEPARTMENT OF ECOLOGY State of Washington

Construction/Decommission *("x" in circle)*

☒ Construction

☐ Decommission *ORIGINAL INSTALLATION*

Notice of Intent Number _____

PROPOSED USE: ☐ Domestic ☐ Industrial ☐ Municipal ☐ DeWater ☐ Irrigation ☐ Test Well ☒ Other Grounding Well

TYPE OF WORK: Owner's number of well (if more than one) _____

☒ New well ☐ Reconditioned *Method:* ☐ Dug ☐ Bored ☐ Driven ☐ Deepened ☐ Cable ☒ Rotary ☐ Jetted

DIMENSIONS: Diameter of well 6 inches, drilled 350 ft.
Depth of completed well 350 ft.

CONSTRUCTION DETAILS

Casing ☐ Welded _____" Diam. from _____ ft. to _____ ft.
Installed: ☐ Liner installed _____" Diam. from _____ ft. to _____ ft.
☐ Threaded _____" Diam. From _____ ft. to _____ ft.

Perforations: ☐ Yes ☒ No

Type of perforator used _____

SIZE of perfs _____ in. by _____ in. and no. of perfs _____ from _____ ft. to _____ ft.

Screens: ☐ Yes ☒ No ☐ K-Pac Location _____

Manufacturer's Name _____

Type _____ Model No. _____

Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Gravel/Filter packed: ☐ Yes ☒ No Size of gravel/sand _____

Materials placed from _____ ft. to _____ ft.

Surface Seal: ☒ Yes ☐ No To what depth? 350 ft.

Material used in seal Cement Grout

Did any strata contain unusable water? ☐ Yes ☒ No

Type of water? _____ Depth of strata _____

Method of sealing strata off _____

PUMP: Manufacturer's Name _____

Type: _____ H.P. _____

WATER LEVELS: Land-surface elevation above mean sea level _____ ft.

Static level _____ ft. below top of well Date _____

Artesian pressure _____ lbs. per square inch Date _____

Artesian water is controlled by _____ (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level

Was a pump test made? ☐ Yes ☒ No If yes, by whom? _____

Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test _____

Bailer test _____ gal./min. with _____ ft. drawdown after _____ hrs.

Airtest _____ gal./min. with stem set at _____ ft. for _____ hrs.

Artesian flow _____ g.p.m. Date _____

Temperature of water _____ Was a chemical analysis made? ☐ Yes ☒ No

CURRENT

Notice of Intent No. ge00398

Unique Ecology Well ID Tag No. bib-700

Water Right Permit No. NA

Property Owner Name t-mobil/swsg

Well Street Address 16th st and 134th ave

City bellevue County king

Location nw1/4-1/4 sw1/4 Sec 27 Twn 25n R 5e **(s, t, r Still REQUIRED)** EWM ☒ Or WWM ☐

Lat/Long Lat Deg _____ Lat Min/Sec _____
Long Deg _____ Long Min/Sec _____

Tax Parcel No. (Required) n/a

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
Brown sand and gravel	0	125
Blue clay	125	327
Blue silt and gravel	327	350
Installed copper grounding		
wire	0	350
Pump via grout line cement		
grout	0	350

Start Date 12/12/12 Completed Date 12/15/12

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee Name (Print) Chris V. Gregory	Drilling Company Gregory Drilling Inc.
Driller/Engineer/Trainee Signature	Address 17609 NE 70th St.
Driller or trainee License No. 2534	City, State, Zip Redmond , WA, 98052
IF TRAINEE: Driller's License No:	Contractor's Registration No. GREGOD1110JP Date 3/12/13
Driller's Signature:	

ECY 050-1-20 (Rev 02/10) *If you need this document in an alternate format, please call the Water Resources Program at 360-407-6872. Persons with hearing loss can call 711 for Washington Relay Service. Persons with a speech disability can call 877-833-6341.*

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

#45

GROUND SOURCE HEAT PUMP BORING 24-5E-9B

375390

START CARD NO. GEO0136

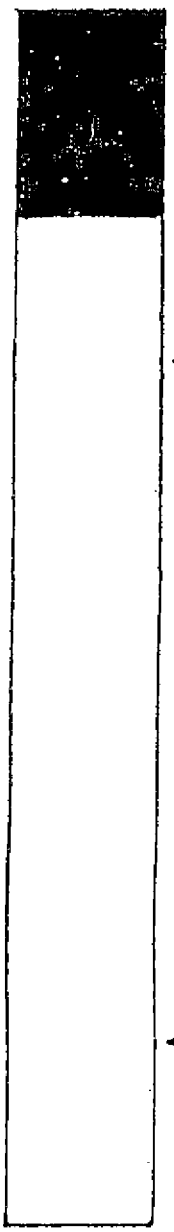
PROJECT NAME:
WELL IDENTIFICATION NO.
DRILLING METHOD: Mud Rotary
DRILLER: Chris Stratten
FIRM: Gregory Drilling
SIGNATURE: Chris Stratten
CONSULTING FIRM: NA
REPRESENTATIVE: NA

COUNTY: King
LOCATION: NW¼ NE¼ Sec 09 Twn 24 R 05E
STREET ADDRESS OF WELL: 2355 128th AVE SE

WATER LEVEL ELEVATION: NA
GROUND SURFACE ELEVATION: NA
INSTALLED: NA 3/22/10
DEVELOPED: NA

Soil Type — Depth (in feet below ground surface)

0-20 Fill
20-80 medium sand
80-95 med gravels
95-135 silt
135-180 till w/ gravel
180-190 gravels
190-200



Surface Seal/#Sacks: NA

Bentonite Seal/#Sacks: 7 grout 2 sand

Diameter of Borehole: 5½"

Well tag # BBT-849

Remarks:

RECEIVED
MAY 12 2010
Dept of Ecology
WR-NWRO

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

#9

Please print, sign and return to the Department of Ecology

RESOURCE PROTECTION WELL REPORT

CURRENT Notice of Intent No. GE00521

SUBMIT ONE WELL REPORT PER WELL INSTALLED)

Construction/Decommission *("x" in box)*

- [x] Construction
- [ ] Decommission

ORIGINAL INSTALLATION Notice of Intent Number:

Consulting Firm EARTHHEAT INC.

Unique Ecology Well IDTag No. BHN 350

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

- [x] Driller [ ] Engineer [ ] Trainee

Name (Print Last, First Name) GOSLING, CURTIS

Driller/Engineer /Trainee Signature

Driller or Trainee License No. 2654

If trainee, licensed driller's Signature and License Number:

Type of Well *("x in box)*

- [ ] Resource Protection HEAT PUMP
- [ ] Geotech Soil Boring BORING

Property Owner BELLEVUE SCH. DISTRICT

Site Address 10615 SE 23RD ST

City BELLEVUE County KING

Location NE 1/4-1/4 NW 1/4 Sec 8 Twn 24N R 5E

EWM [ ] or WWM [ ]

Lat/Long (s, t, r still REQUIRED) Lat Deg _____ Min _____ Sec _____

Long Deg _____ Min _____ Sec _____

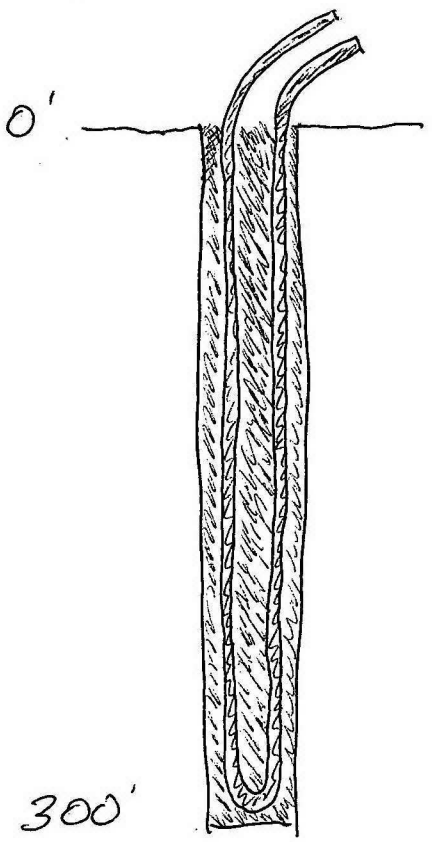
Tax Parcel No. 0824059070

Cased or Uncased Diameter 6" Static Level _____

Work/Decommission Start Date 8-23-14

Work/Decommission Completed Date 8-23-14

Construction Design



Well Data

INSTALL 1" HDPE POLYETHELYNE GROUND LOOP TO 300'

PUMP THERMAL GROUT FROM 300' TO 0' BY TREMMIE

TC TEST BORE

Formation Description

BR. SAND + GRAVELS 0 - 10

BR SOFT COARSE SAND 10 - 33

BR SAND W/SMALL GRAVELS FIRM 33 - 150

DRK BR. COARSE SAND 150 - 185

BR. SILTY SAND 185 - 220

COARSE BR. SAND W/FINE STICKY SAND 220 - 230

COARSE GREY/BLACK/BR. SAND 230 - 300

RECEIVED

SEP 29 2014

DEPT OF ECOLOGY
NWRO - WR

SCALE: 1"= _____ PAGE _____ OF _____

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

#30

420534

24-5E-5P

RECEIVED
JUL 21 2011
Water Resources Program
Department of Ecology

GEOTHERMAL LOOP REPORT

Start Card #	GE00243	Job#	1140
		Start Date	6/16/11
Owner ID	Bore2	End Date:	6/17/11
Owner Name:	Edson		
Owner Address:	10630 SE 22nd Ave		
	Bellevue, WA 98004		

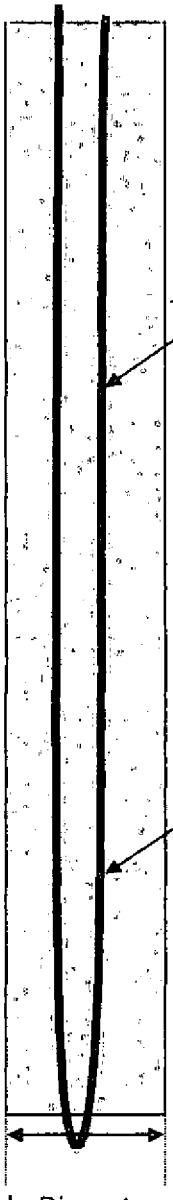
Well Address: 10630 SE 22nd Ave
Bellevue, WA 98004

County: King Tax Lot:

Twp: 24 Range: 5E

Section: 5 QQ/Q: SE of the SW

☐ Auger ■ Mud ☐ Probe ☐ Other:_____



Loop Mat'l: SDR11 HPDE
dia: 0.75
from: 0
to: 300

Seal
mat'l: Thermal Bentonite Grout
amount: 200 gal
weight: 13.4 #/gal
from: 0
to: 300

Borehole Diameter 4 in

Geology

0	to	1	Gravel and Soil
1	to	50	Silty Sand
50	to	225	Silt and Clay, blue
225	to	300	Silty Sand

Notes

Raymundo Dimas — Unbonded Driller Signature — 3127 License No.

Bonded Driller Signature — 2976 License No.

#38

Please print, sign and return by mail to Department of Ecology

RESOURCE PROTECTION WELL REPORT

CURRENT Notice of Intent No. RE 101648

(SUBMIT ONE WELL REPORT PER WELL INSTALLED)

Construction/Decommission *(select one)*
☒ Construction
☐ Decommission *ORIGINAL INSTALLATION Notice of Intent Number* _____

Consulting Firm Shannon & Wilson

Unique Ecology Well ID Tag No. BIK 214

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee Name (Print) Brian Owens

Driller/Engineer /Trainee Signature _____

Driller or Trainee License No. 2997

If trainee, licensed driller's Signature and License No. _____

Type of Well *(select one)*
☒ Resource Protection
☐ Geotech Soil Boring

Property Owner King County Water Treatment

Site Address 3242 110th Ave SE

City Bellevue County King

Location SE 1/4-1/4 NW 1/4 Sec 8 Twn 24N R 5E Select One ☒ BWM ☐ WWM

Lat/Long (s, t, r still REQUIRED) Lat Deg _____ Lat Min/Sec _____ Long Deg _____ Long Min/Sec _____

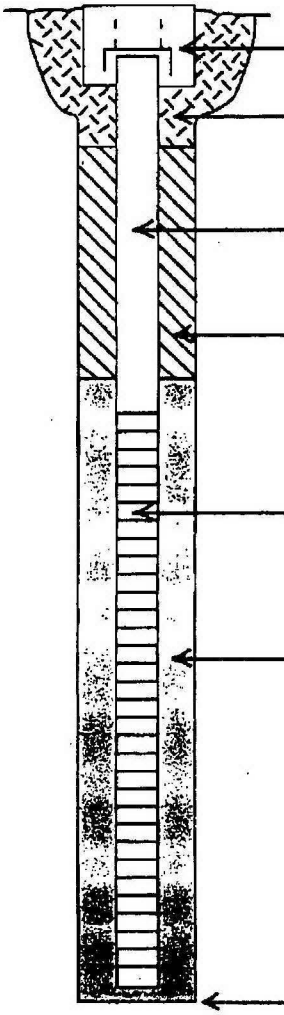
Tax Parcel No. _____

Cased or Uncased Diameter 6 Static Level _____

Work/Decommission Start Date 12-15-14

Work/Decommission Completed Date 12-19-14

Construction/Design



MONUMENT TYPE: Flush

CONCRETE SURFACE SEAL 2 ft. 1' Bentonite

PVC BLANK 2 "x 215'

BACKFILL 208 ft.

TYPE: Grout 2 ft Bentonite

PVC SCREEN 2 "x 15'

SLOT SIZE: .10

TYPE: flush Thread

GRAVEL PACK 17 ft.

MATERIAL: 10x20 silica

WELL DEPTH 230'

Well Data

Formation Description

0 - 5 ft. Fill - Road Base
5-50 Brn silt

50 - 100 ft. med course Brn sand
100 - 120 med Brn sand course - gravel
120-140 med Brn silt

140 - 160 ft. med Brn to grey silty sands

160 - 230 ft.
Blue green clay

- ft.

RECEIVED
MAY 04 2015
DEPT OF ECOLOGY
NWRO - WR

REMARKS VWP Installed @ 148' and 130'

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report

KCWD 68 Well No. 1

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

WELL LOG

No Appli. #182
Cert. #518A

Date July 25, 1946

Record by W. R. Hill

Source Driller record

Location State of WASHINGTON

County King

Area

Map

SE ¼ SW ¼ sec 29 T 25 N, R 5 E W

DIAGRAM OF SECTION

Drilling Co N. C. Jannsen Drilling Co.

Address P. O. Box 3185; Seattle 14, Wn.

Method of Drilling Date Aug. 2 1946

Owner King County Water Dist. #68

Address Bellevue, Washington

Land surface, datum ft above / below

25N/5E-29P
File number

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Sand	0	20
	Sand & large boulders	10	30
	Fine sand & small gravel	30	60
	Hard packed sand & gravel	10	70
	Rock & hard gravel	13	83
	Sand & gravel	15	98
	Sandy clay	24	122
	Sand	48	170
	Hard packed gravel	9	179
	Gravel	8	187
	Clay	60	247
	Sand	15	262
	Small gravel	16	278
	Clay	13	291
	Small gravel	59	350
	(over)		

(Transcribe driller's terminology literally but paraphrase as necessary in parentheses If material water bearing so state and record static level if reported Give depths in feet below land surface datum unless otherwise indicated Correlate with stratigraphic column if feasible Follow ing log of materials list all casings perforations screens etc)

Turn up

Sheet of sheets

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

WELL LOG —Continued No_____/_____-_____

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	———	
	Sandy clay	60	410
	Sand	40	450
	Clay	10	460
	Sandy clay	80	540
	Sand	10	550
	Loose gravel	16	566
	Hard sandstone	8	574
	Gravel	10	584
	Clay	12	596
	Gravel	25	621
	Clay	19	640
	Fine sand	10	650
	Hard packed sand & gravel	10	660
	Clay	30	690
	Fine sand & gravel	20	710
	Clay	216	926
	Sandy clay	49	975
	Sticky clay	19	994
	Sand with streaks of hard shale	26	1020
	Sand & small gravel with streaks of shale	95	1115
	Sandy clay	10	1125
	Pump test: Dim: 1125' x 24"; SWL: 120'; D.D. 100'; Yield: 600 g.p.m.; Casing: 18" dia. from 0 to 641'; 24" dia. from 0 to 170'; 12" dia. from 641 to 1125'. Perforations: perforated - shutter from 247-370; 530-621; 974-1115.		

KCWD 68 Well No. 2

WASHINGTON
CONSERVATION
DEVELOPMENT

No Appli. #490
Cert. #360A

Date July 1, 19 47

Record by F. C. Yett

Source Driller record

Location State of WASHINGTON

County King

Area

Map

SW ¼ SW ¼ sec 32 T 25 N, R 5 E W

DIAGRAM OF SECTION

Drilling Co N. C. Jannsen Drilling & Mfg. Co.

Address 9407 E. Marginal Way; Seattle

Method of Drilling Date July 1 1947

Owner King Co. Water Dist. #68

Address Bellevue, Washington

Land surface, datum ft above / below

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Topsoil	10	10
	Sandy clay	10	20
	Hard pan w/streaks gravel	60	80
	Sand	70	150
	Coarse sand	20	170
	Fine sand	80	250
	Coarse sand	10	260
	Sand medium	30	290
	Sand	10	300
	Coarse sand	10	310
	Sand	10	320
	Sand & clay	10	330
	Sand & gravel	10	340
	Coarse gravel	25	365
	Blue clay	13	378
	(over)		

(Transcribe driller's terminology literally but paraphrase as necessary in parentheses If material water bearing so state and record static level if reported Give depths in feet below land surface datum unless otherwise indicated Correlate with stratigraphic column if feasible Following log of materials list all casings perforations screens etc)

Turn up

Sheet of sh

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

WELL LOG —Continued No_____/_____-____

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	———	
	Sand & gravel	68	458
	Coarse sand	5	463
	Sand hard packed	22	485
	" " "	37	522
	Clay & sand (dry)	534	1056
	Pump test:		
	Dim: 1056' x 24"		
	SWL: 0 ARTESIAN 60 g.p.m.		
	D.D. 57'		
	Yield: 900 g.p.m.		
	Casing: 24" dia. from 0 to 32'		
	12" dia. from 0 to 485'		
	Perforations: 8 rows per foot 1/4" x 3" horizontal beveled from 270 to 475 ft.		

KCWD 68 Well No. 3 (decommissioning)

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

WATER WELL REPORT

Original & 1st copy – Ecology, 2nd copy – owner, 3rd copy – driller

DEPARTMENT OF ECOLOGY State of Washington

Construction/Decommission *("x" in circle)*

☐ Construction

☒ Decommission *ORIGINAL INSTALLATION*

Notice of Intent Number N/A

PROPOSED USE: ☐ Domestic ☐ Industrial ☐ Municipal ☐ DeWater ☐ Irrigation ☐ Test Well ☐ Other _____

TYPE OF WORK: Owner's number of well (if more than one) _____

☐ New well ☐ Reconditioned *Method:* ☐ Dug ☐ Bored ☐ Driven ☐ Deepened ☐ Cable ☐ Rotary ☐ Jetted

DIMENSIONS: Diameter of well 12 inches, drilled 182 ft. Depth of completed well 182 ft.

CONSTRUCTION DETAILS

Casing Installed: ☒ Welded 12" Diam. from 0 ft. to 182 ft.

☐ Liner installed _____" Diam. from _____ ft. to _____ ft.

☐ Threaded _____" Diam. From _____ ft. to _____ ft.

Perforations: ☒ Yes ☐ No

Type of perforator used NA

SIZE of perfs .25in. by 3 in. and no. of perfs 3from 40ft. to 182ft.

Screens: ☐ Yes ☐ No ☐ K-Pac Location _____

Manufacturer's Name _____

Type _____ Model No. _____

Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Gravel/Filter packed: ☐ Yes ☐ No Size of gravel/sand _____

Materials placed from _____ ft. to _____ ft.

Surface Seal: ☐ Yes ☐ No To what depth? _____ ft.

Material used in seal _____

Did any strata contain unusable water? ☐ Yes ☐ No

Type of water? _____ Depth of strata _____

Method of sealing strata off _____

PUMP: Manufacturer's Name _____

Type: _____ H.P. _____

WATER LEVELS: Land-surface elevation above mean sea level _____ ft.

Static level _____ ft. below top of well Date _____

Artesian pressure _____ lbs. per square inch Date _____

Artesian water is controlled by _____ (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level

Was a pump test made? ☐ Yes ☐ No If yes, by whom? _____

Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.

Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.

Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test _____

Bailer test _____ gal./min. with _____ ft. drawdown after _____ hrs.

Airtest _____ gal./min. with stem set at _____ ft. for _____ hrs.

Artesian flow 150g.p.m. Date 10/2/12

Temperature of water _____ Was a chemical analysis made? ☐ Yes ☒ No

Notice of Intent No. AE19194

Unique Ecology Well ID Tag No. N/A

Water Right Permit No. N/A

Property Owner Name WSDOT

Well Street Address NE Northup Way & 520

City Bellevue County King-17

Location SE1/4-1/4 NW1/4 Sec 20 Twn 25N R 5E **(s, t, r Still REQUIRED)** EWM ☒ Or WWM ☐

Lat/Long Lat Deg na Lat Min/Sec na Long Deg na Long Min/Sec na

Tax Parcel No. (Required) N/A

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
Water Well was decommissioned		
by pumping Neat Cement via 3"		
pipe from the bottom of the		
hole to land surface.		
Pumped at a rate of 300-2000		
psi. A total of 8-9 yards of		
cement was pumped into the		
well from the bottom to the		
top.	0	180

RECEIVED

OCT 17 2012

DEPT OF ECOLOGY NWRO - WR

Start Date 10/2/12 Completed Date 10/2/12

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee Name (Print) Chris V. Gregory

Driller/Engineer/Trainee Signature

Driller or trainee License No. 2534

IF TRAINEE: Driller's License No:

Driller's Signature:

Drilling Company	Gregory Drilling Inc.
Address	17609 NE 70th St.
City, State, Zip	Redmond , WA, 98052
Contractor's Registration No.	GREGODI110JP Date 10/2/12

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KCWD 68 Well No. 3

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

WELL LOG

No Appli. #582
Cert. #521A

Date August, 1947
Record by F. C. Yett
Source Driller record

Location State of WASHINGTON
County King
Area
Map

SE ¼ NW ¼ sec 20 T 25 N, R 5 E W

DIAGRAM OF SECTION

Drilling Co N. C. Jannsen Drilling & Mfg. Co.
Address 9407 E. Marginal Way; Seattle, Wash.
Method of Drilling Date August 1947
Owner King County Water District #68
Address Bellevue, Washington
Land surface, datum ft above / below

25N/5E-20F
File number

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Clay	5	5
	Sand	10	15
	Coarse sand	17	32
	Clay	8	40
	Sand	10	50
	Sand & gravel	15	65
	Gravel	20	85
	Coarse sand	46	131
	Coarse sand & gravel	45	176
	Gravel	52	228
	Clay	16	244
	Pump test:		
	Dim: 244' x 24"		
	SWL: 0'		
	(over)		

(Transcribe driller's terminology literally but paraphrase as necessary in parentheses. If material water bearing so state and record static level if reported. Give depths in feet below land surface datum unless otherwise indicated. Correlate with stratigraphic column if feasible. Follow ing log of materials list all casings perforations screens etc.)

Turn up

Sheet of sheets

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

WELL LOG —Continued No._____/_____-_____

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	———	
	D.D. 75'		
	Yield 712 g.p.m.		
	Casing: 24" dia. from 0	to 48'	
	12" dia. from 0	to 244'	
	Perforations: perforated	¼" x 3"	
	horizontal beveled 8 rows	per ft.	
	from 60' to 244'.		

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

Appendix C. Water Quality Analysis

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To:	Douglas Lane, P.E.; City of Bellevue Laurie Fulton, P.E.; Stantec Thomas Bell-Games, P.E.; HDR	**Subject:**	FINAL Water Quality Analysis Technical Memorandum
From:	Virpi Salo-Zieman, P.E. Stephen Booth, Ph.D. Melinda Friedman, P.E.; Confluence	**Project:**	City of Bellevue Emergency Water Supply Master Plan
Date:	February 28, 2018		

EXECUTIVE SUMMARY

The City has identified the following three options for using their groundwater wells as emergency supplies (Robinson Noble, 2015):

1. Drive-up emergency-only use for filling trucks or other containers.
2. Wells are disconnected under normal operating conditions but plumbed for quick connection to the distribution system in an emergency.
3. Full-time continuous use of the well waters as permanent sources for the water system.

This Technical Memorandum presents an assessment of drinking water quality regulatory requirements and other potential water quality effects associated with each of the three options. Samena Well 3 and Crossroads Wells 5, 6, and 7 have been approved by DOH as emergency supplies and all four wells meet primary drinking water standards.

For Option #1, the equipment to support the trucking or filling stations should be installed and the trucking water SOP should be updated. Chlorine addition to the well waters is also required.

For Option #2, the four wells would be pumped into the distribution system as emergency sources of supply. It is recommended to maintain the wells in operable condition, including a temporary connection to the distribution and to develop SOPs for activating and operating the wells in an emergency. Disinfection treatment should be provided and the City should be prepared to respond to customer complaints and to perform flushing, as required.

For Option #3, the wells would be used as permanent sources of supply and the City would need to obtain approval from DOH and the Department of Ecology for permanent use of the sources, which may include well rehabilitation to eradicate iron bacteria and confirmation of water rights. Collecting baseline water quality data to document existing distribution system conditions and to evaluate changes in water quality as the wells are placed in service is also recommended. Disinfection treatment and treatment to remove ammonia, iron, and manganese should be installed. Monitoring plans for coliform, disinfection by-products (DBPs), and for the Lead and Copper Rule (LCR) should be revised, as appropriate.

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1.0 INTRODUCTION

The City of Bellevue (City) is considering alternatives for using their groundwater wells for emergency supplies and to increase the overall resiliency of the City's water supply. The City has identified the following three options (Robinson Noble, 2015):

1. Drive-up emergency-only use for filling trucks or other containers.
2. Wells are disconnected under normal operating conditions and plumbed for quick connection to the distribution system in an emergency.
3. Full-time continuous use of the well waters as permanent sources for the water system.

This Technical Memorandum presents an assessment of regulatory requirements, potential treatment needs, recommended monitoring, and water quality impacts associated with each of these three options.

2.0 BACKGROUND AND ASSUMPTIONS

The City currently has four separate wells, Samena Well 3 and Crossroads Wells 5, 6, and 7 that have been approved by DOH as emergency sources and are available for direct connection to the water system. A previous Technical Memorandum (Robinson Noble, 2015) and the system's Water Facilities Inventory list several additional municipal water rights and possible sources (Table 1). This water quality evaluation was limited to the approved emergency wells for which water quality data were available.

Table 1. Summary of City of Bellevue Municipal Water Rights

Permit/Certificates	Name on Water Rights Document	Source Name	DOH#
73936	KCWD97	Well 3	S04
06041 / 04391	KCWD97	Well 7	S08
06128 / 04454	KCWD97	Well 5	S06
06129 / 04453	KCWD97	Well 6	S07
00232 / 00518	KCWD68	Well 1	None
00437 / 00360	KCWD68	Well 2	None
00528 / 00521	KCWD68	Well 3	None
03807 / 02539	KCWD97	Well 1	None
03043 / 02429	WWSC	Well 1	None
01077 / 02630	WWSC	Hill-Aire	None
07269 / 05820	KCWD68	Lake Wash.	None
08726 / 06489	KCWD68	Lake Wash.	None
Interties:			
77050Y/Seattle/CWA	-	-	S01
42250T/Kirkland	-	-	S02
41750C/CCUD	-	-	S09
71650B/Redmond	-	-	S04

This analysis assumes that the City continues to use water from Seattle Public Utilities (SPU), purchased through the Cascade Water Alliance, as the main supply to the system. Option 2 was evaluated based on using the approved wells only in an emergency sufficiently severe that the existing supply from SPU becomes unavailable or limited and blending of the groundwater with the existing treated surface water would occur in the system. These wells would provide a temporary supply for the system during the period of crisis. After the SPU sources have been restored to service the emergency sources would be shut down.

Options #1 and #2 meet the criteria of an emergency source under WAC 246-290. Under the third option, these wells would be continuously or intermittently pumped to the distribution system (not just during an emergency) and would be considered as permanent sources under current regulations.

3.0 WATER QUALITY AND TREATMENT CONSIDERATIONS

3.1 Existing Distribution Water Quality

The distribution system water quality data were collected from the following sources:

- Four quarterly SPU reports (from July 2016 to June 2017) for the Tolt River supply entry point and distribution system location; and
- Data analysis and June 2016 field sampling completed as part of the Chlorine Residual Evaluation Project for the Cougar Mountain area (MSA and Confluence, 2016).

Table 2 summarizes these data. Temperature varies seasonally ranging from approximately 3.5 to 20°C. For this evaluation, an average of the quarterly averages for the Tolt distribution of 14.5°C was used. The Tolt entry point average pH was 8.1, while the Tolt distribution average was 8.6 for the same time period. The average pH in the City's distribution system in the June 2016 sample set was 8.2. Because of

the fairly large difference between the Tolt entry point and distribution data, the average pH from the June 2016 data was selected as the most representative for this study.

The 2016 study (MSA and Confluence, 2016) also noted the following findings on water quality in the City's distribution system:

- A trend of decreasing pH with increasing water age and corresponding lower chlorine residuals.
- The oxidation-reduction potential (ORP) of the water in the distribution system varied with water age and chlorine residual, but the observed range of 520 to 645 mV still indicates highly oxidized conditions, even in areas with a low chlorine residual.
- The chlorine residuals were generally between 0.8 and 1.0 mg/L at the majority of the sample sites and there was very little difference between free and total residuals, indicating low levels of combined chlorine.
- Microbial activity increased with decreasing chlorine levels, as measured by adenosine triphosphate (ATP) analysis, an unregulated parameter used for investigative monitoring.

Table 2. Existing Distribution System Water Quality Characteristics

Parameter	unit	Regulatory limit	Tolt Entry Point[1]	Tolt Distribution[1]	Bellevue Distribution[2]
pH		6.5-8.5	8.1	8.6	8.2
Temperature	°C	-	9.9	14.5	13.2-15.3
ORP	mV	-	-	-	520-645
Dissolved Oxygen	mg/L	-	21	18	-
Conductivity	µmhos/cm	700	58	64	-
Hardness	mg/L	-	26	27	-
Alkalinity	mg/L as $CaCO_3$	-	19	21	-
Total Dissolved Solids	mg/L	500	37	40	-
Iron	mg/L	0.3	0.036	0.042	ND-0.18
Manganese	mg/L	0.05	0.004	0.001	-
Ammonia	mg/L	-	-	-	-
Arsenic	mg/L	0.010[3]	0.0004	0.0004	-
Nitrate	mg/L	10[3]	-	-	-
Calcium	mg/L	-	9.6	10.0	-
Magnesium	mg/L	-	0.4	0.5	-

Notes:

1. From SPU's Quarterly Reports.
2. From sampling conducted in June 2016 (MSA and Confluence, 2016).
3. Primary MCL

The routine monitoring data from January 2010 to March 2016 for site BE-E8, the site closest to the Crossroads Wells, had an average chlorine residual of 1 mg/L. The lowest residual at that site was 0.3 mg/L and the highest was 1.6 mg/L, for that time period.

3.2 Well Water Quality

The Samena site includes Wells 1 and 3. Well 1 is not in operable condition (Robinson Noble, 2015), and as such, no water quality data were available for that well. The Crossroads Wells are located at the City's property at 16049 NE 8th St, which includes the Lake Hills (Crossroads) pump station and north and

south reservoirs, as well as the Parks Department's Resource Management facility. If the wells were plumbed directly to the distribution system those wells would pump into the LH520 pressure zone.

Table 3 summarizes regulatory monitoring data for the operable emergency wells, including nitrates, coliform, inorganic compounds (IOCs), volatile organic compounds (VOCs), and synthetic organic compounds (SOCs). Radionuclides were tested in 2017. City staff also completed field sampling in August 2017 to fill identified data gaps.

Table 3. Water Quality Data Available for the Approved Well Supplies

Source Name	DOH#	Available Data					
		Coliform	Nitrates	IOC	VOC	SOC	Rads
Well 3	S04	2008 2011 2012 2013 2014 2017	2008 2011 2012 2013 2014 2017	2011 2012 2013 2014 2016 2017	2008 2011 2012 2013 2014 2015 2016 2017	2012 2013 2014 2015 2016 2017	2017
Well 5	S06	2008 2011 2012 2013 2017	2008 2012 2013 2017	2013 2015 2016 2017	2008 2014 2017	2013 2015 2016 2017	2017
Well 6	S07	2008 2017	2008 2017	2017	2008 2014 2017	2017	2017
Well 7	S08	2008 2014 2017	2008 2014 2017	2014 2017	2008 2014 2017	2014 2017	2017

Based on the monitoring conducted to date, the approved wells meet all primary water quality standards under current drinking water regulations. There have been some unexpected detections of regulated compounds, for example toluene in 2008 in Wells 3, 6, and 7, styrene in 2008 in Well 6, and phthalate in 2012 in Well 3. All results were well below the respective MCLs. These organics have not been detected in subsequent sampling and were not detected in the August 2017 sampling event. A leaking underground storage formerly existing at the Crossroads Well site was removed in 1989, and the City has conducted ongoing groundwater and vapor monitoring and sampling (GeoEngineers, 2016). Numerous monitoring wells are located around this site to track the movement of contamination. Additional remediation at the site may be required if the Crossroads Wells are used, to prevent drawing contamination into the zone of influence of the wells and to maintain acceptable groundwater quality.

Water quality standards for groundwaters can be more stringent than drinking water standards (WAC 173-200) and the approved wells may not meet all the groundwater regulatory requirements since testing for all the regulated compounds has not been performed. The approved wells do meet all primary and radionuclide drinking water standards. Testing for some regulated carcinogens has not

been performed, such as acrylonitrile, aniline, and aramite. It is not likely that these compounds would be present in the well waters.

Table 4 presents general water quality parameters for the four wells. The data presented are averages of previously collected data or single values from the 2017 field testing. During that field testing, the wells were pumped until stable measurements were obtained for the field parameters and therefore, these data were considered the most representative of the well water quality.

Table 4. Summary of General Water Quality for Approved Wells

Parameter	unit	Regulatory Limit[1]	Samena	Crossroads			
			Well 3	Well 5	Well 6	Well 7	Average
Source #			**S04**	**S06**	**S07**	**S08**	
pH[2]	s.u.	6.5-8.5	7.8	7.3	7.4	7.4	7.4
Temperature[2]	°C	-	10.5	11.3	11.2	10.8	11.1
ORP[2]	mV	-	-85	-79	-90	-83	-84
DO[2]	mg/L	-	4.2	1.8	2	4.5	2.8
Conductivity[2]	µmhos/cm	700	150	147	127	127	134
Hardness[2]	mg/L		62	58	48	47	51
Alkalinity	mg/L as $CaCO_3$	-	64	64	56	58	59
Total Dissolved Solids	mg/L	500	115	110	98	110	106
Iron	mg/L	0.3	0.32	0.79	0.93	0.69	0.80
Manganese	mg/L	0.05	0.063	0.051	0.060	0.052	0.05
Ammonia	mg/L	-	0.067	0.254	0.247	0.215	0.24
Arsenic	mg/L	0.010[3]	0.002	0.0033	0.0036	0.0035	0.0035
Nitrate	mg/L	10[3]	ND	ND	ND	ND	ND
Total Sulfide	mg/L	-	ND	ND	ND	ND	ND
Calcium	mg/L	-	8.3	11	9.7	9.4	10.0
Magnesium	mg/L	-	8.4	7.6	5.7	5.6	6.3
Silica[2]	mg/L as SiO_2	-	29	25	23	24	24
Chloride	mg/L	250	4.2	2.4	1.9	2.1	2.1
Sulfate	mg/L	250	8.7	1.23	0.62	0.76	0.87
Total Organic Carbon	mg/L	-	0.37	1.1	1.1	1.3	1.2
Coliform/E. coli	CFU/100mL	E. coli - P[3]	ND	ND[4]	ND[4]	ND[4]	-
HPC	CFU/mL	-	ND	137	14.5	6	-
Iron bacteria	A/P	-	A	A	P	A	-
Sulfur bacteria	A/P	-	A	A	A	A	-

Notes:

1. SMCL unless otherwise indicated.
2. From August 2017 data collection.
3. Primary MCL.
4. Total coliform bacteria were detected in 2008 sampling of Crossroads Wells 5, 6, and 7, however, total coliforms have not been detected in other samples.
   ND = not detected, A = absent, P=present

The well water has lower pH, dissolved oxygen (DO), and ORP than the Tolt supply. The negative ORP of the well waters is typical of Western Washington groundwaters, and indicates highly reduced conditions. The temperature of the groundwater supply is not expected to vary seasonally and is

anticipated to be 10-12°C year-round. The mineral content of the well waters is higher than in the Tolt Supply. The Crossroads Wells have significant ammonia levels and the iron and manganese levels exceed their respective Secondary Maximum Contaminant Levels (SMCLs), whereas, arsenic and nitrate levels have not been of concern. The Crossroads Wells have similar water quality although those three wells differ in water quality compared to Samena Well 3 and Bellevue staff report an odor is evident in the Crossroads well water. Samena Well 3 has higher pH, lower levels of iron and manganese, and negligible ammonia compared to the Crossroads Wells.

Iron bacteria were detected in Crossroads Wells 6 and both Crossroads Well 5 and 6 had significant levels of heterotrophic plate counts (HPCs). These data indicate vulnerability of these wells to microbial contamination. Disinfection or other remediation of the wells may be required prior to introducing the well water into the distribution system. Iron bacteria proliferation within distribution system and premise plumbing can be extremely difficult to eradicate.

All four of the well waters have a hardness approximately between 50 and 60 mg/L, and therefore would be considered soft waters and similar to the Tolt supply; however, total dissolved solids (TDS) is three to four times higher compared to the Tolt supply, and silica levels are likely significantly higher. Some customers may find the well water mildly objectionable given the difference in mineral content between the well waters and the existing supplies from SPU.

3.3 Treatment Considerations

Treatment considerations for the well waters are discussed in this section and summarized in Table 5. Section 3 discusses treatment and other regulatory requirements specific to each emergency well use option.

3.3.1 Chlorination/Disinfection

Since the existing supply for the City is surface water, there is a requirement to maintain a detectable chlorine residual throughout the distribution system for ensuring adequate microbial control. Therefore, the well sites should be equipped with chlorination facilities. Although fecal contamination has not been detected in the approved wells, Samena Well 3 is located close to a sewer main and these older wells may not have surface seals, making them more susceptible to contamination from the surface. Also, Crossroads Well 5, 6, and 7 had detectable HPCs, and iron bacteria were detected in Well 6. For these reasons, it would be beneficial for the City to provide disinfection treatment that achieves 4-log virus inactivation (CT = 6 mg/L-min) prior to the first customer. Additional well rehabilitation to eliminate iron bacteria may also be needed.

Chlorination would also help to match the existing ORP in the distribution system which is critical for maintaining stability of existing scales. The well water is in a highly reduced state with a negative ORP and if pumped to the distribution system, it would likely destabilize scales and cause significant disinfectant demand and discolored water events.

Ammonia, iron, and manganese in the well water will exert chlorine demand. Estimated chlorine demands based on stoichiometry with an additional 20% factor of safety are 3.5 mg/L for the Crossroads Wells and 1.5 mg/L for Samena Well 3. Breakpoint chlorination is required to oxidize ammonia (unless removed before chlorine addition) and to provide a detectable free chlorine residual in the distribution system. The breakpoint reactions may require a chlorine dose higher than anticipated based on stoichiometric considerations and/or a significant contact time to stabilize

downstream residuals. The organic carbon present in the well waters will exert additional chlorine demand although the specific demand associated with organic carbon is difficult to predict from a desk-top analysis. Bench-scale chlorine demand and decay (CDD) testing is recommended to better define the needed chlorine dose and to characterize the time required to complete breakpoint reactions for each well water.

3.3.2 Iron and Manganese Removal

The Crossroads Wells have iron and manganese levels exceeding the SMCLs of 0.3 mg/L and 0.05 mg/L, respectively. These levels of iron and manganese are anticipated to cause discoloration and taste and odor concerns. Long-term use could result in accumulation within the distribution system and premise plumbing components. Treatment to remove these metals is recommended, especially if the wells are used as regular sources of supply.

Iron and manganese removal is typically achieved through oxidation with chlorine and/or potassium or sodium permanganate with downstream granular media filtration. Another option is to consider biological filtration, to potentially remove ammonia, iron, and manganese by enriched microbial communities in a single unit process. Sequestration, another approach, does not remove iron or manganese but instead is intended to keep the metals in a soluble form to minimize accumulation in the distribution system. Sequestration typically involves addition of some form of polyphosphate and has a lower cost than the other alternatives, but its effectiveness may be limited since the metals are not removed from the water. If the water is exposed to air prior to sequestration, some metals may oxidize to an insoluble form, in which case they would be unaffected by sequestration and could pose problems within the distribution system over time. Bench- and pilot-scale testing is recommended to develop design criteria for sequestration or an iron/manganese removal system.

3.3.3 pH Adjustment

The pH of the Crossroads Wells is almost one full pH unit below the prevailing pH in the distribution system. If the wells were used without pH adjustment some disruption to existing scales and increased corrosion is anticipated. Also, the pH of the Crossroads Wells is below 7.5, the level often considered as the minimum acceptable level for maintaining corrosion control for well waters. For these reasons, treatment to adjust the pH to better match existing conditions in the distribution system should be considered. A formal corrosion control study would be required if the wells were to be used as regular sources of supply to determine optimal corrosion control. If the wells are used only during rare emergencies (under Option #2) for short periods of time, the cost and operations and maintenance complexity of pH adjustment are likely not justified.

3.3.4 Summary of Treatment Alternatives

The parameters for which treatment could be considered and the treatment process alternatives are summarized in Table 5. Treatment needs associated with specific emergency use options are discussed in Section 4.

Table 5. Summary of Well Water Treatment Alternatives

Treatment Objective	Treatment Process Alternatives	Comments
Disinfection (with chlorine)	• Chlorine gas • On-site chlorine generation • Liquid sodium hypochlorite • Pellet chlorinator (using calcium hypochlorite)	• Sodium hypochlorite injection is recommended due to its tendency to slightly raise the pH • Evaluation of the potential effect of higher hardness is recommended if pellet chlorinator is selected • Desk-/bench-scale testing is required to verify pH effects
Ammonia removal	• Breakpoint chlorination • Biological filtration	• Bench-scale CDD testing required to define dose/contact time requirements • Biological filtration would not be an option for intermittent or rare use due to acclimation time
Fe/Mn removal	• Sequestration • Oxidation and granular media filtration • Biological filtration	• Sequestration does not remove metals but is a less expensive/complex alternative • Common oxidants include chlorine and sodium/potassium permanganate • Pyrolusite and greensand are common granular media types • Biological filtration is a novel alternative • Pilot testing is recommended prior to design
pH Adjustment	• Caustic soda addition • Aeration	• Likely not needed unless increased corrosion becomes an issue or if chlorine gas is used and further reduces the well water pH significantly

4.0 OPTIONS ANALYSIS

This section summarizes possible regulatory and water quality monitoring requirements, as well as considerations before, during, and after an emergency for each identified use option. It should be noted that this discussion is intended to provide a general overview of considerations for comparative purposes at this preliminary planning phase, and that additional requirements may apply.

4.1 Option #1: Drive-up Emergency-Only Use

This discussion focuses on using the wells to provide potable water. The City could consider providing non-potable drive-up supply in an emergency as well. In that case, there does not appear to be an applicable regulatory framework for trucking and handling non-potable water. The City would appropriately label the water as being for non-potable uses and provide appropriate advisory notifications. Potential uses of the water could include preparation of concrete, irrigation, as long as nearby surface waters are not adversely affected, and fire-fighting.

Since the approved wells meet all primary drinking water standards, the wells could be used for potable use at any time. For potable use of the well water the City would provide tanker trucks or other

portable containers. For this option the well water would not be pumped into the distribution system. Regulatory requirements for trucking potable water are summarized below.

If the City plans to provide a filling station for public use at the well site, adequate protection of the source from cross connections should be provided, such as an air gap between the supply and the containers and measures to keep the tap/filling station clean. The City should provide instructions for proper filling.

4.1.1 Regulatory Requirements for Water Trucking

The regulatory requirements concerning trucking water for potable purposes (WAC 246-290-131(4)) should be incorporated into the City's water hauling standard operating procedure (SOP). Specific requirements include:

- Obtaining permission from the local authority for using trucked water.
- Addition of chlorine to each individual truck load (estimated dose of at least 3.5 mg/L for Crossroads wells and 1.5 mg/L for Samena well).
- Maintaining a minimum free chlorine residual of 0.5 mg/L at the time of delivery.
- Using contaminant-free equipment that is protected from contamination and has not been previously used to carry non-food items, toxic substances, or petroleum products.
- Maintaining records of the trucking and chlorine addition and testing results.

The estimated chlorine dose accounts for the demand exerted by ammonia, iron, and manganese. The organic carbon in the well waters would also consume chlorine and rather than relying on desk-top estimates, the City should perform recommended CDD tests on the wells. At the time of trucking, the applied chlorine dose would also need to consider the chlorine demand due to the containment used for trucking and/or storage while maintaining the minimum required free chlorine residual of 0.5 mg/L at the point of delivery.

If an adequate chlorine residual is not maintained during trucking, the City should contact the Department Health to determine if the water could be served with a health advisory (such as a boil water notice).

4.1.2 Water Quality Monitoring

The minimum testing requirement under the regulations is to monitor the acute contaminants of coliform and nitrate before the wells are placed into service. It is recommended that the City collect these samples on a yearly basis to ensure the water quality remains acceptable and to avoid delayed use of the wells in an emergency. Additionally, the City would be expected to monitor for chlorine residuals at the time of trucking.

4.1.3 Considerations Before an Emergency

To be better prepared, it is recommended to perform the following tasks prior to the occurrence of an emergency:

- Obtain Department of Ecology approval for emergency water rights.
- Review the applicable regulatory requirements for trucking/delivery of potable water.
- Review operations and maintenance practices of the wells.

- Ensure the SOP for water trucking is up to date and includes the monitoring requirements and requirements for DOH notification prior to transfer of water to delivery trucks or other delivery mechanisms outside the distribution system.
- Ensure access to appropriate delivery trucks or install plumbing that adequately protects the wells.
- Obtain the appropriate equipment to add and monitor chlorine.
- Develop action plans and notification templates to alert DOH, staff and/or customers if the chlorine residual is too low or testing indicates the presence of microbial contamination.
- Continue annual nitrate and coliform monitoring at the wells.
- Develop report templates for record keeping.
- Complete CDD tests to obtain a more accurate estimate of the chlorine demand of the well waters.

4.1.4 Considerations During an Emergency

During the emergency, the City should notify DOH first, follow all requirements and the City's SOP for trucking water, implement the recommended water quality monitoring, and maintain records.

4.1.5 Considerations After an Emergency

The City should return the wells to standby mode, review the records, and revise the procedures and chemical dosing, as needed. Notify the Department of Ecology that the emergency use has been discontinued.

4.2 Option #2: Disconnected and Plumbed for Quick Connection to the Distribution System

Option #2 considers using the well water supplies as a temporary, emergency supply until full service from SPU-supplied sources can be restored. The approved wells currently meet all primary water quality standards and the wells have been approved by DOH for emergency supply purposes. Therefore, the wells could be pumped to the distribution system in an emergency. The City's emergency response program should detail the procedures required to bring the wells on-line.

4.2.1 Regulatory Requirements

Since the City's regular water supply is treated surface water, the City is required to maintain a detectable chlorine residual in the distribution system. If the City switched entirely to groundwater, maintaining a chlorine residual may not be required. However, since during an emergency the SPU-supplied sources may be partially or intermittently available, it is prudent to provide the appropriate equipment to chlorinate the well waters during an emergency to avoid blending groundwater without a residual with surface water containing a free chlorine residual. Chlorination has multiple other benefits, such as, helping to maintain microbial control, maintaining the stability of existing scales, and better matching the ORP of the existing distribution system water. If during an emergency the chlorination equipment at the wells was not operable or if chlorine deliveries were not possible the City could pump the well waters directly into the system without chlorination. In that case, the City would be required to issue a boil water advisory and follow the appropriate DOH guidance.

Depending on the nature and extent of damage to the distribution system, it is possible the well(s) would not be capable of providing sufficient pressure within the distribution system. During such a depressurization event, bulk delivery of water (Option #1) would be more appropriate.

4.2.2 Water Quality Considerations and Blending Analyses

Water quality and blending analyses are discussed in this section.

Blending Analysis

To evaluate how the water quality in the distribution system may change if the well water and SPU supplies blend in the system, WaterPro 6_30 software was used to calculate concentrations of specific water quality parameters at different blending levels. The blends selected included 0, 25%, 50%, 75%, and 100% well water for both Samena Well 3 and the average of the three Crossroads wells. A combination of 25% Samena and 75% average Crossroads well water quality was also selected for blending with existing water from SPU.

Table 6 presents the key water quality parameters included in the blending evaluation. The groundwater has a lower pH, higher dissolved inorganic carbon (DIC), and higher alkalinity than the existing water in the distribution system. The blended water pH is largely controlled by the groundwater due to its higher alkalinity and buffering capacity. Samena Well 3 has a higher pH than the Crossroads Wells.

Table 6. Key Water Quality Parameters for the Blending Analyses

Parameter	Unit	Samena Well 3	Crossroads Wells	Well Water Blend	Existing Distribution
pH		7.8	7.4	7.4	8.2
Temperature	°C	10.5	11.1	11.0	14.5
Alkalinity	mg/L as $CaCO_3$	64	59	60	20
Total Dissolved Solids	mg/L	115	106	108	39
Iron	mg/L	0.32	0.801	0.681	0.039
Manganese	mg/L	0.0628	0.054	0.056	0.002
Calcium	mg/L	8.3	10.0	9.6	9.8
DIC	mg/L as C	16	16	16	5

Aesthetics

The well water is of different quality than the surface water and customers are likely to notice the change in supplies. The groundwater has a higher mineral content and elevated iron and manganese levels that can cause discoloration and taste and odor. There could also be odors caused by sulfides since sulfides have been historically reported as being present in the well waters. Depending on the chlorine dose, chlorination may not be sufficient to completely remove rotten-egg odors associated with sulfides.

Potential aesthetic water quality issues associated with contaminants with a Federal SMCL are presented in Table 7. Note that not all the contaminants listed have been regulated by Washington State.

If the City does not provide treatment to remove iron and manganese but does provide chlorination, these metals will be oxidized resulting in the formation of brown and black precipitates. Depending

on the nature of the emergency, the City could consider supplying water to meet basic needs and to help maintain system pressures, even without treatment. The existing SPU supply could also be used, if at least a limited capacity was available, to effectively dilute the well water to minimize anticipated water quality effects. However, if ammonia in the well water is not oxidized prior to distribution, chloramines will form in the blended waters. The blended well water may also not be acceptable for certain industrial processes or customers using equipment sensitive to water quality (such as hospitals, kidney dialysis centers, etc.).

Table 7. Potential Aesthetic Water Quality Concerns

Contaminant	SMCL	Potential Effects	Anticipated Effects for Approved Wells
Corrosivity	Non-corrosive	Metallic taste; corroded pipes/ fixtures staining	Potential increased corrosivity if pH not adjusted
Iron	0.3 mg/L	Rusty color, sediment, metallic taste, reddish or orange staining	Staining and taste and odor issues likely if iron and manganese treatment not provided
Manganese	0.05 mg/L	Black to brown color, black staining, bitter metallic taste	
Odor	TON = 3	Objectionable odor	Potential for rotten egg odors due to sulfides
pH	6.5 - 8.5	Bitter, metallic taste, possible increased corrosion, if pH low	Taste effects not anticipated, increased corrosion possible
Zinc	5 mg/L	Metallic taste	No[1]

Notes:

1. Zinc detected in Samena Well 3 (3.1 mg/L) in 2016. Zinc levels in the Crossroads Wells < 0.5 mg/L in 2017. Zinc may be naturally occurring. Other sources of zinc may be release from brass fixtures or corrosion of galvanized plumbing.

Treatment of the Tolt supply includes lime addition for corrosion control and, therefore, the calcium hardness of the water is very similar to the well water. Calcium levels in both waters are approximately 10 mg/L indicating a calcium hardness of 25 mg/L as $CaCO_3$. Magnesium levels are one order of magnitude higher in the well water (5.6 to 8 mg/L compared to 0.5 mg/L for the Tolt supply) which adds to the total hardness. Silica levels are also likely higher in the well water. This could mean that customers notice increased water spot formation. The City may receive an increased volume of complaints depending on the severity of the emergency. Calcium carbonate precipitation should not be an issue if the pH is maintained at or below pH of 8.6. The calcium carbonate precipitation potential for the well waters are lower than for the existing surface water, but the parameters affecting calcium carbonate precipitation may change depending on the type and level of treatment provided by the City.

Metals Release/Corrosion Considerations

The pH of the Crossroads Wells is almost one full pH unit below the prevailing pH in the distribution system. If those wells were used without pH adjustment some disruption to existing scales and increased corrosion is anticipated.

Figure 1 presents calculated pH, DIC, and theoretical copper and lead solubilities. The lead and copper solubilities are calculated based on theoretical considerations and do not necessarily

correspond directly to lead and copper results at customers' taps in the City's system. These calculated values are useful for determining trends. Copper solubility is predicted to increase as the proportion of groundwater increases, corresponding to the lower pH of the well waters. Lead solubility did not vary significantly as a function of blend ratio. Increasing the ratio of Samena Well 3 water had less effect on copper solubility due to its higher pH. All groundwater blends are anticipated to increase copper solubility to some extent due to the higher DIC of the groundwaters.

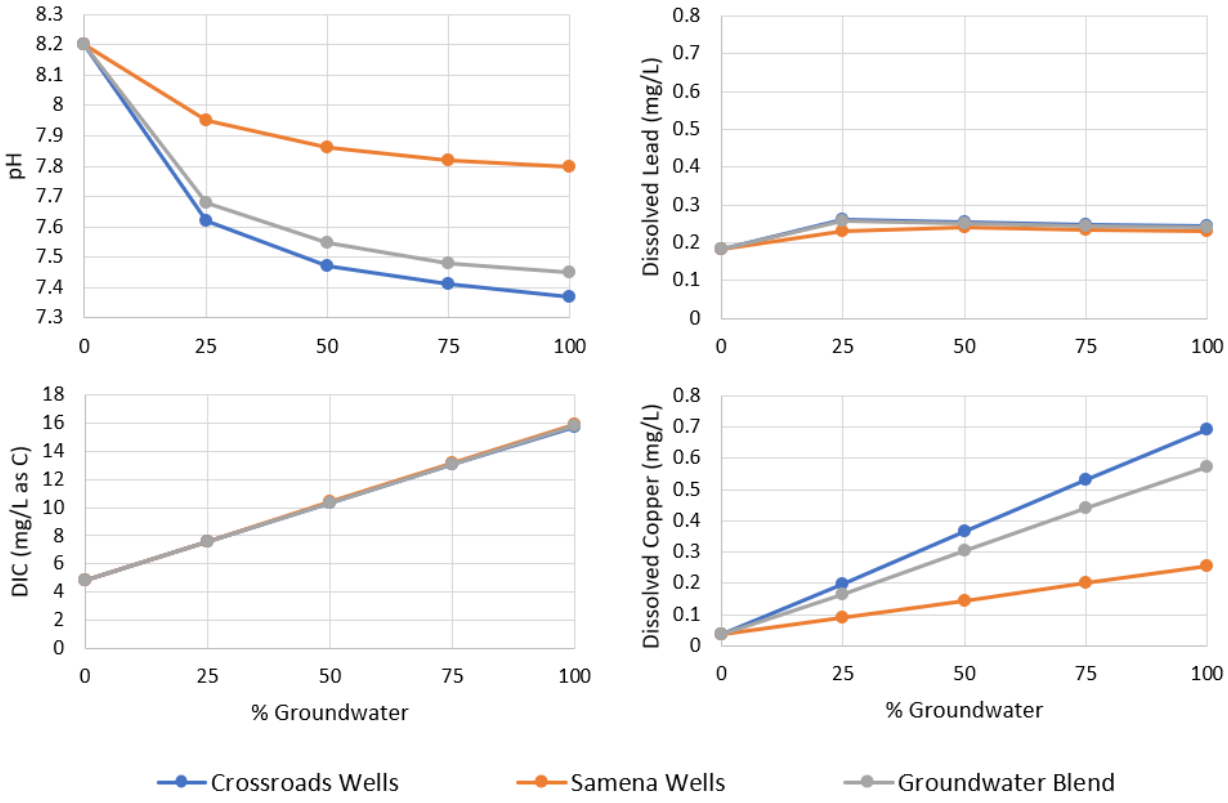

Figure 1. Predicted water quality characteristics for different levels of blending.

As the blend of well water increases, the predominant thermodynamically stable form of lead is anticipated to shift from hydrocerussite to cerussite. As this shift occurs, destabilization of existing lead scale is anticipated as re-equilibration occurs. Such shifts in the thermodynamically stable form of other metals are also possible, given the different chemistry of the groundwater compared to the existing surface water supply. The extent of destabilization and the impact on existing scales would depend on the duration of well use and the extent of the emergency which necessitated bringing the well supplies on line. A more detailed evaluation of potential effects on scale stability could be conducted once the level of treatment of the groundwater supplies has been established and accurate treated water quality data are available.

Chlorine Demand and Disinfection By-Products

Disinfection would likely take place at the Crossroads and Samena Well sites using continuous injection of chlorine into the water as it is pumped into the distribution system. Chlorine demand estimates should be confirmed by performing CDD tests to establish the appropriate chlorine dose for each well water. The goals of disinfection are to maintain a detectable chlorine residual

throughout the distribution system and, if feasible, to provide 4-log virus inactivation. The other purpose of chlorine addition is oxidation of ammonia, iron, and manganese.

Since the wells would be used only in an emergency, and not continuously or regularly, the compounds regulated due to their potential to cause adverse health effects over long-term, chronic exposure, such as DBPs, would not be a major concern. The extent of DBP formation could be evaluated as part of the CDD tests.

Compatibility of Pipe Materials

Per the City's 2015 Water System Plan, the distribution pipes consist of ductile iron (49.9%), asbestos cement (42.5%), and cast iron (6.8%) with less than 1% of other pipe materials. Ductile iron, asbestos cement, cement-lined, and plastic pipe are considered non-scale forming pipes, while unlined cast-iron has the tendency to form significant scales. Non-scale forming pipes can accumulate scales and sediment but do not generally form corrosion by-products and tubercles. The pipe deposits can be a complex mixture of sediments, metals, biofilm, calcium scales, and various by-products of metallic pipe corrosion. The exact type and mobility of the deposits depend on site-specific factors such as current and historical water quality, pipe type, lining, age, condition, routine hydraulic conditions, and maintenance history. The outer layers of an existing scale are generally in equilibrium with the bulk water chemistry and any shifts in this environment can lead to release of metals, destabilization of scales and water quality deterioration as the scale re-equilibrates (AWWA 2017). For the City's system, the stability of existing scales is anticipated to be affected by:

1. Significant changes in pH and DIC due to use of the Crossroads Wells.
2. Inability to maintain sufficient ORP within the well waters or blends within the distribution system.
3. Changes in hydraulic conditions such as modification of pressure and direction of flow during the emergency.

It is difficult to predict the level of upset and the time required to achieve a new equilibrium. Table 8 lists contaminants of concern related to typical materials in the drinking water system. Once released these compounds may travel with the water throughout the distribution system. Scales and sediments also provide shelter for microbes that can be released and cause additional chlorine demand.

To minimize the impact, the ideal approach would be to complete unidirectional flushing (UDF) when the wells are turned on and again when the regular sources are returned to service. While this may not be an option given the emergency situation, the City could also consider spot flushing or localized UDF in selected areas of the distribution system.

Table 8. Potential Contaminants from Different Pipe Materials[1]

Plumbing Material	Primary contaminant from pipe	Trace metals that could be released
Asbestos-cement, concrete, and cement linings	asbestos fibers from erosion, increase in pH, aluminum, and calcium	cadmium, chromium, barium, aluminum
Brasses and bronzes	lead, copper, zinc	selenium, bismuth, phosphorus
Copper	copper, iron, zinc	tin, antimony, arsenic, cadmium, lead
Galvanized iron or steel	zinc, iron	cadmium, chromium, barium, aluminum, lead
Iron, unlined cast or ductile	iron, turbidity	
Lead	lead	
Plastic	plasticizers (lead)	
Steel	iron, turbidity	

Notes:

1. Modified from Table 5-2 (AWWA, 2017).

4.2.3 Water Quality Monitoring

The City should continue testing the wells for acute contaminants (nitrate, and coliform) on an annual basis. The City should also establish baseline water quality including source tracking parameters, trace metals, substrate elements, and general water chemistry (AWWA, 2017). This baseline will help to determine the extent the well water is affecting the system and when conditions have returned to normal after the emergency.

4.2.4 Considerations Before an Emergency

The following is a list of recommended actions to be performed prior to an emergency:

- Annual water quality monitoring.
- Review the water needs within the service area so that the City can decide the preferred level of treatment for emergency supplies and develop any special notification procedures.
- Obtain Department of Ecology approval for emergency water rights.
- Obtain design approval from DOH for chlorination (and other treatment if installed) at the approved wells.
- Secure and maintain a source of chlorine and chlorination feed and testing equipment
- Determine the area of influence of the wells within the distribution system by conducting hydraulic modelling.
- Develop SOPs for activating the emergency sources including identification of methods and materials required for making temporary connections between the wells and the distribution system.
- Complete CDD tests to obtain a better estimate of the required chlorine dose for meeting the minimum disinfectant residual requirements.
- Develop reporting forms for well operations.
- Develop a monitoring plan including:
    - Chlorine testing at the entry points and in locations throughout the distribution system.

    - Coliform monitoring during an emergency.
    - General water quality parameter testing plan to enable evaluation of the effect of the wells on water quality. This could include ORP, pH, alkalinity, and conductivity (for source tracking).
- Evaluate and amend the flushing plan as needed for the areas served by the wells.
- Implement regular main cleaning programs, such as UDF to manage pipe deposits.
- Ensure the wells remain operable by performing regular operations and maintenance activities.
- Develop a response plan for customer inquiries and potential health advisory.

4.2.5 Considerations During an Emergency

The following actions are recommended during an emergency:

- Monitor and record well pumping rates, volume treated, chlorine consumption, and chlorine residual levels. Perform all regular operations and maintenance activities, if possible.
- Keep records of customer complaints (type, area).
- Collect water quality data for the distribution system to aid in source tracking and determining the extent of variation from prevailing conditions prior to the emergency.

4.2.6 Considerations After an Emergency

The time and effort for the recovery will depend on the extent of disturbance caused during the emergency due to differing water quality and system hydraulics. If disinfection treatment remained in place during the emergency and adequate ORP was maintained in the distribution system, scale stability would be of less concern than if significant variation in ORP occurred during the emergency. A system-wide UDF plan should be implemented to help draw the normal supply from SPU into the system and to displace groundwater from the system. UDF velocities should be adjusted based upon pipe type and the City should take care to avoid disturbing tubercles in cast iron mains. Depending on the flow patterns and the time the wells were in use, reservoirs near the well sites may need to be cleaned to remove iron/manganese deposits. At the end of the event, notify the Department of Ecology that emergency water withdrawal has been discontinued.

4.3 Option #3: Full-time Connected Supply

As full-time sources of supply, increased on-going monitoring requirements would apply to the Samena and Crossroads Wells. The system would qualify for monitoring waivers given the extensive history of source monitoring; however, the historical contamination at the Crossroads site and the potential presence of gasoline compounds would need to be addressed. The MCLs for compounds of potential concern are as follows:

- Xylenes (total) 10 mg/L
- Benzene 0.005 mg/L
- Ethylbenzene 0.7 mg/L
- Toluene 1 mg/L
- Chlorobenzene 0.1 mg/L.

Under Option #3, iron and manganese removal treatment in addition to disinfection and ammonia removal are recommended. The goals of disinfection treatment would be to achieve 4-log virus

inactivation, maintain a free chlorine disinfectant residual in the distribution system, and better match the ORP of the existing water. Also, the City would be required to complete a corrosion control study to determine if additional treatment (such as pH adjustment) is required for optimal corrosion control, under the Lead and Copper Rule.

4.3.1 Regulatory Requirements

In summary, the regulatory requirements for Option #3 are as follows:

- Obtain approval from DOH for permanent use of the sources and treatment systems.
- Complete a corrosion control study for blending the well waters in the distribution system.
- Install and maintain disinfection treatment.
- Install and maintain iron and manganese removal and ammonia oxidation treatment. If the treatment consists of more than chemical injection, the plant would need to be operated by a certified water treatment plant operator (the certification level would depend on the complexity of the treatment. The City should plan for WTPO2-level certification at the minimum).
- Perform on-going treatment performance monitoring.
- Perform regulatory source monitoring at the entry points to the distribution system.
- Revise the City's water quality monitoring plans including the coliform monitoring plan to reflect the requirement to sample these wells if they were in use at the time of a positive coliform sample. Revise the DBP site evaluation to ensure the sites meet the requirements of the Stage 2 DBP Rule, and revise LCR compliance monitoring, as required. Use of groundwater could impact the City's participation in regional monitoring plans.

The Crossroads Wells have a TOC of approximately 1.2 mg/L. This level of TOC can be expected to result in significant DBP formation, based on a previous study of Washington groundwaters (Leslie et al., 2017). The TOC of Samena Well 3 is sufficiently low that it is not likely to cause significant formation of DBPs, although DBP formation should be evaluated as part of CDD testing for both the Samena and Crossroads Wells.

4.3.2 Water Quality Considerations and Blending Analyses

The effect of blending treated groundwater with the surface water in the existing distribution system depends on the level of treatment installed at the wells. As discussed under Option #2 above, blending groundwater without pH adjustment would decrease pH and increase alkalinity, DIC, and copper corrosion in the City's distribution system. The dominant lead scale type would also change, and the City can expect complaints related to water spot formation and iron and manganese staining unless the well waters are adequately treated.

The same mitigation measures as identified for Option #2 apply to Option #3; however, better identification of the areas of influence of the wells, blending zones within the system, and source tracking are recommended.

4.3.3 Water Quality Monitoring

Prior to implementation, the City should complete baseline water quality monitoring to establish existing conditions and to better track potential changes. Example parameters to be included in the baseline monitoring are summarized in Table 9 (modified from Table 3-3 AWWA, 2017).

Table 9. Recommended Water Quality Monitoring Parameters

Baseline Water Quality Characteristics and Chemistry	
pH	Temperature
Total Alkalinity	Conductivity
Dissolved inorganic carbon	Dissolved Oxygen
Free Chlorine	Apparent color
Total Chlorine	Heterotrophic Plate Count
Oxidation Reduction Potential (ORP)	ATP (adenosine triphosphate)
Chloride	Total organic carbon
Sulfate	Turbidity
Calcium	Total and dissolved lead, copper, iron, and manganese
Hardness	

5.0 SUMMARY

Samena Well 3 and Crossroads Wells 5, 6, and 7 have been approved by DOH as emergency supplies and the water quality test results to date have demonstrated that the water for all four wells meets primary drinking water standards. In an emergency, these wells could be pumped directly into the distribution system. However, if the well water is supplied to the distribution system, the City should maintain a free chlorine residual in the well waters to keep ORP close to current levels and to remove ammonia present in the Crossroads well waters. The key findings and recommendations are summarized below for each of the three alternatives. based on this preliminary review. Additional recommendations may be identified as the options are developed further.

5.1 Option #1: Drive-up Emergency-Only Use

The key recommendations for the City for Option #1 are:

1. Install piping/plumbing to support the trucking or filling station.
2. Ensure the trucking water SOP includes the current regulatory requirements.
3. Maintain the wells in operable condition and test them annually for VOC, coliform, and nitrate.
4. Complete CDD tests at the wells to better quantify chlorine dosing requirements for each truck load.
5. Maintain the appropriate equipment needed for adequate chlorine addition and testing.

5.2 Option #2: Disconnected and Plumbed for Quick Connection to the Distribution System

Under Option #2, the four wells will be pumped into the distribution system as emergency sources of supply. The key findings and recommendations for the City are:

1. Maintain the wells in operable condition and develop SOPs for activating and operating the wells in an emergency. Consider need for rehabilitation to eradicate iron bacteria in Well 6.
2. Maintain the appropriate equipment needed for temporary connection of the wells to the distribution system.
3. Provide disinfection treatment at the wells and maintain the ability to monitor for free and total chlorine.
4. Continue annual monitoring of VOC, coliform, and nitrate at the wells.

5. Complete CDD tests to better estimate the required chlorine dose, needed oxidation time, and ability to maintain an adequate disinfectant residual.
6. Develop and implement baseline water quality monitoring program to allow changes on water quality to be tracked when the wells are placed in service and during the recovery when the SPU supplies are brought back to full capacity.
7. Be prepared to respond to customer inquiries. All the wells have elevated iron and manganese and if not treated discoloration and staining issues could be problematic. Furthermore, the well water is of different quality than the currently supplied water: it has lower pH, higher alkalinity, hardness, and DIC. Customers will likely notice the difference in water quality.
8. Be prepared to issue a boil water advisory if adequate disinfection treatment cannot be maintained.
9. Some instability of existing scales may occur if an adequate chlorine residual and ORP cannot be maintained in the distribution system that can lead to release of corrosion byproducts, biofilm, and other compounds typically associated with the scales.
10. Be prepared to complete UDF of the area served by the wells once the SPU supply is back online and the wells are no longer in service.

5.3 Option #3: Full-time Connected Supply

If the wells were used as permanent sources of supply, the key recommendations for the City are as follows:

1. Complete a more comprehensive water quality and treatment alternatives evaluation including optimal corrosion control study and bench-/pilot-scale testing.
2. Collect baseline water quality data to document existing distribution system conditions and to evaluate changes in water quality as the wells are placed in service.
3. Design, obtain approval, and install disinfection treatment and treatment to remove ammonia, iron, and manganese.
4. Conduct remediation at the site of the leaking underground storage tank to ensure gasoline-related contaminants do not reach the area of influence of the Crossroads wells.
5. Conduct well rehabilitation to eradicate iron bacteria.
6. Obtain approval from DOH for permanent use of the sources. In addition to DOH approval, the City would need approval from the Department of Ecology as a permanent connection to the distribution system is not permitted under emergency use regulations. This would require confirmation of the City's water rights for wells intended for this purpose.
7. Be prepared to operate and maintain the needed treatment (including having an appropriately certified water treatment plant operator in staff or under contract).
8. Update the existing flushing plan to ensure adequate coverage of the area served by the wells.
9. Revise monitoring plans for coliform, Stage 2 DBP Rule, and LCR compliance.

5.4 Summary of Treatment Recommendations

Recommended levels of treatment for each of the three options are summarized in Table 10.

Table 10. Summary of Treatment Recommendations

Treatment Objective	Treatment Recommendation		
	Option #1	**Option #2**	**Option #3**
Disinfection (with chlorine)	Chlorine residual required but 4-log virus inactivation not necessary		4-log virus inactivation recommended
Ammonia removal	Breakpoint chlorination required to achieve stable free chlorine residual		
Fe/Mn removal	Not required	Recommended to avoid loading Fe/Mn to distribution system	
pH Adjustment	Not required	Likely not justified based on cost/complexity	Consider based on results of corrosion control study

6.0 REFERENCES

City of Bellevue Water System Plan, 2015.

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Appendix D. Economic Losses Due to Potential Water Outage

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Technical Memorandum

To:	Laurie Fulton, Stantec, Doug Lane, City of Bellevue
From:	Kevin Lorentzen, HDR
Date:	May 4, 2018
Subject:	Economic Losses Due to Potential Water Outage

1.1 Introduction

The City of Bellevue (the City) is located in the greater Seattle-Tacoma Metropolitan Area within King County. The City receives 100% of its treated water from the Cascade Water Alliance (CWA) which is ultimately supplied by Seattle Public Utilities (SPU) sourced from the Tolt and Cedar Rivers. Even before the formation of the CWA, the City received water from SPU dating back to the 1960s. Prior to the switch over to purchased water from SPU, the City's legacy water districts operated their own wells and operated a surface water treatment system. The City now purchases treated water and has no water treatment facilities itself but still owns wells and is evaluating alternatives to optimize use of its water rights. However, those facilities are unable to serve the City's entire water needs. Bellevue's water system includes over 37 thousand service connections and approximately 620 miles of water mains.

1.2 Purpose

The City has requested an analysis to quantify the potential economic impact of an interruption of water service, in support of planning for an emergency water supply. The City intends to consider economic risks to the community when evaluating disaster mitigation alternatives, and to help determine if certain investments or operational changes would be economically justified.

To provide the City with a reasonable estimate of the cost of an outage and streamline the analysis, the study was limited to information and data that is readily available from the City and additional information from similar studies conducted for other agencies or professional journals. A more extensive study could survey local businesses about their disaster plans and the specific impact they might experience in the event of a water outage.

1.3 Methodologies for Measuring Economic Impacts

Disasters are often described or defined by the magnitude of the earthquake or the category of the hurricane, but for purposes of this study it is more relevant to quantify disasters in terms of the resulting economic impact. The most common and easily understood method for measuring the economic impact of a disaster is estimated property damage or insured losses. However, losses from property damages are only part of the story when measuring the full economic impact of an event. Since there are different ways to estimate the economic impact of an event it is important to define what is and what is not being measured. In this analysis economic impact will be defined as a measure of the effect of an event on the economy of a specified area, which is the City of Bellevue. The areas outside the City that the City serves were excluded because of the lack of supporting tax data in these areas served which was the basis of the estimate of economic activity. The measured economic impact of the disaster is expressed as a monetary value which can include several types of costs that are either directly or indirectly caused by the event. Some of the types of costs include:

- **Direct Losses**, are losses from the immediate impact of the disaster. As an example, a direct loss in the case of an earthquake would be value of damaged assets and infrastructure due to the results of the earthquake.
- **Market Losses**, a type of direct loss where the impact can be quantified based on the market value or replacement value of the asset.

- **Non-market Losses**, a type of direct loss where the impact cannot be, or is difficult to quantify based on market value. An example of this might be cultural resources or loss of life.
- **Indirect Losses** are losses due to the disaster but are not a direct consequence of the disaster. As an example, business interruption may occur as a result of damaged infrastructure caused by a disaster. Indirect losses are often considered output losses or the reduction of economic output.
- **Negative Costs** are gains in economic activity due to increased construction activity in the course of a recovery from the disaster.

Measurements of economic impacts are not an exact science and are most accurately measured in hindsight. A common method, and often reported method, in the media for determining economic impact is to estimate cost to repair property damaged as a direct result of the event. In contrast, pure economic loss is a difficult term to define and quantify. It can best be described as indirect losses that would likely affect a balance sheet specifically excluding property damage.

1.4 Scope of Study

This analysis is intended to be a narrow look at the economic impact of a water outage for a range in duration from 3 to 60 days. In this case the event is an unspecified disaster which could include but is not limited to a severe earthquake or other disaster. The cause of the outage is unspecified but the analysis is based on a total outage, not just contamination, and alternative sources are not available either through interties with adjacent cities' water systems, through use of the City's wells, or from other surface water sources.

Direct Losses were not included in this analysis because, depending on the disaster, the degree and type of infrastructure damage will likely extend beyond the city's water system (e.g. failure of power grid, transportation systems, etc.), compounding impacts to residents as well as complicating repairing damage to the water system. Such external damages could themselves cause business and residential losses regardless of the condition of the water system, so those losses are not included in this evaluation to avoid double-counting. This analysis was intended to isolate and evaluate damages resulting specifically from a loss of water supply. A fire event during a water outage would be exasperated due to the lack of water. However, the possible economic impact from a fire event is not calculable with any level of accuracy due to the wide range of scenarios that might surround a fire event including the event that caused the water outage. As an example an earth quake could increase the chance and severity of a fire event depending on the magnitude. The following impacts were not included in this analysis:

- Utility outage other than water and sewer
- Cost of repairing water supply
- Damage to private or public property
- Loss of life
- Loss of non-monetary assets
- Also not a consideration in this analysis is the extent of private property damage.

This analysis will be limited to indirect costs, specifically:

- Business production losses to commercial water customers
- Lost wages to residential customers
- Lost local government sales tax and business & occupation (B&O) tax collections
- Lost water and sewer revenues for the City's Utilities Department

1.5 City of Bellevue Economic Profile

Geographically, Bellevue is within the Seattle-Tacoma Metropolitan area which consists of Snohomish, King, and Pierce Counties. The Metropolitan area is made up of many cities which have deep economic ties where people often do not live in the same city they work. Though Seattle is often the highest profile city in the Puget Sound it accounts for less than 20% of the population. Bellevue is the third largest city in the metropolitan area behind Tacoma. Bellevue has a thriving job market with many large businesses and is currently the second largest city in terms of jobs in the State. The downtown core has gone through a period of rapid growth and is currently in the midst of another building boom. Bellevue serves as a significant base of operations to several large companies such as Microsoft, T-Mobile, Expedia, and Boeing to name a few. All the businesses operating in Bellevue, combined, generate approximately $26 billion per year in gross receipts. The Washington State Office of Financial Management estimates the resident population at 139,400. Merely looking at population figures does not give a full picture of Bellevue. It is estimated that almost 100,000 people commute to Bellevue for work during the work week from around the metropolitan area while only 44,000 both live and work in Bellevue. Chart 1 provides the population as well as an estimated number of jobs within the city limits.

Chart 1

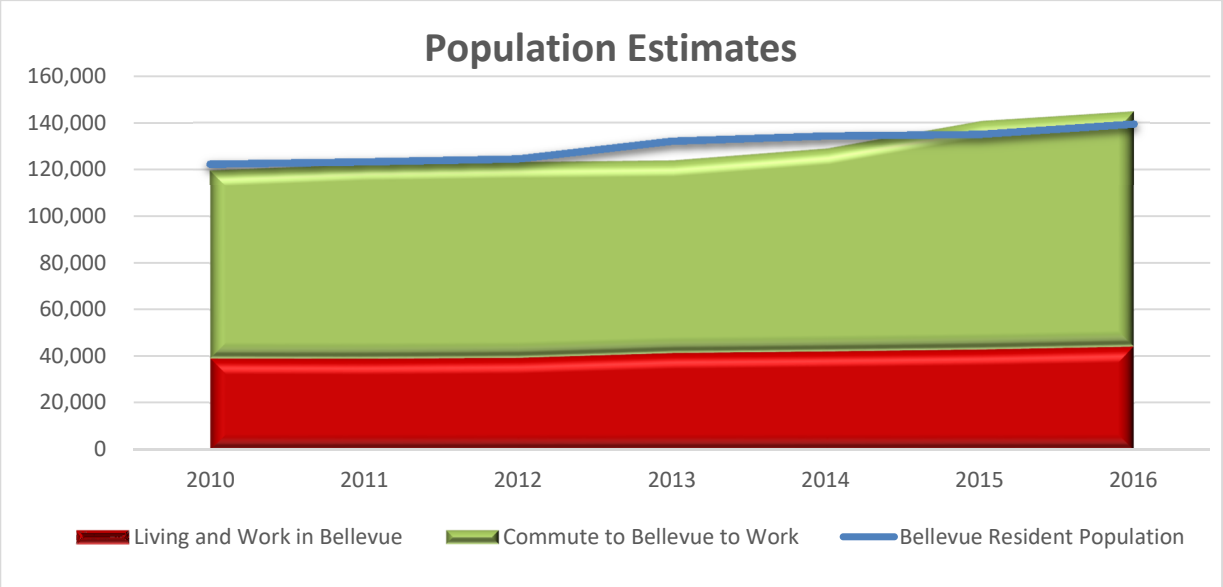
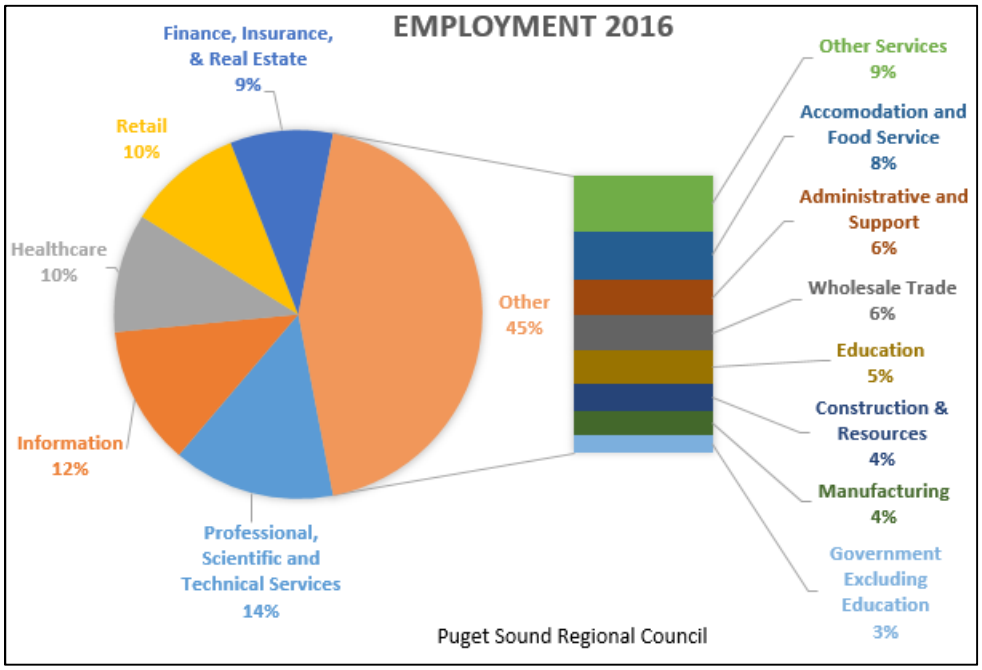


*Chart 1 data was taken from Puget Sound Regional Council (PSRC) and Bureau of Labor Statistics (BLS).

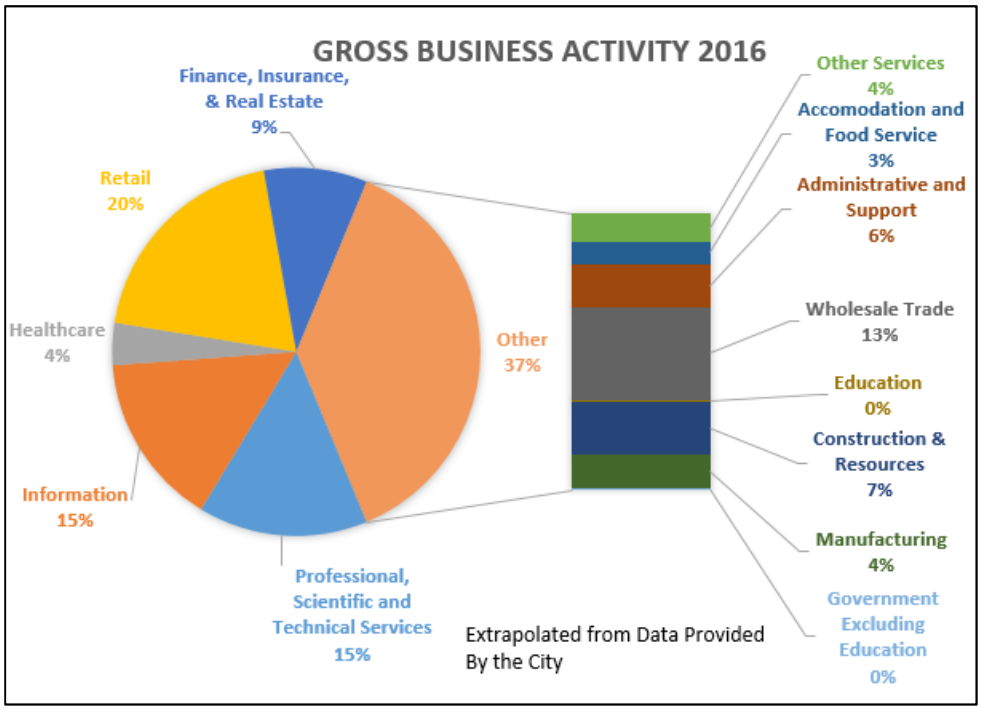
Bellevue's largest employment sector is services, wholesale trade, transportation, and utilities. Within this category the majority of these jobs are office-type jobs including professional, scientific and technical services. When finance, insurance and real estate jobs are included, nearly three quarters of Bellevue's employment base is dominated by office jobs as represented in Chart 2 below.

Chart 2



The makeup of business activity sectors is similar to the employment sectors with some differences. A notable exception is the retail sector where 10% of the jobs accounts for 19% of the business activity. The downtown core has many large office buildings as well as a shopping mall and other retail establishments. Again when finance, insurance and real estate are combined with service wholesale trade, transportation and utilities it makes up the majority of business activity in Bellevue at 68% as shown in Chart 3.

Chart 3



1.6 Assumptions

For this analysis the impact to the local economy is assumed to be the impact to Gross Domestic Product (GDP). GDP is a measure of the market value of production within a specific area. GDP is a good measure of the economy because it avoids double counting transactions that account for the same activity such as the value of good or service and the labor to produce that good or service. GDP is commonly calculated in three ways as shown in diagram 1 below, a production approach, income approach and expenditure approach. In a perfect world these three methods, when calculated over the same area and time frame would yield the exact same value. However the data used in these GDP calculations are not perfect and this will result in a range of values among these GDP calculations. Components of each of these three methods were used in this analysis to provide a broad perspective of the economic impact for this analysis. It is important to understand that, while it is tempting to add the impacts of the three economic measures together to do so would double count some portion of the GDP or overestimate the economic impact.

Diagram 1

Expenditure Approach	
+	Consumption
+	Investment
+	Government expenditures*
+	Exports
-	Imports
=	Gross Domestic Product

*Includes Taxes Water and Sewer Services

Production Approach	
+	Value of Production*
-	Value of Goods and Services used in Production
=	Gross Domestic Product

* Gross Sales

Income Approach	
+	Income*
+	Sales Tax
+	Depreciation
+	Net Foreign Investment
=	Gross Domestic Product

* Wages

To conduct this analysis, estimates and assumptions need to be made to account for unknown factors. Data sources used for this analysis included the City's records, state and federal agencies such as the Bureau of Labor Statistics and Bureau of Economic Analysis, as well as published journal articles on estimating economic impacts of infrastructure.

The first estimate that needed to be made was the level of business activity or gross receipts produced in the City of Bellevue on the average day. There are no available records that simply state what the City's total gross receipts are. As a result, this was estimated using available Business and Occupancy (B&O) tax and sales tax collection data provided by the City. The City provided this data grouped by the North American Industrial Classification System (NAICS) codes.

Employment statistics were also gathered from the Puget Sound Regional Council (PSRC) which tracks local employment statistics within the Puget Sound area. Employment statistics from PSRC are grouped by NAICS code.

Another important factor in this analysis is the degree to which a company may be affected by a water outage, often referred to as the business resiliency factor. This factor is represented as a number between zero and one where one indicates the business is unaffected by the water outage and zero mean the business is completely vulnerable to a water outage. After reviewing some of the research regarding water outages and their effects, the most commonly cited source was a paper titled "Linking infrastructure and urban economy: simulation of water-disruption impacts in earthquakes" by Chang and Svekla. The resiliency factors used are based on the premise that there is a difference in business impact on the first day of a service interruption versus after 60 days. The resiliency factors used were grouped by NAICS code like the tax and employment data received from the City. Since the resiliency factor is a representation of the level of business at some level of water outage, then subtracting one from the resiliency factor will give you the estimated losses when multiplied by the gross receipts.

Table 1

Resiliency Factors	Less Than 1 Week	1-2 Weeks	Greater than 2 Weeks
Agriculture	0.53	0.35	0.30
Mining	0.73	0.48	0.44
Construction	0.68	0.47	0.43
Nondurable Manufacturing	0.42	0.34	0.28
Durable Manufacturing	0.42	0.34	0.28
Transportation	0.65	0.49	0.43
Communication/utilities	0.65	0.49	0.43
Wholesale Trade	0.51	0.36	0.30
Retail Trade	0.64	0.32	0.28
Finance, Insurance, and Real Estate	0.44	0.27	0.24
Business/Repair Services	0.45	0.33	0.27
Personal Services	0.45	0.33	0.27
Entertainment Services	0.45	0.33	0.27
Health Services	0.27	0.21	0.19
Educational Services	0.45	0.33	0.27
Other Services	0.45	0.33	0.27

Chang S. E., W.D. Svekla, and M. Shinzuka (2002), "Linking infrastructure and urban economy: simulation of water-disruption impacts in earthquakes", *Environment and Planning B: Planning and Design*, 29, 281-301.

1.7 Analysis

As mentioned earlier in this document there are several types of economic impacts a water outage could have on a city. The main purpose of this analysis was to quantify the impact on the economy in a narrowly defined scenario where the absence of water was the only impact. The purpose of the study was to determine the impact of the loss of water, not other damages that may have occurred as a result of the disaster. Damage to the water system was not estimated because without specifying the type and magnitude of the disaster, the cost to repair the system could be anywhere from zero to several billion dollars depending on if the damage was only on the CWA system or if the disaster resulted in the virtual complete destruction of the water system. Losses due to business transactions outside Bellevue were not quantified due to the lack of available data that would provide a reasonable basis for an estimate. Workforce availability was also not quantified in this analysis because of the lack of available research on the subject.

Business resiliency factor is an important assumption for this analysis. The analysis was intended to cover a range of outages from three days to 60 days, but the estimates based on the available survey data did not have a three-day estimate. To calculate the impact for an outage less than three days the choice was to use the less than one week value or assume a more resilient number. The obvious trend of the resiliency factors was that the longer a water outage the less resilient a business would be. To factor this trend into an estimated value, it was assumed that the less than three-day resiliency factor

would be exactly half way between a business day with water service, and the factor used for a water outage for less than one week. An estimated resiliency factor was used to show more conservative results in the earlier days of an outage. As the days of the outage are increased this assumption plays only a minor difference.

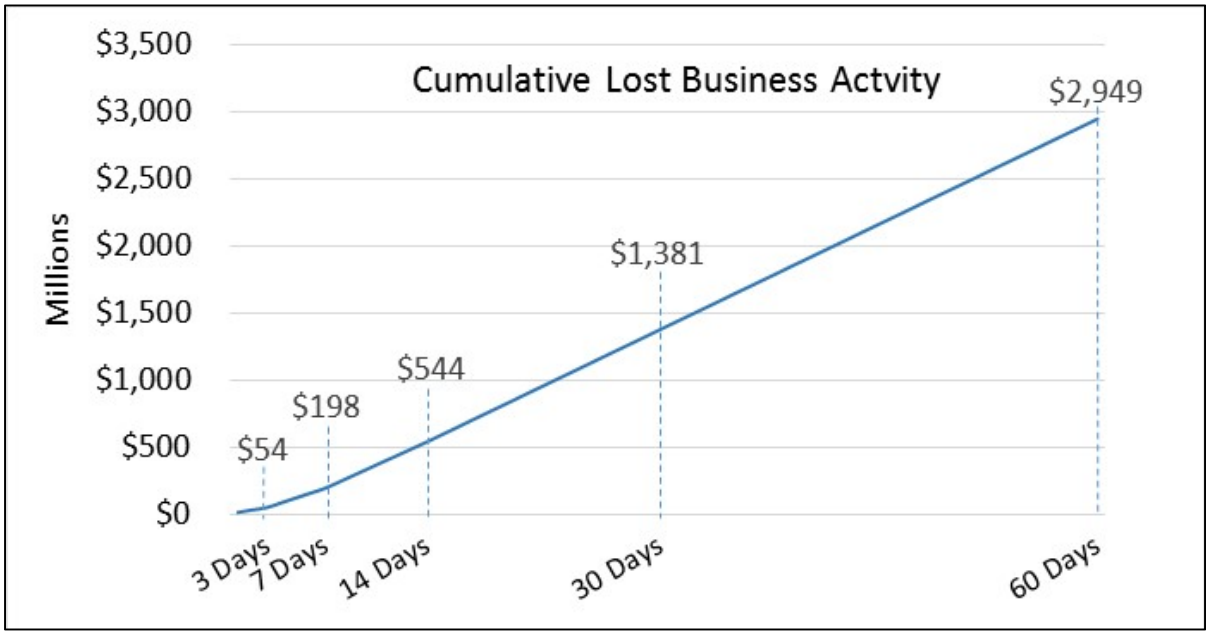
Business Activity

The calculation for the production approach for calculating GDP is sales of goods and services plus value of changes of inventory. Using the sales and B&O tax can be used to approximate sales of goods and service but the data to determine the value of changes of inventory was available. Using sale and B&O tax is not a perfect means to extrapolate the gross sales but will capture the majority of sales, there are business activities that are not subject to either tax that would otherwise be included in gross sales when calculating GDP.

The estimated amount of business activity as measured as gross receipts is $72 million per day. This figure was calculated using the City's sales (non-store or web sales were excluded from this figure) and B&O tax collection data for 2015 and 2016. Integral to determining the loss in business activity is the resiliency factor by NAICS code which represents the level of reduction in business depending on the number days of outage. As discussed earlier, subtracting one from the resiliency factor then multiplying by gross receipts provides estimated business losses. The resiliency factors used are temporal in nature so there are different factors that are appropriate depending on the number of days of a water outage. Losses were calculated by multiplying the average day gross receipt by the resiliency factor corresponding to the number of days it has been since water service ceased. The sum of these figures were added depending on the number of days of losses to arrive at the cumulative losses by the number of days of outage. Losses were calculated for each day up to 60 days to determine the cumulative loss.

The results of the analysis were that a three-day water outage would yield a $54 million in lost business activity while a 60 day water outage would yield almost a $3 billion loss in business activity. On a per day basis, for an outage less than three days the lost business activity would be approximately $18 million, less than a week would be $36 million per day, between one and two weeks losses would be $49 million per day and greater than two weeks losses would be $52 million per day. Chart 4 shows the cumulative impact of lost business activity due to a water outage from three to 60 days.

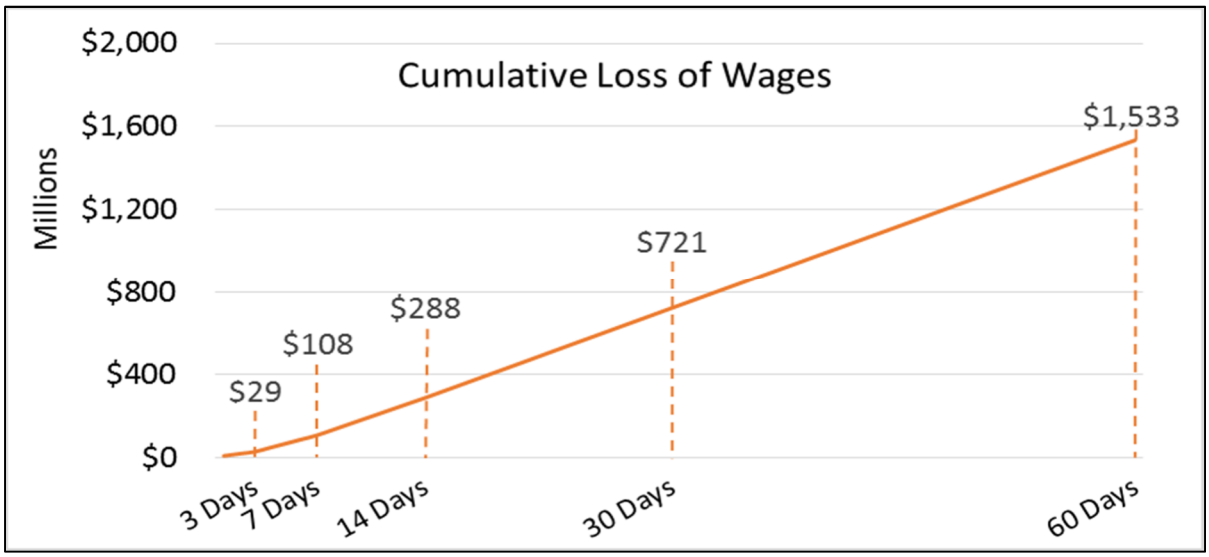
Chart 4



Lost Wages

The income approach is a method for calculating GDP by summing employment compensation, corporate business profit, interest income. One of the components of this method for calculating GDP that is readily available for analysis at the City's level is wages. This is also something that will most directly affect the people who live and work in the City. The resiliency factors used for the business activity loss calculation can also be applied to the loss of wages by residents and people who work in Bellevue. Estimates of potential loss in wages due to a water outage were calculated using 2016 employment data from the BLS and PSRC coupled with the resiliency factors in Table 1 in the same manner as the calculation in lost business activity and lost tax collections. The figures calculated might be somewhat inflated due to the different requirements under the Fair Labor Standards Act to pay salaried workers if the persons place of work was not open due to weather or disaster of some sort while hourly workers would only get paid for hours worked. The distribution between hourly and salaried workers could not be found from a verifiable source so no adjustments were assumed in this analysis. As the chart below shows, cumulative lost wages has the same shaped curve as the business activity losses. This is because they are both based on the same resiliency factors. For a three day outage the estimated lost wages was approximately $29 million while after 60 days of no water service the impact is $1.5 billion. Chart 5 below provides cumulative wages lost from three to 60 days.

Chart 5



Lost Local Tax and Water and Sewer Rate Collections

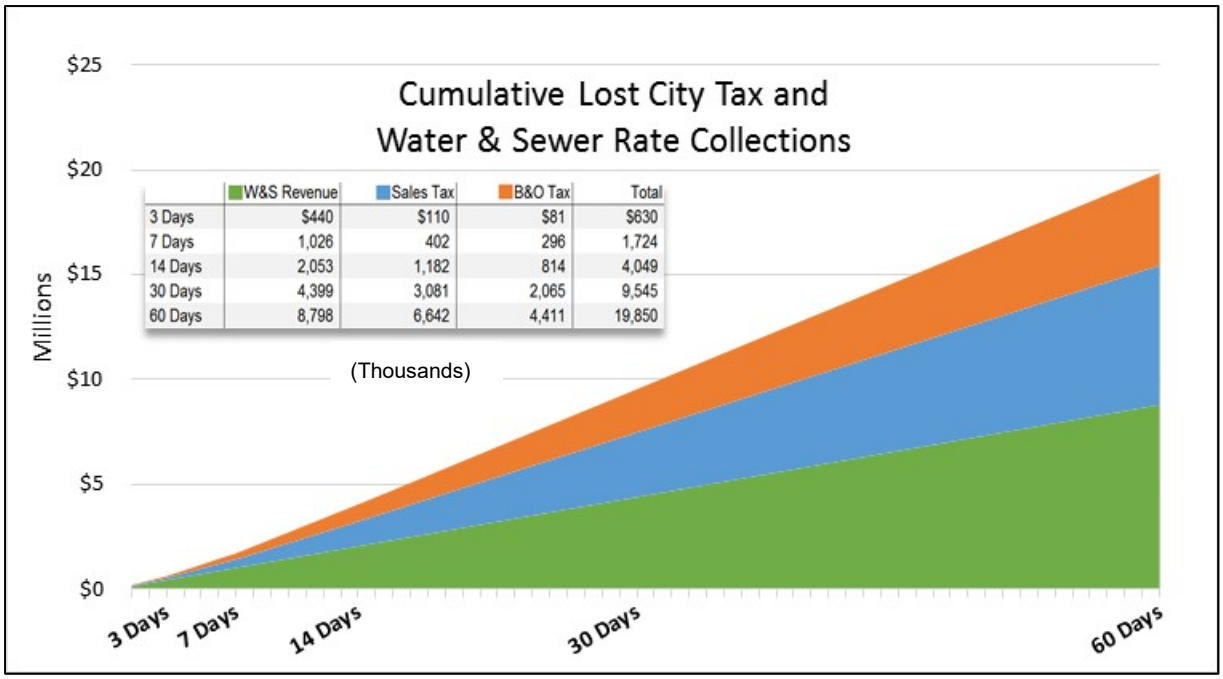
Finally, the last method for calculating GDP is the Expenditure method. This method is the sum of consumption (Private expenditures), investment, government spending, and net exports. Taxes collected by the City is a surrogate for government spending and water & sewer rate revenue are expenditures.

Since the focus of this analysis is on the City, a measurable effect of a disaster would be the impact on the City itself. Two obvious losses the City would experience is a reduction in tax and utility rate collections. The tax figures provided here are limited to local City taxes - they do not include other tax authorities such as the county, state or federal government. Bellevue benefits from its diverse mix of tax revenue but this analysis only includes B&O and Sales tax. Other taxes were not included because they were immaterial when compared to B&O and Sales tax. Bellevue's average sales tax collections per day is approximately $170,000, while B&O tax collections were $108,000 per day according to City provided records. Due to the downtown core's concentration of office buildings and retail establishments the City receives a substantial portion of their revenue from Sales and B&O tax. Many neighboring cities do not have the degree of business activity as Bellevue and are primarily reliant on property tax. While having a more diverse mix of taxes is a benefit for Bellevue, it also leaves the City open to suffer due to lost revenue from changes in economic environment as well as events like a disaster that may affect local

business, preventing them from operating. Similar to the business activity loss calculation, tax collection losses were determined by subtracting one from the resiliency factors and multiplying this against tax collections as used in the previous calculation. This gives an estimated reduction in tax collections of $63,000 per day for the first three days of a water outage. After three days total tax loss is expected to climb to $190,000 and then ultimately $11 million after 60 days.

Rate revenue losses unlike taxes, would not change per day depending on the duration of the outage. The City collects approximately $87,000 per day in variable water revenue and approximately $60,000 in variable sewer revenue. After three days the total lost rate revenue is estimated to be $440,000 and that value grows to $8.8 million after 60 days. The assumptions used to determine the lost rate revenue was that fixed charges would still be collected in full while variable water and sewer rates would not. The lost variable revenue is based on an annual average so for water the actual effect might be different depending on the time of year due to seasonal variations in water usage. Chart 6 shows the cumulative lost local taxes and water and sewer rate revenue broken out by type.

Chart 6



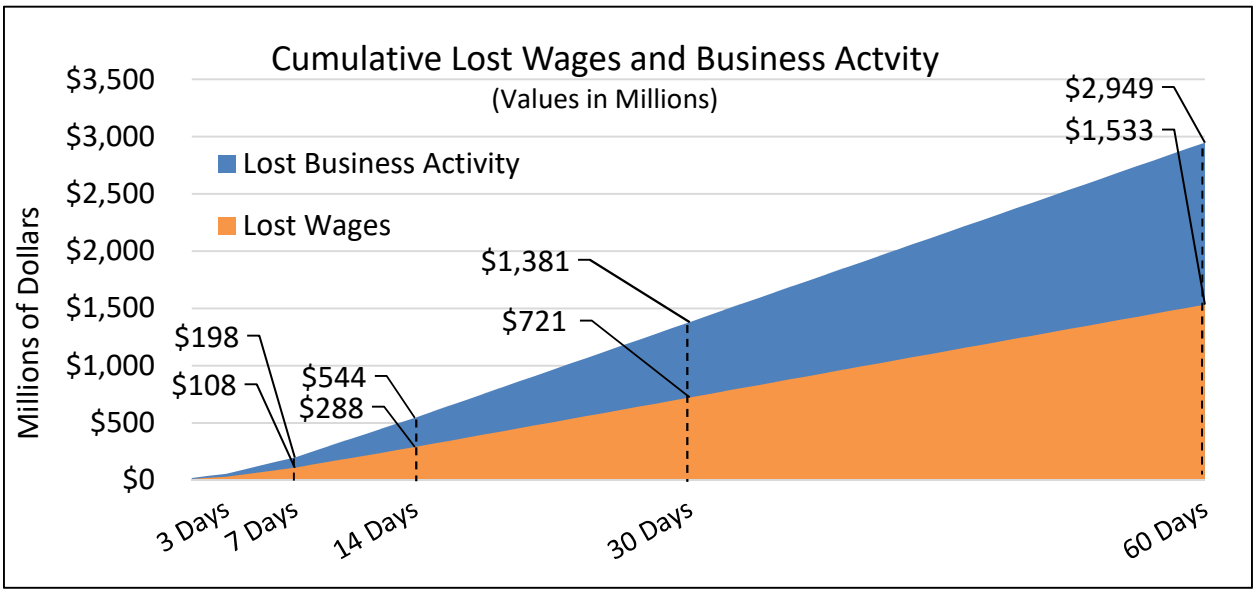
	W&S Revenue	Sales Tax	B&O Tax	Total
3 Days	$440	$110	$81	$630
7 Days	1,026	402	296	1,724
14 Days	2,053	1,182	814	4,049
30 Days	4,399	3,081	2,065	9,545
60 Days	8,798	6,642	4,411	19,850

1.8 Conclusions

The goal of the analysis was to provide an estimated impact on the local economy. This evaluation has analyzed three components of the local economy: businesses, wage earners and the City government. This study has concluded that a water outage would have very significant effect on all three components analyzed and the impacts become more severe depending on the duration of the outage.

The actual values this analysis contains are estimates of future events and, with any prediction of the future, there is a margin of error which will result in the effects being greater or less than estimated herein. The level of the margin of error is dependent on a number of known and unknown variable factors. Provided here are three measures of economic loss. The reason for including each of the three measures was to provide perspective from different points of view, companies within Bellevue, those who work in Bellevue and finally the City of Bellevue itself. Chart 7 provides both lost wages and business activity on a cumulative basis. City Taxes and Rate Losses were not provided on this chart because the size of the taxes and rates lost are much smaller in comparison to the lost wages and business activity.

Chart 7



Please note that the above chart is a side by side view of two independent measures of Bellevue's economy. It is important to understand these economic measures are two components of alternative methods to calculate GDP, where business activity is one part of the production approach, and wages is one part of the income approach for calculating GDP. It would be inaccurate to add lost business activity and lost wages together and would overstate the economic impact.

Water is an essential service for many aspects of daily life and is necessary for our wastewater system to function properly. Without water service the ability for people to live and work in Bellevue will be reduced to an increasing extent over time resulting in severe economic losses. Bellevue's economy is predominately retail and professional services type jobs concentrated in the downtown core. An important consideration when contemplating economic loss is the City's stated Council Vision Priorities. The Council Vision Priorities are a set of seven strategic target areas on which the City has decided to place emphasis for achievement. Among those priorities is economic development. With economic development as a priority of the City, it is important for the City to provide an environment where business can flourish.

For a business to flourish it is important for the City to provide reliable services such as water service. Further, Bellevue's utility department's website states, ***"Bellevue Utilities provides high-quality, essential services that you rely on every day - drinking water, wastewater, storm and surface water and solid waste. We take pride in making sure these services are dependable, a good value for the money and delivered with the customer in mind."*** Having dependability among their stated goals and objectives shows that the City is aware of how necessary water service is to all aspects of the City's well-being. This analysis provides additional supporting evidence of the importance of dependable water service.

Appendix E. Aquifer-Stream Delineation and Assessment

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TECHNICAL MEMORANDUM

DATE July 12, 2019 **Project No.** 1775477.3.1

TO Thomas Bell Games, PE; Laurie Fulton, PE
HDR Inc., Stantec

CC Doug Lane, PE, City of Bellevue

FROM Michael Klisch, LHG and
David Banton, LHG, RG

EMAIL mklisch@golder.com

CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN – AQUIFER–STREAM DELINEATION AND ASSESSMENT

EXECUTIVE SUMMARY

This technical memorandum presents an initial assessment of the potential effects on surface water flow (stream depletion) resulting from pumping of the City of Bellevue (City) emergency supply wells for up to 100 days in an emergency situation. The assessment focuses on the potential effects on flow in Kelsey Creek and a small tributary (Wilkins Creek) to Lake Sammamish. Analytical spreadsheet models were used to evaluate the potential effect on streamflow. Based on the conceptual hydrogeological model, Kelsey Creek is interpreted to be perched on a thin layer of till and the creek is not in hydraulic continuity with the aquifer where the Emergency wells are completed, whereas the tributary to Lake Sammamish is assumed to be in hydraulic continuity with the pumped aquifer.

The results of the initial assessment suggest that the stream depletion to Kelsey Creek could range from about 2 gallons per minute (gpm) to 66 gpm after 100 days of pumping from a single well depending on the pumping rate and the properties used in the model. For a 4-well wellfield pumping 2,600 gpm, the predicted depletion ranges from about 6 gpm to 290 gpm after 100 days of pumping. Low-flow streamflow in Kelsey Creek may be about 4 cubic feet per second (about 1,800 gpm). Therefore, the predicted depletion after 100 days of pumping is up to 3.7 percent of the low-flow streamflow for a single well and up to 16 percent for a wellfield.

For Wilkins Creek, the predicted stream depletion is greater than for Kelsey Creek because the stream is assumed to be in hydraulic continuity with the aquifer. For a single well pumping, the predicted depletion ranges from about 270 to 705 gpm; the predicted depletion for a wellfield pumping ranges from about 1,170 gpm to 2,500 gpm. The depletion predicted by the analytical model likely overestimates the actual depletion because of the limitations of the analytical model, which predicts depletion for an infinite stream length located perpendicular (north-south) about 4,700 feet east of the pumping well. In reality Wilkins Creek is about 2,200 feet in length.

Collection of additional data is recommended to refine the conceptual hydrogeological model of the aquifer and stream system and provide the information needed to develop increased confidence in the estimates of stream depletion. A numerical groundwater flow model would provide more reliable estimates of stream depletion, along with wellfield yield, and pumping interference effects if development of emergency wells proceeds.

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1.0 INTRODUCTION

This technical memorandum provides a general assessment of groundwater-surface water interaction and an assessment of the potential effects of pumping the City emergency water supply wells on surface water flow. The assessment is based on the hydrogeological setting, well construction and pumping rates, aquifer hydraulic properties, and the estimated characteristics of the stream (i.e. width, sediment thickness, and sediment hydraulic conductivity) and till overlying the aquifer (thickness, hydraulic conductivity, and specific yield). This assessment does not consider potential impacts of climate change on future stream flows or any potential changes in water quality that could result from changes in streamflow resulting from pumping.

The City water supply wells include former King County Water District (KCWD) 97 Wells No. 1, 3, 5, 6, and 7, KCWD 68 Wells No. 1, 2, and 3, and Washington Water Service Company (WWSC) Well No. 1 and Hill-Aire Well (Figure 1). The Water District's wells were absorbed by the City as the City grew (Golder 2018a). KCWD 97 Wells No. 3, 5, 6, and 7 were designated as emergency wells by the Washington State Department of Health in 2010. The remaining wells have been designated as reserve wells in the City's Water System Plan (City of Bellevue 2016). The assessment focuses on the effects of pumping the four KCWD 97 wells (the emergency wells).

1.1 Scope of Work and Data Sources

This memorandum was prepared to address part of Subtask 3.1 Existing Conditions in the scope of work for the City of Bellevue Emergency Water Supply Master Plan to assess groundwater-surface water interactions. The existing conditions at the City wells were documented in the Well Condition Assessment (Golder 2018a), and the Aquifer Characterization and Well Yield memorandum (Golder 2018b) documents hydrogeologic conditions and potential well yields.

This memorandum provides an evaluation of potential impacts to surface water (stream depletion) resulting from the pumping of KCWD 97 Wells No. 3, 5, 6, and 7 (or new, similarly located and constructed wells). The scenarios evaluated are similar to the scenarios evaluated for the well capacity evaluations presented in Golder 2018b:

- Evaluation of pumping a single well at rates ranging from 500 to 850 gallons per minute (gpm).
- Evaluation of pumping a 4-well wellfield with a combined pumping rate of 2,600 gpm.
- Evaluation of the sensitivity of the predicted results to changes in the input parameters.

Information on the City water supply wells is summarized on Table 1. Additional information on each well is included in Golder 2018a.

The assessment used analytical models to estimate stream depletion from pumping the emergency wells. The analytical models provide a scoping-level estimate of potential depletion because of the limited level of hydrogeological information currently available. The scoping-level assessment was performed to provide a general assessment of the range of stream depletion based on the limited hydrogeological information currently available, identify the parameters that most influence the results (a sensitivity analysis), and guide future data collection that is needed to refine the conceptual hydrogeological model. More detailed estimates of stream depletion would require further groundwater investigations including drilling and pumping tests, stream surveys

and gaging, and construction of a numerical groundwater flow model. The current scoping-level assessment was based on the following data sources:

- Information provided by the City including well logs, consultant reports, water quality reports, stream gage data and water district records.
- Water resource evaluations prepared by the Washington State Department of Ecology and the U.S. Geological Survey (USGS).
- Well logs on file with Washington State Department of Ecology.

Information on the City wells is presented in the City of Bellevue Water Rights Master Plan – Well Condition Assessment (Golder 2018a). The locations of the wells are shown on Figure 1, and information on the wells is summarized in Table 1. Information on the hydrogeologic conditions in the area of the City wells, including aquifer units and aquifer hydraulic properties, is presented in the City of Bellevue Water Rights Master Plan – Aquifer Characterization and Well Yield Assessment (Golder 2018b).

2.0 HYDROGEOLOGIC CONDITIONS

The hydrogeological conditions in the vicinity of KCWD 97 Wells No. 3, 5, 6, and 7 are described in Golder 2018b. KCWD 97 Wells 3, 5, 6, and 7 are located on the Interlake Drift Plain, a glacial till-mantled upland between Lake Sammamish and Lake Washington (Leisch et al. 1963). Relatively thin surficial deposits consist of unconsolidated advance glacial outwash, alluvium, and undifferentiated unconsolidated sediments and peat. These surficial deposits are underlain by till which is up to about 150 feet of till in the upland areas, and much thinner in the valley bottoms. A thick sequence of glacial and non-glacial unconsolidated sediments underlie the till, with a total thickness of over 1,000 feet.

The hydrogeologic units underlying the till include (Troost 2015):

- Vashon Advance Outwash and Unnamed Sand - sand, gravel, and silt up to 300 feet thick.
- C2 Confining Unit - silt and clay up to 200 feet thick where present.
- A3 Hydrogeologic Unit – sand, gravel, and silt up to 200 feet thick.
- A4 Hydrogeologic Unit – series of glacial and non-glacial deposits forming aquifers and confining units over 450 feet thick.

KCWD 97 Wells 3, 5, 6, and 7 are completed in the A3 hydrogeologic unit (Table 1). The following are the key hydrogeologic conditions in the vicinity of the KCWD 97 wells:

- The till thickness is about 60 to 80 feet, with the base of the till at an elevation of about 360 feet at Wells No. 5, 6, and 7 and about 200 feet above mean sea level (amsl) at Well No. 3 (NAVD 88). The till thickness decreases to the west to about 10 feet in the vicinity of Kelsey Creek.
- About 60 to 120 feet of advance outwash and silt and clay underlie the till. Some of the sand and gravel materials in the advance outwash are saturated.
- The C2 confining unit is not present in the vicinity of the wells based on cross-sections presented in Golder (2018b).

- The A3 aquifer is about 50 feet thick at KCWD 97 Wells No. 5, 6, and 7 and about 80 to 100 feet thick at Well No. 3. At Wells No. 5, 6, and 7, the top of the A3 aquifer is about 250 feet below ground surface, or an elevation of 200 feet (NAVD 88). At Well No.3, the top of the A3 aquifer is at an elevation of about 100 feet (NAVD 88).
- The A3 aquifer is confined and has a transmissivity of about 6,600 to 7,400 feet squared per day (ft^2/d) based on short-term testing of Wells No. 3, 5, 6, and 7.
- Groundwater in the A3 aquifer is recharged by downward leakage of precipitation through the overlying till and surficial units and seepage from lakes and groundwater in the recessional outwash overlying the till. Groundwater discharge from the A3 aquifer occurs where the aquifer is exposed on the margins of the drift plain along Lake Sammamish and Lake Washington, and along the incised valleys of Kelsey Creek and Richards Creek in the interior of the drift plain.

The KCWD 97 wells were capable of pumping about 500 to 850 gpm immediately after they were completed.

3.0 SURFACE WATER

Surface water bodies on the Interlake Drift Plain near the KCWD 97 wells are shown on Figure 2. This evaluation focuses on two areas of surface water. The first is Kelsey Creek, the largest surface water body on the Interlake Drift Plain. Kelsey Creek is located west of Wells No. 5, 6, and 7. The second is tributary flow to Lake Sammamish that originates from springs and small streams surfacing on the hillside on the west side of the lake. Lake Sammamish is located east of the KCWD 97 wells (Figure 2).

3.1 Kelsey Creek

The Kelsey Creek basin is about 10,870 acres. The mainstem of Kelsey Creek originates in the Phantom and Larsen Lake wetlands in the Lake Hills area and flows northwards before turning west and then south in the Overlake area. Kelsey Creek discharges to Mercer Slough and Lake Washington. Principal tributaries to Kelsey Creek include Richards Creek, Goff Creek, and Valley Creek (Figure 2).

A surficial geological map with surface water features is shown on Figure 3. The elevation of the headwaters of Kelsey Creek is about 270 feet amsl. The elevation of the base of the till is interpreted to be about 200 feet amsl near KCWD 97 Wells No. 1 and 3 and therefore till underlies the upper reaches of the creek. The stream channel is at an elevation of about 200 feet amsl (top of the A3 aquifer at Wells No. 5, 6, and 7) where the creek is immediately south of Bel-Red Road, between 140th Ave NE and 148th Ave NE, which is about 4,100 feet northwest of Wells No. 5, 6, and 7 (Figure 2). Below that point (i.e., downstream), the stream has eroded through the till and is in hydraulic continuity with the A3 aquifer.

The channel of Kelsey Creek occupies a former recessional outwash channel that is in part filled with peat and stream alluvial deposits. Review of well logs in along the north-flowing reach of the creek from the headwaters to about NE 12th Street indicate there is about 10 feet of till underlying recessional sand and gravel materials. As Kelsey Creek flows towards Mercer Slough, the elevation of the channel decreases and the geological materials underlying the till including the advance outwash and unnamed sand (A3 aquifer) are exposed along the stream channel. This occurs where the stream channel is just south of Bel-Red Road (Figure 3).

The City of Bellevue maintains a gaging station on Kelsey Creek at NE 8th Street (COB_KCF; Figure 2). Data are available from January 1, 2017 to April 9, 2019 (D. Lane, personal communication, April 9, 2019). The gage location includes a pressure transducer to measure stream stage that is tied into the City's telemetry system and

a staff plate gage. A reading of 1.0 feet at the pressure transducer corresponds to a head of 0.44 feet on the staff plate. The City developed a rating curve for the gage location using the staff plate gage measurements and flows measured in 1999 that ranged from about 4 to 107 cubic feet per second (cfs). The offset between the staff plate and pressure transducer and the rating curve were used to estimate the streamflow at the gage location.

Figure 4 shows the estimated streamflow at the COB_KCF gage. The estimated streamflow ranges from about 4 to 15 cfs during the low-flow portion of the year (late summer) representing baseflow conditions when streamflow is sustained by groundwater discharge to several hundred cfs during winter storm events. As reported by the City, the estimated streamflows at the COB_KCF gage may not reflect the actual streamflow in the creek because:

- The stream channel was affected by high flows in November 2001, altering the stream geometry downstream of the gage.
- The pressure transducer may not capture the low flows as the rating curve for the gage is based on the staff plate, and pressure transducer levels of less than 0.56 feet (i.e. below the base of the staff plate) cannot be used to calculate flows with the rating curve.
- The pressure transducer data were reported in 0.1-foot increments. At low flows, a change of 0.1-foot results in a potentially large change in the calculated streamflow.
- Flows reported for the USGS gage on Mercer Creek (see below) which is located downstream of the COB_KCF gage (and measures streamflow from a much larger basin than the Kelsey Creek gage) are lower than the calculated flows at the COB_KCF gage.

The USGS operates a gage on the lower reaches of Mercer Slough (USGS 12120000 Mercer Creek near Bellevue, Washington; Figure 2). The period of record for the USGS gage is October 1, 1987 through June 15, 2019 when the data were accessed. Figure 5 is a streamflow hydrograph for the gage from October 1, 2009 to June 15, 2019. Flow measured at this gage includes flow from both Kelsey Creek and Richards Creek and reports lower flows than for Kelsey Creek alone at the COB_KCF gage, suggesting the calculated flows at the COB_KCF gage are in error. The measured flows of about 4 to 6 cfs in the late summer and early fall reflect baseflow conditions when streamflow is sustained by groundwater discharge. Peak flows are in the range of 100 to 200 cfs during late fall and winter storm events (USGS 2019).

3.2 Lake Sammamish

Lake Sammamish is about 6,500 feet east of Wells No. 5, 6, and 7. The lake area is 4,897 acres and the elevation of the lake is approximately 26 to 28 feet amsl. Lake Sammamish is fed by streams that discharge to the lake such as Issaquah Creek and by groundwater discharge to springs and small streams where the A3 aquifer is exposed on hillsides along the western shore of the lake. One of these small streams, Wilkins Creek, is an approximate north-south trending stream (located about 4,700 feet east of Wells No. 5, 6, and 7 [Figure 3]). No streamflow data are available for Wilkins Creek. The outlet of Lake Sammamish is the Sammamish River.

4.0 GROUNDWATER-SURFACE WATER ASSESSMENT

Pumping can result in a decrease in streamflow (stream depletion) through interception of groundwater that would otherwise discharge to the creek, or to other surface water bodies such as lakes, or by inducing leakage from the stream or lake as the water table is lowered. The amount of stream depletion is dependent on the distance between the well and the surface water body, the hydrogeological conditions including whether the aquifer is

confined or unconfined, the aquifer hydraulic properties between the well and the water body, the thickness and hydraulic properties of the sediments and till or other materials overlying the aquifer, the hydraulic connection between the aquifer and water body, and the pumping rate and duration.

This scoping-level assessment of stream depletion using analytical models includes two components:

1) An estimate of stream depletion in Kelsey Creek where the creek is perched on till overlying the A3 aquifer. Stream depletion in this reach of the creek results from induced leakage from the stream through the underlying till.

2) An estimate of stream depletion (reduced flow) to springs and small tributaries that discharge to Lake Sammamish where the A3 aquifer is exposed on hillsides on the west side of the lake. Stream depletion in this area would occur during pumping by intercepting groundwater that would otherwise discharge to the springs or small tributaries flowing into Lake Sammamish.

The total estimated depletion on surface water bodies in the vicinity of the emergency wells was estimated by adding the two components.

4.1 Kelsey Creek Watershed

Kelsey Creek is the closest stream to KCWD 97 Wells No. 3, 5, 6, and 7 (about 4,000 feet west of Wells 5, 6, and 7; Figures 2 and 3). The key components of the conceptual model for Kelsey Creek in the vicinity of the KCWD 97 wells are shown on Figure 4 and described as follows:

- Kelsey Creek is located 4,000 feet to the west of the emergency wells.
- The A3 aquifer is overlain by till which has low hydraulic conductivity, and advance outwash. The till is thickest at the locations of KCWD 97 wells (about 80 to 100 feet thick), and the till thickness decreases to the west towards Kelsey Creek where it thins to about 10 feet.
- The A3 aquifer is confined and the groundwater level is above the top of the aquifer. There are unsaturated zones in the till materials overlying the aquifer.
- The stream is on the till surface (partially penetrates the till) until the stream channel reaches an elevation of about 200 feet amsl. As a result, Kelsey Creek is not in direct hydraulic continuity with the A3 Aquifer but is in continuity with groundwater in the till.
- The aquifer is recharged by downward leakage through the till and advance outwash.
- Streamflows are sustained by groundwater discharge in the late summer and fall (baseflow conditions).

The conceptual model for the hydrogeological system is shown on Figure 6.

Potential stream depletion in Kelsey Creek from pumping was estimated using the Hunt (2003) analytical method implemented in the Streamdepletionv3 (Environment Canterbury Regional Council 2003) software package implemented in a Microsoft Excel™ spreadsheet. The Hunt analytical method is a simplified representation of the hydrogeological system that is well-documented and is appropriate for a scoping-level assessment.

The conceptualization of the Hunt (2003) method and the assumptions used in the model are shown on Figure 7, and the inputs to the model are summarized on Table 2. The Hunt method requires inputs for the aquifer hydraulic properties and the thickness and hydraulic properties of the overlying till and streambed. The analyses

assumed the hydraulic conductivity of the till and streambed materials were identical, and the thickness of the till below the streambed was one foot less than the till thickness away from the streambed.

The inputs to the Hunt model used to evaluate depletion are shown on Figure 7 and summarized on Table 2. The pumping rates and aquifer hydraulic properties were the same as used to estimate drawdown and well yields in the well yield assessment evaluation (Golder 2018b). The pumping duration for the emergency wells was assumed to be a maximum of 100 days.

Key assumptions of the analytical model used for this analysis are:

- The stream at least partially penetrates the till and is in continuity with groundwater in the till.
- The stream is infinitely long.
- The aquifer is infinite, homogeneous, and isotropic.
- The till thickness is uniform across the aquifer.
- There is leakage from the overlying till to the aquifer during pumping.
- Precipitation recharge to the aquifer is not simulated.

4.1.1 Kelsey Creek Stream Depletion

This section describes the results of the evaluation for a single well pumping and for pumping of a 4-well wellfield. Pumping rates of 500 to 850 gpm (Scenarios 1a through 1d; Table 3) were used in the simulation of pumping from a single well. The pumping rate for a 4-well wellfield was 2,600 gpm. The model was run using a pumping duration of 100 days, and a recovery (no pumping) duration of 300 days to evaluate whether the maximum impact was reached after 100 days and to evaluate the rate of decrease in stream depletion once pumping ceased.

4.1.1.1 Single Well Simulation

4.1.1.1.1 Stream Depletion Effects

The results of the evaluation for pumping of a single well are shown on Figure 8, which shows the total stream depletion over the reach of Kelsey Creek modeled during 100 days of pumping (the assumed maximum emergency pumping duration). As shown on Figure 8, the predicted stream depletion after 100 days ranges from 8.7 gpm at a pumping rate of 500 gpm to 14.9 gpm at a pumping rate of 850 gpm from a single well. Table 3 summarizes the predicted stream depletion for 7, 30, and 100 days of pumping, respectively, similar to anticipated emergency pumping durations.

The maximum stream depletion is estimated to occur about 75 days after pumping stops and ranges from about 12.5 gpm (pumping at 500 gpm) to 21.2 gpm (pumping at 850 gpm) (Figure 8). After the maximum depletion in the creek occurs, the estimated residual depletion (stream depletion occurring after pumping ends) slowly decreases. After 300 days of no pumping, the estimated residual stream depletion ranges from 9.5 gpm (500 gpm pumping) to 16.2 gpm (850 gpm pumping).

4.1.1.1.2 Sensitivity Analysis

The sensitivity of the predicted stream depletion to a range of hydraulic properties and till properties was performed. The sensitivity scenarios for aquifer hydraulic properties are similar to those used to evaluate the

sensitivity of predicted drawdown in an individual well and wellfield described in Golder 2018b. The sensitivity scenarios are summarized on Table 2 and described below:

- Base case: Scenario 1b – pumping rate 600 gpm.
- Aquifer Transmissivity: low transmissivity of 5,000 ft^2/d (scenario 2) and high transmissivity of 7,400 ft^2/d (scenario 3).
- Aquifer Storativity: low storativity of 5 x 10^{-5} (scenario 4) and high storativity of 5 x 10^{-3} (scenario 5).
- Till Hydraulic Conductivity: high hydraulic conductivity of 2.83 ft/d (scenario 6) and low hydraulic conductivity of 2.83 x 10^{-2} ft/d (scenario 7).
- Till Thickness: thin till of 2 feet (scenario 8) and thick till of 15 feet (scenario 9).
- Till Specific Yield: low specific yield of 0.05 (scenario 10) and high specific yield of 0.15 (scenario 11).

The sensitivity analyses were performed using a pumping rate of 600 gpm for all scenarios.

Figure 9 shows the results of the sensitivity analysis for aquifer parameters (transmissivity and storativity). As shown on Figure 9, the estimated stream depletion after 100 days of pumping for the base case scenario (1b) is 10.5 gpm. Assuming the transmissivity is 5,000 ft^2/d, the estimated stream depletion decreases to 8.7 gpm, and assuming the transmissivity is 7,400 ft^2/d, the estimated stream depletion increases slightly to 11.1 gpm. Assuming the aquifer storativity is 5 x 10^{-5} (and the transmissivity is 6,600 ft^2/d), the estimated stream depletion increases slightly to 10.7 gpm. Assuming the aquifer storativity is 5 x 10^{-3}, the estimated stream depletion decreases to 9.9 gpm. The estimated stream depletion is only slightly sensitive to the aquifer hydraulic properties and is slightly more sensitive to the aquifer transmissivity than the storativity.

Figure 10 shows the results of the sensitivity analysis for the properties of the till for 100 days of pumping with the base case aquifer hydraulic parameters – transmissivity 6,600 ft^2/d and storativity 1 x 10^{-3}. Assuming the till hydraulic conductivity is 2.83 ft/d, the estimated stream depletion increases to 66 gpm. Assuming the till hydraulic conductivity is 2.83 x 10^{-2} ft/d, the estimated stream depletion decreases to 1.67 gpm. Assuming the till thickness is 2 feet, the estimated stream depletion increases to 62 gpm. Assuming the till is thicker (15 feet) the estimated stream depletion decreases to 7.1 gpm. Assuming the till specific yield is 0.05 feet, the estimated stream depletion increases to 25 gpm. Assuming the specific yield of the till is higher (0.15 feet) the estimated stream depletion decreases to 1.9 gpm. The estimated stream depletion is more sensitive to the till properties (thickness, hydraulic conductivity, and specific yield) than the aquifer hydraulic properties, and is most sensitive to the hydraulic conductivity (Table 3).

Assuming the low-flow streamflow in Kelsey Creek is about 4 cfs (1,800 gpm), the predicted depletion after 100 days of single-well pumping is up to 3.7 percent of the low-flow streamflow, depending on the pumping rate and properties used in the model.

4.1.2 Wellfield Simulation

Stream depletion in Kelsey Creek resulting from pumping of a 4-well wellfield pumping at 2,600 gpm (the wellfield scenario evaluated in Golder 2018b) was evaluated using the Hunt analytical model. Table 4 summarizes the wellfield scenario inputs and sensitivity analysis.

4.1.2.1.1 Stream Depletion Effects

The results of the wellfield simulation are summarized on Table 4 and shown on Figure 11. The estimated stream depletion is 45.6 gpm after 100 days of pumping. Similar to the single-well model, the wellfield model was run for 100 days of pumping, followed by 300 days of no pumping (recovery) to evaluate the magnitude and timing of maximum depletion, and the rate of decrease in stream depletion following pumping. The maximum estimated depletion of about 64.8 gpm occurred about 75 days after pumping stopped, and the estimated depletion slowly decreases to about 49.5 gpm 300 days after pumping stopped. (Figure 11).

4.1.2.1.2 Sensitivity Analysis

A sensitivity analysis was performed for the wellfield simulation by varying the same aquifer hydraulic properties and streambed parameters that were varied in the single well analysis. Figure 11 shows the sensitivity of the predicted stream depletion on the aquifer hydraulic properties (transmissivity and storativity) and Figure 12 shows the sensitivity of the estimated stream depletion to the till parameters (thickness, hydraulic conductivity, and specific yield). Similar to the single well scenarios, the estimated stream depletion is most sensitive to the till parameters and less sensitive to the aquifer hydraulic properties.

The predicted depletion after 100 days of wellfield pumping is up to 16 percent of the estimated low-flow streamflow in Kelsey Creek depending on the properties used in the model.

4.2 Lake Sammamish Tributaries

Groundwater from the A3 aquifer naturally discharges to springs and creeks on the western side of Lake Sammamish. A tributary to Lake Sammamish (Wilkins Creek) is located about 4,700 feet east of KCWD 97 Wells No. 3, 5, 6, and 7 (Figures 2 and 3). This tributary is incised into the glacial deposits and receives groundwater discharge from the A3 aquifer. Pumping from the emergency wells could reduce the groundwater flow to this tributary (or other tributaries and springs along the western shoreline of the lake) ultimately affecting Lake Sammamish. The approach was to develop a scoping-level estimate of this overall potential reduction in groundwater flow to Lake Sammamish by using a simplified analytical model.

The key components of the conceptual model to estimate the depletion on springs and Lake Sammamish tributaries in the vicinity of the KCWD 97 wells are shown on Figure 13 and described as follows:

- The A3 aquifer is overlain by a significant thickness of till which has low hydraulic conductivity, and advance outwash. On the hillslopes along Lake Sammamish and tributary headwaters, the A3 aquifer is exposed in the hillslopes.
- The A3 aquifer is confined, and the groundwater level is above the top of the aquifer but decreases below the top of the aquifer to the east. Where the aquifer is exposed in the hillslopes, groundwater discharge occurs. There are unsaturated zones in the till materials overlying the aquifer.
- The aquifer is recharged by downward leakage through the till and advance outwash.
- The stream partially penetrates the A3 aquifer and groundwater discharge to the tributary occurs as from seepage faces where the aquifer is exposed in the tributary.

The conceptual model for the hydrogeological system is shown on Figure 13.

The approach with this analysis was to assume that the potential depletion in groundwater flow toward Lake Sammamish from the pumping of the emergency wells could be estimated using an analytical stream depletion

model and assuming a north-south stream boundary equivalent at the distance of the unnamed tributary from the emergency wells. Potential stream depletion in the Lake Sammamish tributary from pumping was estimated using the Hunt (1999) analytical method implemented in the Streamdepletionv3 (Environment Canterbury Regional Council 2003) software package implemented in a Microsoft Excel™ spreadsheet. The Hunt analytical method is a simplified representation of the hydrogeological system.

The conceptualization of the Hunt (1999) method and the assumptions used in the model are shown on Figure 14, and the inputs to the model are summarized on Table 2. The Hunt method requires inputs for the aquifer hydraulic properties and the thickness and hydraulic properties of the streambed.

The inputs to the Hunt model used to evaluate depletion are shown on Figure 14 and summarized on Table 2. The pumping rates and aquifer hydraulic properties were the same as used to estimate drawdown and well yields in the well yield assessment evaluation (Golder 2018b). The pumping duration for the emergency wells was assumed to be a maximum of 100 days.

Key assumptions of the analytical model used for this analysis are:

- Discharge from the A3 aquifer to springs and small tributaries feeding Wilkins Creek is represented by an infinitely long north-south stream located 4,700 feet to the east of the emergency wells.
- The springs and small tributaries are represented by a stream that at least partially penetrates the aquifer and is in continuity with groundwater in the aquifer.
- The aquifer is infinite, homogeneous, and isotropic.
- Precipitation recharge or leakage from overlying hydrogeological units to the aquifer are not simulated.

4.2.1 Lake Sammamish Tributaries (Wilkins Creek) Depletion

This section describes the results of the evaluation for a single well pumping and for pumping of a 4-well wellfield. Pumping rates of 500 to 850 gpm (Scenarios 1a through 1d; Table 5) were used in the simulation of pumping from a single well. The pumping rate for a 4-well wellfield was 2,600 gpm.

4.2.1.1 Single Well Simulation

4.2.1.1.1 Stream Depletion Effects

The results of the evaluation for pumping of a single well are shown on Figure 15, which shows the estimated total stream depletion over the tributary reach modeled during 100 days of pumping (the assumed maximum emergency pumping duration). As shown on Figure 13, the estimated stream depletion after 100 days ranges from 405 gpm at a pumping rate of 500 gpm to 705 gpm at a pumping rate of 850 gpm from a single well. Table 5 summarizes the estimated stream depletion for 7, 30, and 100 days of pumping, respectively, similar to anticipated emergency pumping durations.

The model was run for 100 days of pumping followed by 300 days of recovery to evaluate the magnitude and timing of the maximum impact and the rate of depletion following the end of pumping. After 100 days of pumping, the estimated stream depletion ranged from 415 gpm (500 gpm pumping) to 705 gpm (850 gpm pumping) as shown on Figure 15. The maximum impact was reached immediately before pumping stops. Once pumping stops, the estimated depletion decreases, ranging from 6.6 gpm (500 gpm pumping) to 11.1 gpm (850 gpm) after 300 days of recovery.

4.2.1.1.2 Sensitivity Analysis

The sensitivity of the predicted stream depletion to a range of hydraulic properties and streambed properties was performed. The sensitivity scenarios for aquifer hydraulic properties are similar to those used to evaluate the sensitivity of predicted drawdown in an individual well and wellfield described in Golder 2018b and for the Kelsey Creek scenarios. The sensitivity scenarios are summarized on Table 2 and described below:

- Base case: Scenario 1b – pumping rate 600 gpm.
- Aquifer Transmissivity: low transmissivity of 5,000 ft^2/d (scenario 2) and high transmissivity of 7,400 ft^2/d (scenario 3).
- Aquifer Storativity: low storativity of 5 x 10^{-5} (scenario 4) and high storativity of 5 x 10^{-3} (scenario 5).
- Streambed Hydraulic Conductivity: high hydraulic conductivity of 2.83 ft/d (scenario 6) and low hydraulic conductivity of 2.83 x 10^{-2} ft/d (scenario 7).
- Streambed Thickness: thin streambed of 0.5 feet (scenario 8) and thick streambed of 3 feet (scenario 9).

The sensitivity analyses were performed using a pumping rate of 600 gpm for all scenarios.

Figure 16 shows the results of the sensitivity analysis for aquifer parameters (transmissivity and storativity). As shown on Figure 16, the estimated stream depletion after 100 days of pumping for the base case scenario (1b) is 498 gpm. Assuming the transmissivity is 5,000 ft^2/d, the estimated stream depletion decreases to 494 gpm, and assuming the transmissivity is 7,400 ft^2/d, the predicted stream depletion increases slightly to 499 gpm. Assuming the aquifer storativity is 5 x 10^{-5}, (and the transmissivity is 6,600 ft^2/d) the estimated stream depletion increases slightly to 576 gpm. Assuming the aquifer storativity is 5 x 10^{-3}, the estimated stream depletion decreases to 382 gpm. The estimated stream depletion is only slightly sensitive to the aquifer transmissivity, and is moderately sensitive to the aquifer storativity.

Figure 17 shows the results of the sensitivity analysis for the properties of the streambed for 100 days of pumping with the base case aquifer hydraulic parameters – transmissivity 6,600 ft^2/d and storativity 1 x 10^{-3}). Assuming the streambed hydraulic conductivity is 2.83 ft/d, the estimated stream depletion increases to 533 gpm. Assuming the streambed hydraulic conductivity is 2.83 x 10^{-2} ft/d, the estimated stream depletion decreases to 269 gpm. Assuming the streambed thickness is 0.5 feet, the estimated stream depletion increases to 517 gpm. Assuming the streambed is thicker (3 feet) the estimated stream depletion decreases to 426 gpm. The estimated stream depletion is more sensitive to the streambed properties (thickness and hydraulic conductivity) than the aquifer hydraulic properties, and is most sensitive to the streambed hydraulic conductivity (Table 5).

4.2.2 Wellfield Simulation

Stream depletion in springs and small tributaries flowing to Lake Sammamish resulting from pumping of a 4-well wellfield pumping at 2,600 gpm (the wellfield scenario evaluated in Golder 2018b) was evaluated using the analytical model. Table 6 summarizes the wellfield scenario inputs and sensitivity analysis.

4.2.2.1.1 Stream Depletion Effects

The results of the wellfield simulation are summarized on Table 6 and shown on Figure 18. The estimated stream depletion is 2,159 gpm after 100 days of pumping. Similar to the single-well model, the wellfield model was run for 100 days of pumping followed by 300 days of recovery to evaluate the magnitude and timing of maximum depletion and rate of depletion after pumping stopped. The estimated depletion had not stabilized after 100 days

of pumping. The predicted depletion decreased after pumping stopped. After 300 days of recovery, the predicted depletion was 34 gpm (Figure 18).

4.2.2.1.2 Sensitivity Analysis

A sensitivity analysis was performed for the wellfield simulation by varying the same aquifer hydraulic properties and streambed parameters that were varied in the single well analysis. Figure 18 shows the sensitivity of the estimated stream depletion on the aquifer hydraulic properties (transmissivity and storativity) and Figure 19 shows the sensitivity of the estimated stream depletion to the streambed parameters (thickness and hydraulic conductivity). Similar to the single well scenarios, the estimated stream depletion is most sensitive to the streambed parameters and less sensitive to the aquifer hydraulic properties.

4.3 Total Pumping Effects on Surface Water

Figure 20 shows the estimated total stream depletion in Kelsey Creek and the tributary to Lake Sammamish (Wilkins Creek) for the single-well pumping scenarios (500 gpm to 850 gpm). After 100 days of pumping, the total predicted depletion ranges from 423 gpm (500 gpm) to 720 gpm (850 gpm; Table 7). The predicted depletion to Wilkins Creek is about 98 percent of the total predicted stream depletion. The estimated depletion decreases when pumping stops. After 100 days of recovery, the estimated residual depletion ranges from 36.7 gpm (500 gpm pumping) to 62.4 gpm for pumping at 850 gpm.

4.4 Summary

The analytical model predicts a range of stream depletions in Kelsey Creek and Wilkins Creek depending on the estimated aquifer hydraulic properties and the properties of the overlying till and streambed (thickness, hydraulic conductivity, and specific yield).

The results of the depletion analyses can be summarized as follows:

- The rate of depletion increases with increasing pumping rate and pumping duration, and decreasing distance to surface water bodies.
- The predicted rate of depletion in Kelsey Creek is relatively small and is most sensitive to the properties of the till overlying the aquifer (thickness, hydraulic conductivity, and specific yield). The proportion of depletion compared to baseflow in Kelsey Creek is uncertain because of the limited confidence in the streamflow measurements.
- The estimated rate of depletion in Wilkins Creek (springs and small tributaries to Lake Sammamish) is the greatest component of the total depletion resulting from pumping (about 98 percent) and is most sensitive to the hydraulic conductivity of the streambed sediments.
- Greater depletion occurs for a stream that partially penetrates and is in hydraulic continuity with the A3 aquifer than for a stream that partially penetrates a till layer overlying the aquifer and is not in direct hydraulic continuity with the aquifer.

4.4.1 Conclusions

The analytical model provides a preliminary assessment of the potential impacts to surface water from pumping because the analytical model incorporates many simplifying (and potentially conservative) assumptions regarding a relatively complex groundwater-surface water system. For example, in the case of depletion on Wilkins Creek, the analytical model assumes groundwater discharge from the aquifer is to an infinitely long stream that partially

penetrates the aquifer. Groundwater discharge from the A3 aquifer to springs and small tributaries appears to occur to small stream channels and springs rather than a long, continuous stream boundary. In addition, the analytical model does not account for leakage from hydrogeological units overlying the A3 aquifer during pumping.

4.4.2 Next Steps

Assuming the City proceeds with the development of emergency wells, a numerical groundwater flow model should be prepared representing the geological, hydrogeological and hydrological conditions to provide more reliable estimates of wellfield yield, pumping interference effects and stream depletion. Additional data collection is recommended to develop the conceptual framework for the numerical groundwater flow model including:

- Further geological and hydrogeological characterization of the emergency wells and surrounding area.
- Completion of longer pumping tests (3 to 7 days) and stream gaging to evaluate the aquifer hydraulic properties and boundaries and the response in the streams to extended pumping.
- Completion of stream surveys to characterize the physical hydrologic conditions in Kelsey Creek and Wilkins Creek.
- Develop an updated rating curve for the COB_KCF gage.
- Groundwater level and streamflow monitoring to characterize seasonal changes in the groundwater and surface water systems.

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Figure 20: Aquifer-Stream Evaluation Combined Stream Depletion Analysis Single Well 100 Days Pumping

5.0 REFERENCES

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Tables

Table 1: City of Bellevue Water Supply Well Information

Well Number	Location	Date Drilled	Depth Drilled (feet bgs)	Completion Interval (feet bgs)	Aquifer interval (feet bgs)	Completion Interval Geology	Aquifer Unit[a]
KCWD 97 Well No. 1	Samena	1955	160	130 to 160	135-154	Sand and Gravel	A3
KCWD 97 Well No. 3		1956	229	195 to 220	120-223	Coarse to Fine Sand	A3
KCWD 97 Well No. 5	Crossroads	1959	293	263 to 293	252 to 297	Coarse Sand and Gravel	A3
KCWD 97 Well No. 6		1959	302	282 to 302	No Log	Coarse Sand and Gravel	A3
KCWD 97 Well No. 7		1963	300	275 to 299	No Log	Coarse Sand and Gravel	A3
KCWD 68 Well No. 1	KCWD 68	1946	1,125	247 to 370	247-350	Sand, Gravel, Clay	A3/A4?
				530 to 621	550-621	Sand, Gravel, Clay	A4
				974 to 1,115	994-1,115	Sand, Clay	A4
KCWD 68 Well No. 2		1947	1,056	270 to 475	170-463	Sand, Gravel, Clay	A3/A4?
KCWD 68 Well No. 3		1947	244	60 to 244	50-228	Sand and Gravel	Qva/A3
WWSC Well No. 1	WWSC	1954	105	93 to 103	79 -102	Sand	Qva
WWSC Hill-Aire		Unknown	183	183 to 193?	155-183	Sand and Gravel	Qva

Notes:
bgs - below ground surface
gpm - gallons per minute
See Figure 1 for well locations
a. Troost 2015

Table 2: Analytical Model Inputs

Hunt 2003 Model				
		Sensitivity Analysis		
Model Input	**Input Value**	**Low**	**High**	**Source**
Aquifer Transmissivity (ft^2/d)	6,600	5,000	7,400	Aquifer Testing Wells No. 3, 5, 6, and 7 (Golder 2018a, 2018b)
Aquifer Storativity (-)	1.00E-03	5.00E-05	5.00E-03	Estimate (Golder 2018b)
Till Specific Yield (-)	0.1	0.05	0.15	Estimate
Till Hydraulic Conductivity (ft/d)	0.283	2.83E-02	2.83	Estimate - Freeze and Cherry (1979) for silty sand
Till Thickness (feet)	10	2	15	Ecology well logs
Stream Width (feet)	15	na	na	Estimate
Stream Depth (feet)	1	na	na	Estimate

Hunt 1999 Model				
		Sensitivity Analysis		
Model Input	**Input Value**	**Low**	**High**	**Source**
Aquifer Transmissivity (ft^2/d)	6,600	5,000	7,400	Aquifer Testing Wells No. 3, 5, 6, and 7 (Golder 2018a, 2018b)
Aquifer Storativity (-)	1.00E-03	5.00E-05	5.00E-03	Estimate (Golder 2018b)
Stream Width (feet)	15	na	na	Estimate
Stream Depth (feet)	1	0.5	3	Estimate
Stream Hydraulic Conductivity	0.283	2.83E-02	2.83	Estimate - Freeze and Cherry (1979) for silty sand

Table 3: Single Well Analysis Scenarios and Results - Kelsey Creek

Scenario	Analysis	Sensitivity Analysis Variable	Pumping Rate (gpm)	Aquifer Transmissivity (ft^2/d)	Aquifer Storativity (-)	Till Specific Yield (-)	Till Hydraulic Conductivity (ft/d)	Till Thickness (feet)	Stream Width (feet)	Stream Depth (feet)	Stream Depletion after 7 Days of Pumping (gpm)	Stream Depletion after 30 Days of Pumping (gpm)	Stream Depletion after 100 Days of Pumping (gpm)	Residual Stream Depletion after 300 days of Recovery (gpm)
1a	Single Well		500	6,600	1.00E-03	0.1	0.283	10	15	1	0.06	1.0	8.7	9.5
1b	Single Well	Base Case	600	6,600	1.00E-03	0.1	0.283	10	15	1	0.07	1.2	10.5	11.4
1c	Single Well		700	6,600	1.00E-03	0.1	0.283	10	15	1	0.08	1.5	12.2	13.3
1d	Single Well		850	6,600	1.00E-03	0.1	0.283	10	15	1	0.10	1.8	14.9	16.2
2	Sensitivity	Low T	600	5,000	1.00E-03	0.1	0.283	10	15	1	0.03	0.78	8.7	12.2
3	Sensitivity	High T	600	7,400	1.00E-03	0.1	0.283	10	15	1	0.09	1.5	11.1	11.0
4	Sensitivity	Low S	600	6,600	5.00E-05	0.1	0.283	10	15	1	0.08	1.3	10.7	11.5
5	Sensitivity	High S	600	6,600	5.00E-03	0.1	0.283	10	15	1	0.05	1.1	9.9	11.2
6	Sensitivity	High Till K	600	6,600	1.00E-03	0.1	2.83	10	15	1	0.03	5.9	66	37
7	Sensitivity	Low Till K	600	6,600	1.00E-03	0.1	2.83E-02	10	15	1	0.31	0.61	1.6	1.3
8	Sensitivity	Low Till thickness	600	6,600	1.00E-03	0.1	0.283	2	15	1	0.05	5.8	62	36
9	Sensitivity	High Till thickness	600	6,600	1.00E-03	0.1	0.283	15	15	1	0.09	1.0	7.1	7.8
10	Sensitivity	Low Till Sy	600	6,600	1.00E-03	0.05	0.283	10	15	1	0.25	4.6	25	15.9
11	Sensitivity	High Till Sy	600	6,600	1.00E-03	0.15	0.283	10	15	1	0.11	0.40	1.9	2.5

Note:
Streambed hydraulic conductivity assumed to be equal to till hydraulic conductivity.

Table 4: Wellfield Analysis Scenarios and Results - Kelsey Creek

Scenario	Analysis	Sensitivity Analysis Variable	Pumping Rate (gpm)	Aquifer Transmissivity (ft^2/d)	Aquifer Storativity (-)	Aquifer Thickness (feet)	Till Specific Yield (-)	Till Hydraulic Conductivity (ft/d)	Till Thickness (feet)	Stream Width (feet)	Stream Depth (feet)	Stream Depletion after 7 Days of Pumping (gpm)	Stream Depletion after 30 Days of Pumping (gpm)	Stream Depletion after 100 Days of Pumping (gpm)	Residual Stream Depletion after 300 Days of Recovery (gpm)
1	Wellfield	Base Case	2,600	6,600	1.00E-03	50	0.1	0.283	10	15	1	0.31	5.40	45.6	49.5
2	Sensitivity	Low T	2,600	5,000	1.00E-03	50	0.1	0.283	10	15	1	0.14	3.36	37.9	52.8
3	Sensitivity	High T	2,600	7,400	1.00E-03	50	0.1	0.283	10	15	1	0.41	6.37	48.3	47.9
4	Sensitivity	Low S	2,600	6,600	5.00E-05	50	0.1	0.283	10	15	1	0.33	5.56	46.2	49.7
5	Sensitivity	High S	2,600	6,600	5.00E-03	50	0.1	0.283	10	15	1	0.24	4.81	42.9	48.4
6	Sensitivity	High Till K	2,600	6,600	1.00E-03	50	0.1	2.83	10	15	1	0.13	25.7	287	160
7	Sensitivity	Low Till K	2,600	6,600	1.00E-03	50	0.1	2.83E-02	10	15	1	1.35	2.66	7.10	5.64
8	Sensitivity	Low Till thickness	2,600	6,600	1.00E-03	50	0.1	0.283	2	15	1	0.20	25.3	270	158
9	Sensitivity	High Till thickness	2,600	6,600	1.00E-03	50	0.1	0.283	15	15	1	0.40	4.30	30.7	33.9
10	Sensitivity	Low Till Sy	2,600	6,600	1.00E-03	50	0.05	0.283	10	15	1	1.09	19.8	108	68.8
11	Sensitivity	High Till Sy	2,600	6,600	1.00E-03	50	0.15	0.283	10	15	1	0.16	2.38	24.4	38.6

Note:
Streambed hydraulic conductivity assumed to be equal to till hydraulic conductivity.

Table 5: Single Well Analysis Scenarios and Results - Lake Sammamish Tributaries

Scenario	Analysis	Sensitivity Analysis Variable	Pumping Rate (gpm)	Aquifer Transmissivity (ft^2/d)	Aquifer Storativity (-)	Streambed Hydraulic Conductivity (ft/d)	Streambed Thickness (feet)	Stream Width (feet)	Stream Depth (feet)	Stream Depletion after 7 Days of Pumping (gpm)	Stream Depletion after 30 Days of Pumping (gpm)	Stream Depletion after 100 Days of Pumping (gpm)	Residual Stream Depletion after 300 Days of Recovery (gpm)
1a	Single Well		500	6,600	1.00E-03	0.283	1	15	1	219	349	415	6.6
1b	Single Well	Base Case	600	6,600	1.00E-03	0.283	1	15	1	263	419	498	7.9
1c	Single Well		700	6,600	1.00E-03	0.283	1	15	1	307	488	581	9.2
1d	Single Well		850	6,600	1.00E-03	0.283	1	15	1	373	593	705	11.1
2	Sensitivity	Low T	600	5,000	1.00E-03	0.283	1	15	1	250	411	494	8.2
3	Sensitivity	High T	600	7,400	1.00E-03	0.283	1	15	1	513	421	499	7.8
4	Sensitivity	Low S	600	6,600	5.00E-05	0.283	1	15	1	513	557	576	1.8
5	Sensitivity	High S	600	6,600	5.00E-03	0.283	1	15	1	70	244	382	17
6	Sensitivity	High Streambed K	600	6,600	1.00E-03	2.83	1	15	1	361	480	533	5.1
7	Sensitivity	Low Streambed K	600	6,600	1.00E-03	2.83E-02	1	15	1	64	161	269	24
8	Sensitivity	Low streambed thickness	600	6,600	1.00E-03	0.283	0.5	15	1	312	452	517	6.3
9	Sensitivity	High streambed thickness	600	6,600	1.00E-03	0.283	3	15	1	157	315	426	13

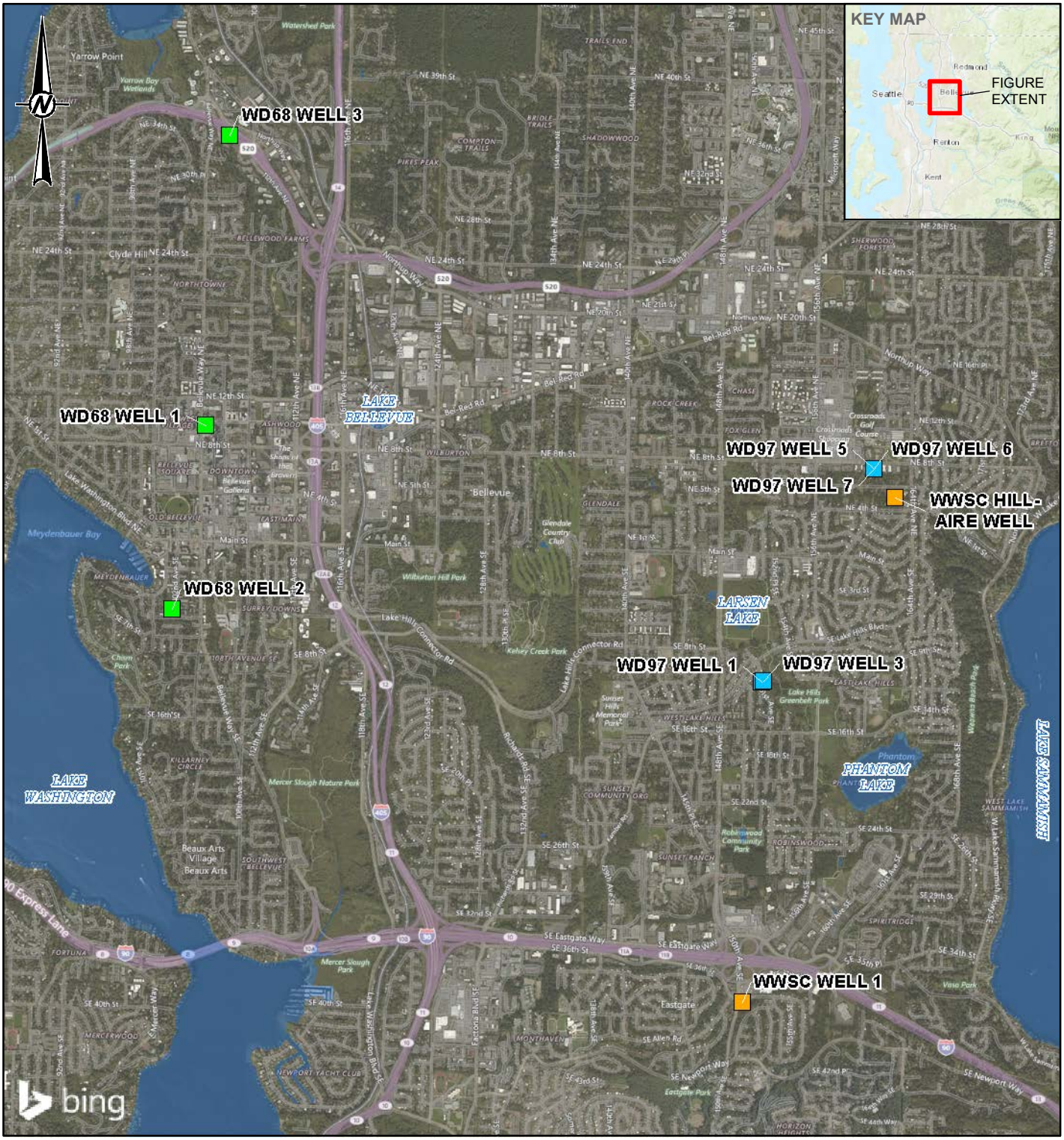
Table 6: Wellfield Analysis Scenarios and Results - Lake Sammamish Tributaries

Scenario	Analysis	Sensitivity Analysis Variable	Pumping Rate (gpm)	Aquifer Transmissivity (ft^2/d)	Aquifer Storativity (-)	Aquifer Thickness (feet)	Streambed Hydraulic Conductivity (ft/d)	Streambed Thickness (feet)	Stream Width (feet)	Stream Depth (feet)	Well Radius (ft)	Stream Depletion after 7 Days of Pumping (gpm)	Stream Depletion after 30 Days of Pumping (gpm)	Stream Depletion after 100 Days of Pumping (gpm)	Residual Stream Depletion after 300 Days of recovery (gpm)
1	Wellfield	Base Case	2,600	6,600	1.00E-03	50	0.283	1	15	1	1	1,143	1,816	2,159	34.1
2	Sensitivity	Low T	2,600	5,000	1.00E-03	50	0.283	1	15	1	1	1,084	1,785	2,142	35.4
3	Sensitivity	High T	2,600	7,400	1.00E-03	50	0.283	1	15	1	1	1,162	1,825	2,163	33.8
4	Sensitivity	Low S	2,600	6,600	5.00E-05	50	0.283	1	15	1	1	2,226	2,418	2,500	7.7
5	Sensitivity	High S	2,600	6,600	5.00E-03	50	0.283	1	15	1	1	306	1,058	1,657	73.2
6	Sensitivity	High Streambed K	2,600	6,600	1.00E-03	50	2.83	1	15	1	1	1,566	2,083	2,314	22.1
7	Sensitivity	Low Streambed K	2,600	6,600	1.00E-03	50	2.83E-02	1	15	1	1	277	700	1,168	104
8	Sensitivity	Low streambed thickness	2,600	6,600	1.00E-03	50	0.283	0.5	15	1	1	1,354	1,960	2,244	27.5
9	Sensitivity	High streambed thickness	2,600	6,600	1.00E-03	50	0.283	3	15	1	1	683	1,368	1,847	58.4

Table 7: Total Predicted Stream Depletion - Kelsey Creek and Lake Sammamish Tributaries

			Kelsey Creek				Lake Sammamish Tributary				Total			
Scenario	Analysis	Pumping Rate (gpm)	Stream Depletion after 7 Days of Pumping (gpm)	Stream Depletion after 30 Days of Pumping (gpm)	Stream Depletion after 100 Days of Pumping (gpm)	Residual Stream Depletion after 300 days of Recovery (gpm)	Stream Depletion after 7 Days of Pumping (gpm)	Stream Depletion after 30 Days of Pumping (gpm)	Stream Depletion after 100 Days of Pumping (gpm)	Residual Stream Depletion after 300 days of Recovery (gpm)	Stream Depletion after 7 Days of Pumping (gpm)	Stream Depletion after 30 Days of Pumping (gpm)	Stream Depletion after 100 Days of Pumping (gpm)	Residual Stream Depletion after 300 days of Recovery (gpm)
1a	Single Well	500	0.06	1.0	8.7	9.5	219	349	415	6.6	220	350	423	16.1
1b	Single Well	600	0.07	1.2	10.5	11.4	263	419	498	7.9	263	420	508	19.3
1c	Single Well	700	0.08	1.5	12.2	13.3	307	488	581	9.2	307	490	593	22.5
1d	Single Well	850	0.10	1.8	14.9	16.2	373	593	705	11.1	373	595	720	27.3

Figures



LEGEND

- KING COUNTY WATER DISTRICT 68 WELL
- KING COUNTY WATER DISTRICT 97 WELL
- WASHINGTON WATER SERVICE COMPANY WELL
- LAKE

0 2,000 4,000 8,000

Feet

REFERENCE(S)

1. TROOST GEOSCIENCES (WELL LOCATIONS, CITY LIMITS)
2. COORDINATE SYSTEM: NAD 1983 STATE PLANE WASHINGTON NORTH (FT)
3. SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, DELORME, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), SWISSTOPO, MAPMYINDIA, © OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY

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PROJECT
CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN

TITLE
CITY OF BELLEVUE WATER SUPPLY WELL LOCATION MAP

CONSULTANT
GOLDER

YYYY-MM-DD	2018-08-28
DESIGNED	BVJ
PREPARED	HJ
REVIEWED	MK
APPROVED	MK

PROJECT NO.	PHASE	REV.	FIGURE
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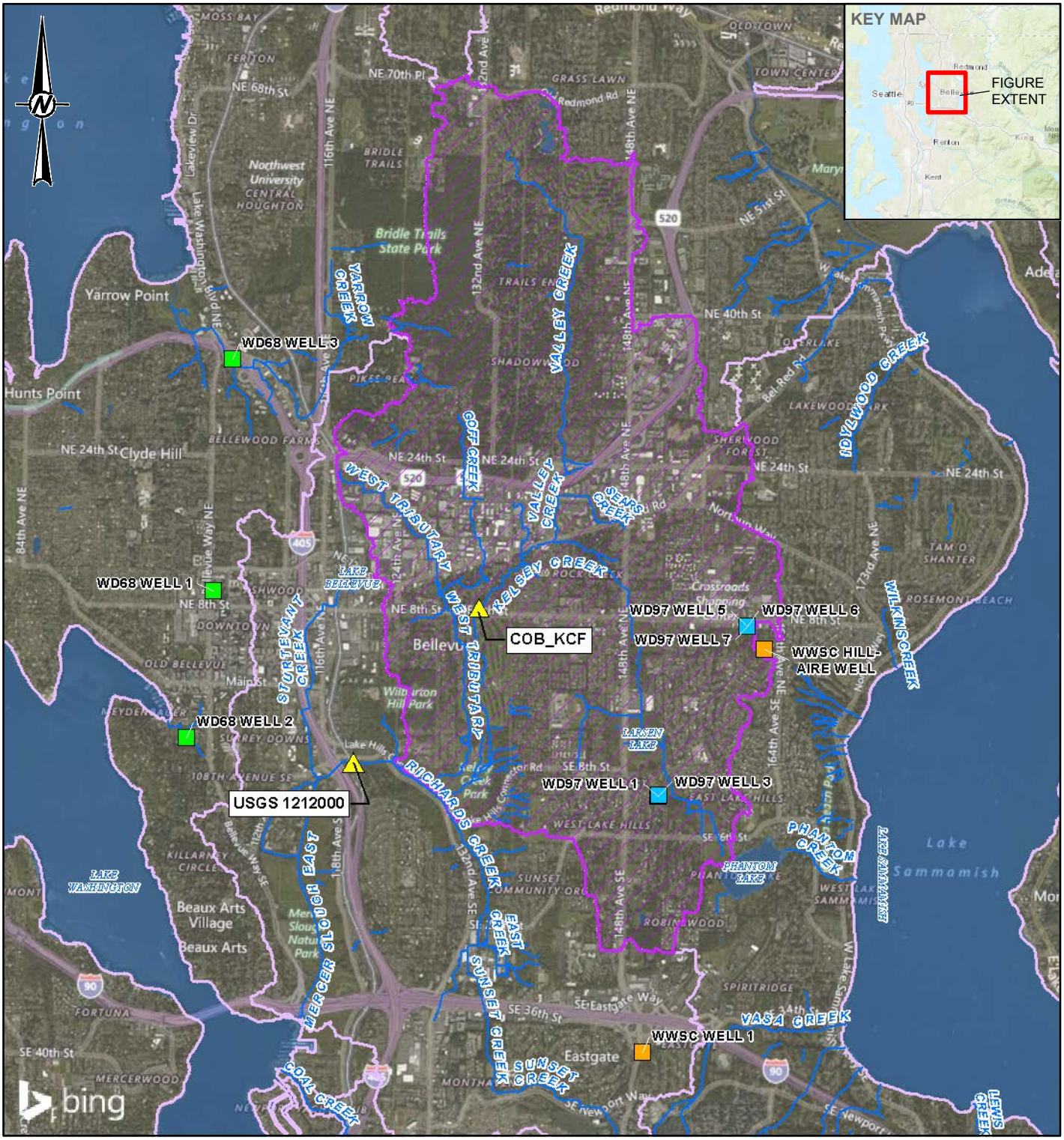

LEGEND

- KING COUNTY WATER DISTRICT 68 WELL
- KING COUNTY WATER DISTRICT 97 WELL
- WASHINGTON WATER SERVICE COMPANY WELL
- STREAM GAGE AND DESIGNATION
- STREAM
- LAKE
- KELSEY CREEK DRAINAGE BASIN
- DRAINAGE BASIN

2,000 4,000 8,000 Feet

REFERENCE(S)

1. TROOST GEOSCIENCES (WELL LOCATIONS, CITY LIMITS)
2. KING COUNTY (DRAINAGE BASINS)
3. COORDINATE SYSTEM: NAD 1983 STATE PLANE WASHINGTON NORTH (FT)
4. SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, DELORME, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), SWISSTOPO, MAPMYINDIA, © OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY

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PROJECT
CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN

TITLE
SURFACE WATER FEATURES

CONSULTANT
GOLDER

YYYY-MM-DD	2019-07-12
DESIGNED	BVJ
PREPARED	HJ
REVIEWED	MK
APPROVED	MK

PROJECT NO.	PHASE	REV.	FIGURE
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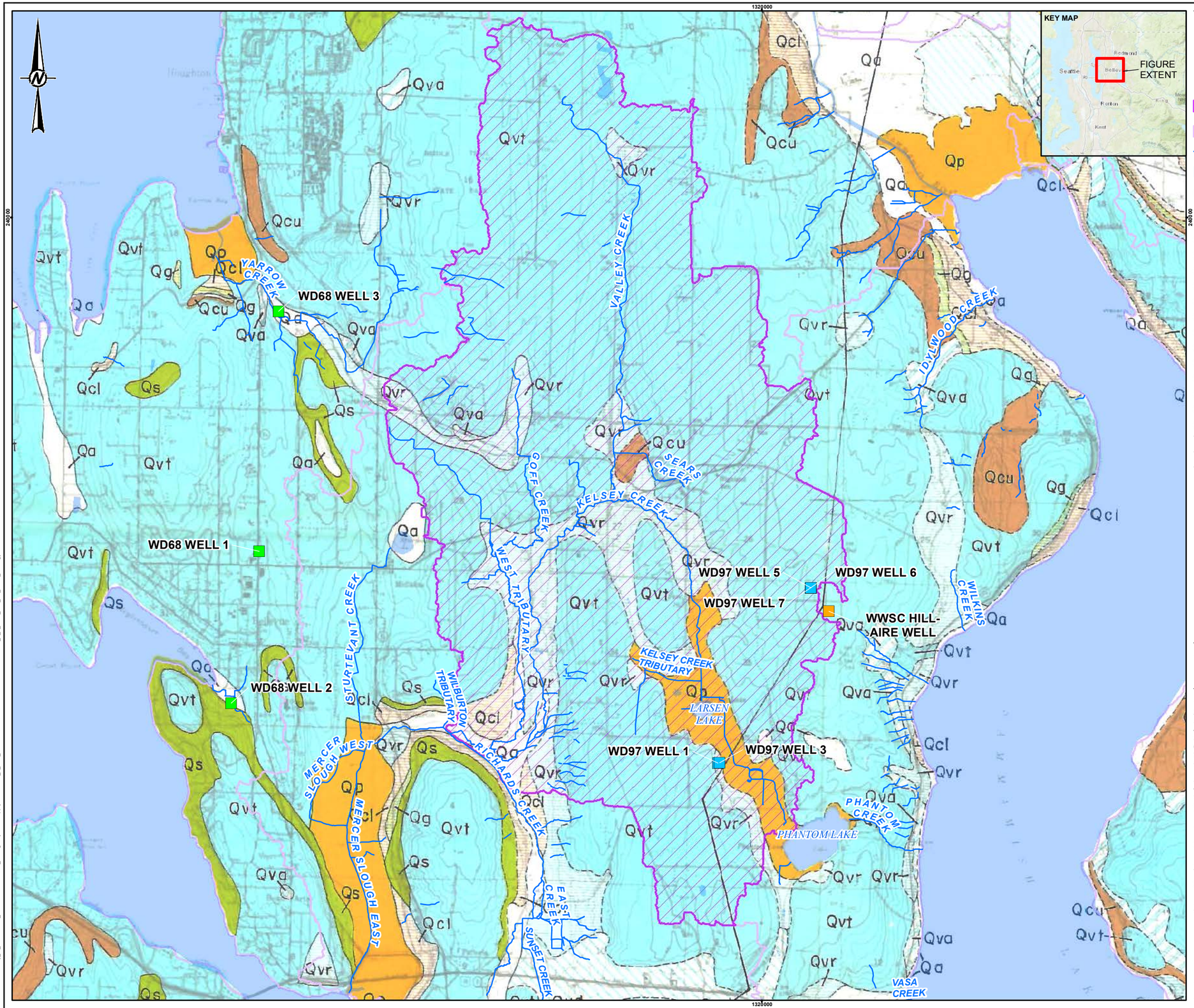

LEGEND

- KING COUNTY WATER DISTRICT 68 WELL
- KING COUNTY WATER DISTRICT 97 WELL
- WASHINGTON WATER SERVICE COMPANY WELL
- KELSEY CREEK DRAINAGE BASIN
- DRAINAGE BASIN
- STREAM
- LAKE

GEOLOGIC UNIT DESCRIPTIONS:

ma – MODIFIED LAND AND FILL
Qa – UNDIFFERENTIATED QUATERNARY SEDIMENTARY DEPOSITS
Qp – PEAT
Qvr – VASHON RECESSIONAL OUTWASH
Qvd - VASHON RECESSIONAL OUTWASH DELTA
Qvt – VASHON TILL
Qva – VASHON ADVANCE OUTWASH
Qs – UNNAMED SAND
Qcu – UPPER CLAY UNIT
Qg – UNNAMED GRAVEL
Qc - UNDIFFERENTIATED CLAY
Qcl – LOWER CLAY UNIT
QTou – OLDER UNCONSOLIDATED DEPOSITS
Tom – MARINE SEDIMENTARY ROCKS
Tp – PUGET GROUP SEDIMENTARY ROCKS
Tv – VOLCANIC ROCKS

0 3,250 6,500
1 INCH = 3,250 FEET FEET

NOTE(S)
1. WELLS LOCATED TO NEAREST ¼ - ¼ SECTION IN DATABASE.

REFERENCE(S)
1. TROOST GEOSCIENCES (WELL LOCATIONS, CITY LIMITS)
2. GOLDER (GEOLOGIC CROSS SECTION)
3. WASHINGTON DEPARTMENT OF ECOLOGY (WELL LOCATIONS)
4. WASHINGTON DIVISION OF WATER RESOURCES (GEOLOGY MAP)
5. KING COUNTY (DRAINAGE BASINS)
6. COORDINATE SYSTEM: NAD 1983 STATE PLANE WASHINGTON NORTH (FT)
7. SERVICE LAYER CREDITS: SOURCES: ESRI, HERE, DELORME, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), SWISSTOPO, MAPMYINDIA, © OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY

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PROJECT
CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN

TITLE
SURFICIAL GEOLOGIC MAP

CONSULTANT
GOLDER

YYYY-MM-DD	2018-08-28
DESIGNED	BVJ
PREPARED	HJ
REVIEWED	MK
APPROVED	MK

PROJECT NO.	PHASE	REV.	FIGURE
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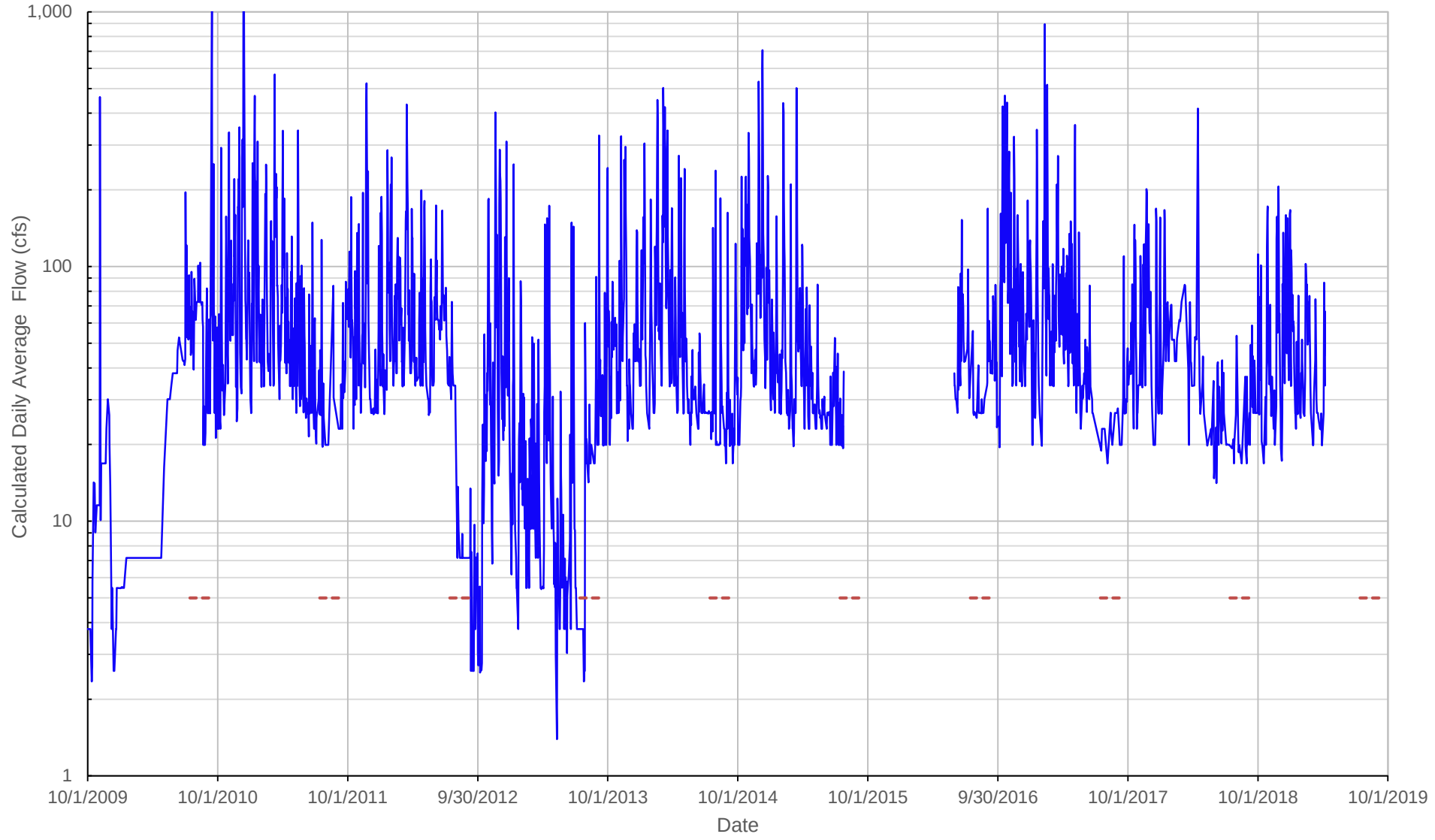

LEGEND

Note:

Calculated flows may be in error because of channel shifts and changes in rating curve and low flows not being captured with pressure transducer

Calculated Flow

Baseflow Period (approximate)

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PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
CITY OF BELLEVUE
KELSEY CREEK GAGE (COB_KCF)
STREAMFLOW HYDROGRAPH

PROJECT NO.	PHASE	REV.	FIGURE
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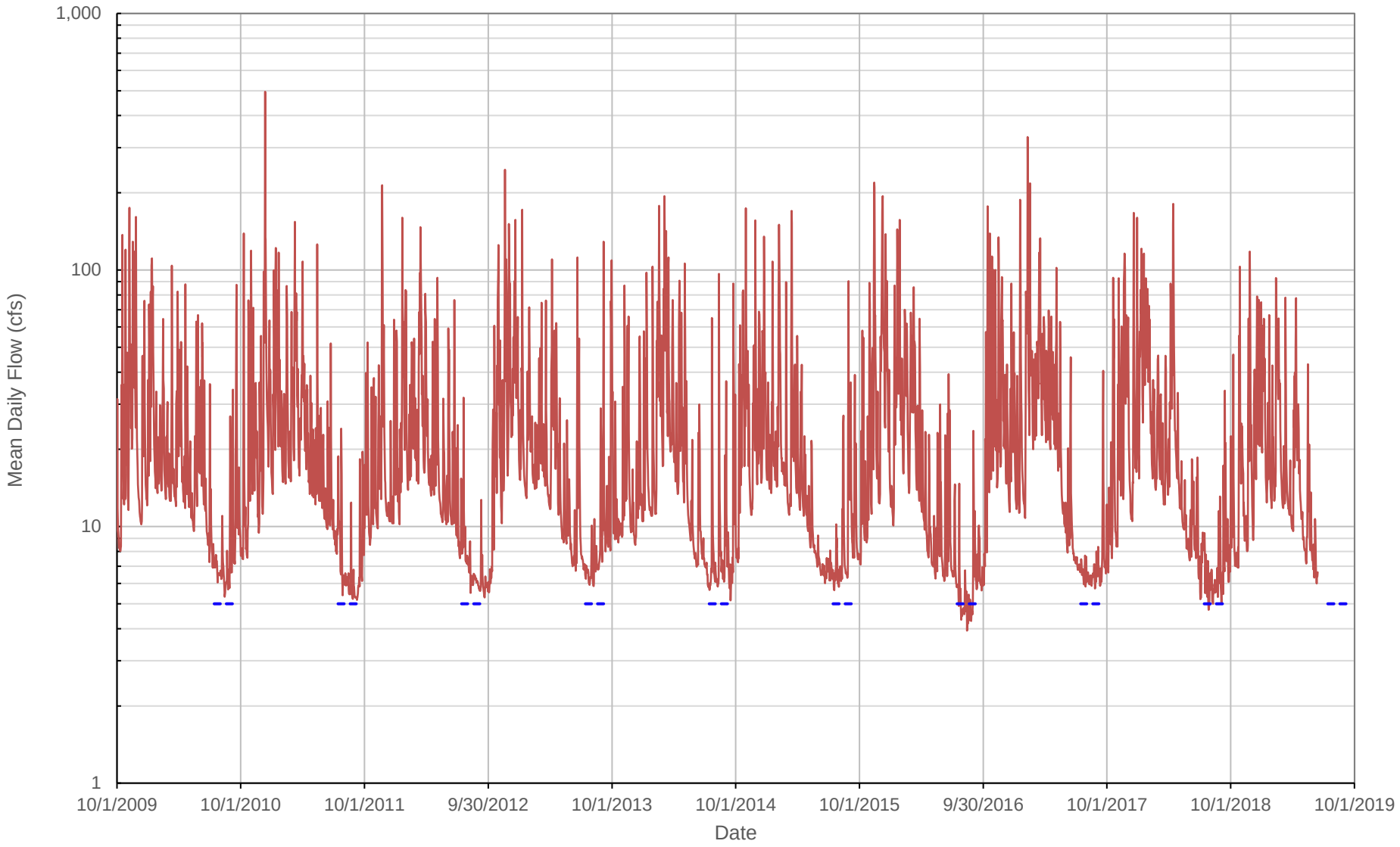

LEGEND

Measured Mean Daily Flow

Baseflow Period (approximate)

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PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
MERCER CREEK NEAR BELLEVUE GAGE
USGS 12120000
STREAMFLOW HYDROGRAPH

PROJECT NO.	PHASE	REV.	FIGURE
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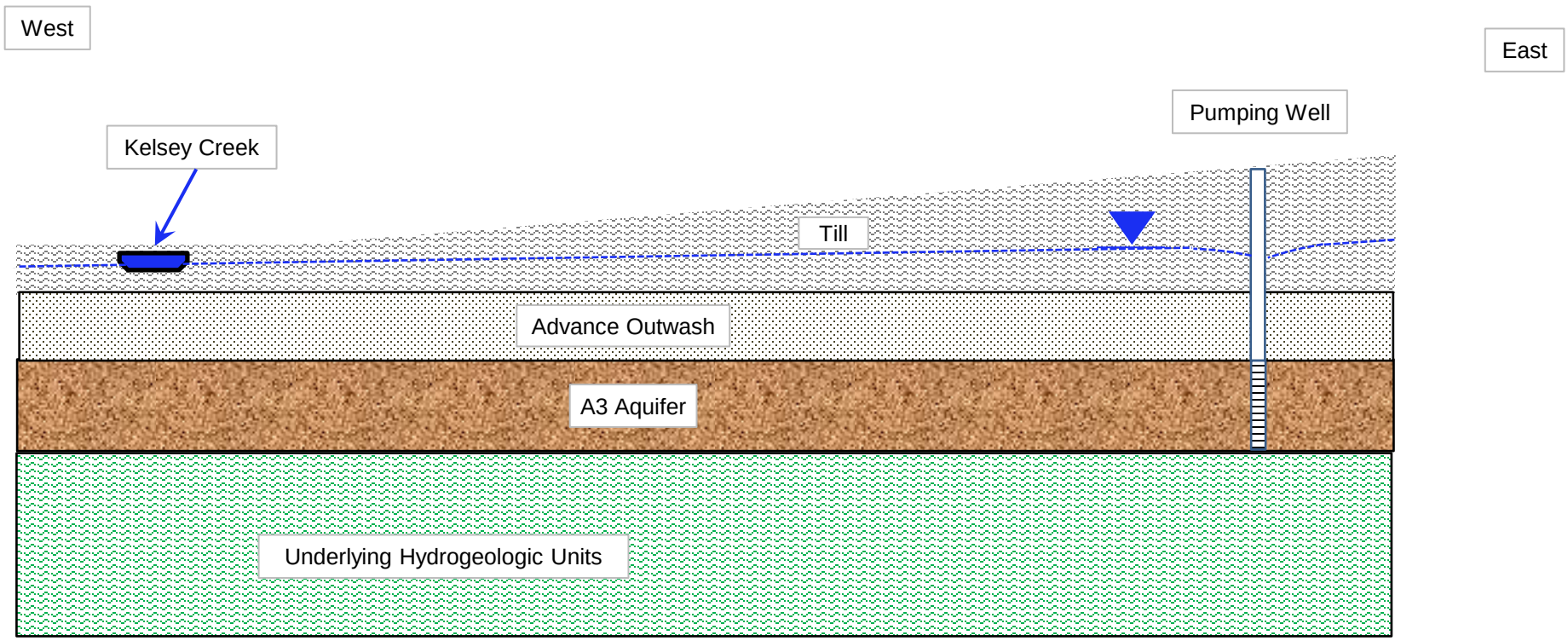

Conceptual Model:
Heterogeneous, non-infinite, isotropic aquifer and till
Confined aquifer
Stream perched on till
Downward leakage through till and advance outwash
Stream not in direct hydraulic continuity with aquifer

LEGEND

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PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

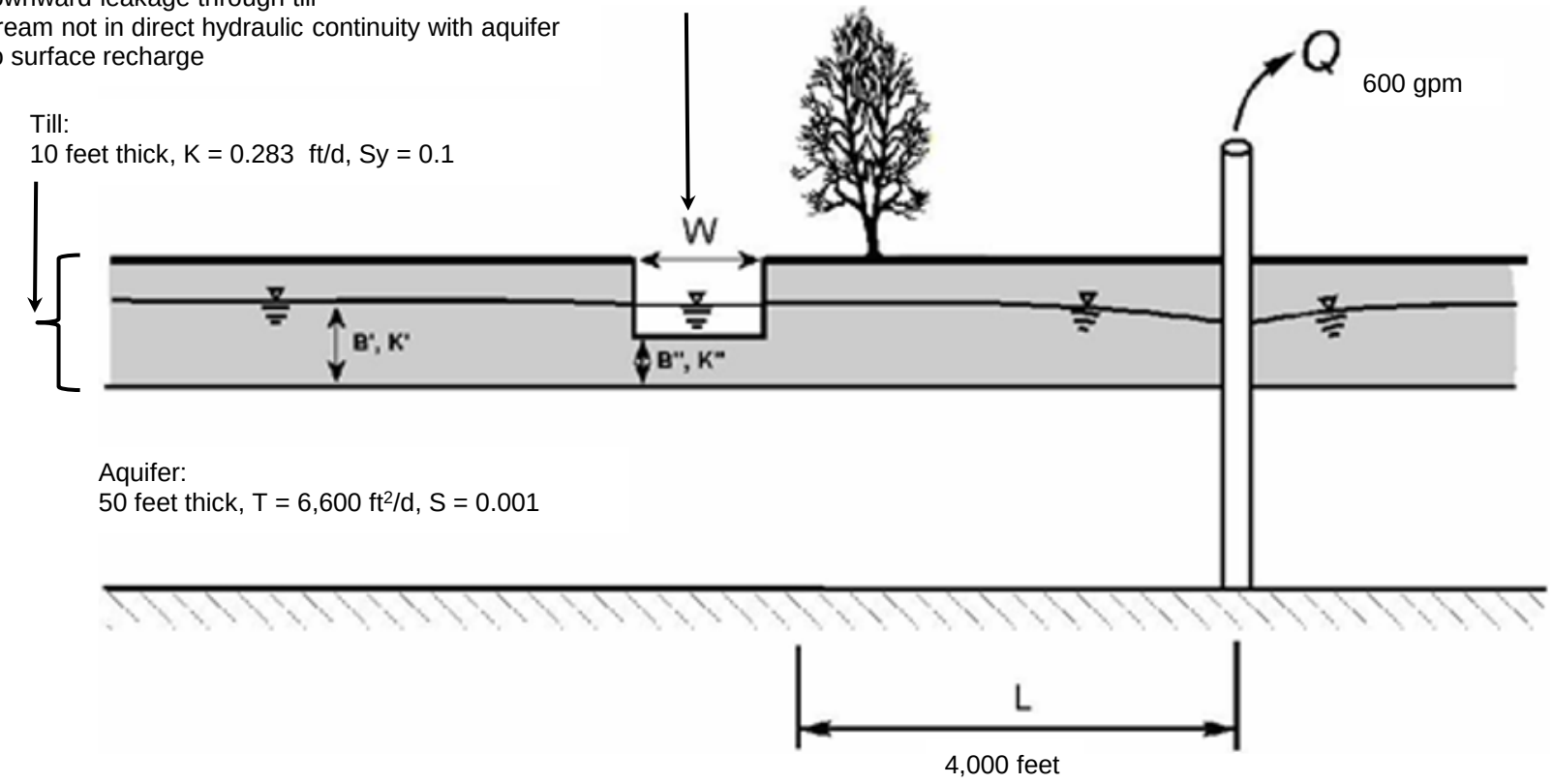
TITLE
AQUIFER-STREAM EVALUATION
CONCEPTUAL MODEL
FOR KELSEY CREEK

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	6

Analytical Model Conceptualization:
Homogeneous, infinite, isotropic aquifer and till
Confined, leaky aquifer
Stream partially penetrates till and is infinitely long
Downward leakage through till
Stream not in direct hydraulic continuity with aquifer
No surface recharge

Streambed:
15 feet wide, K = 0.283 ft/d, till thickness below stream is 9 feet

Till:
10 feet thick, K = 0.283 ft/d, Sy = 0.1



Aquifer:
50 feet thick, T = 6,600 ft^2/d, S = 0.001

Data Input for Scenario 1b (see Table 2)

LEGEND

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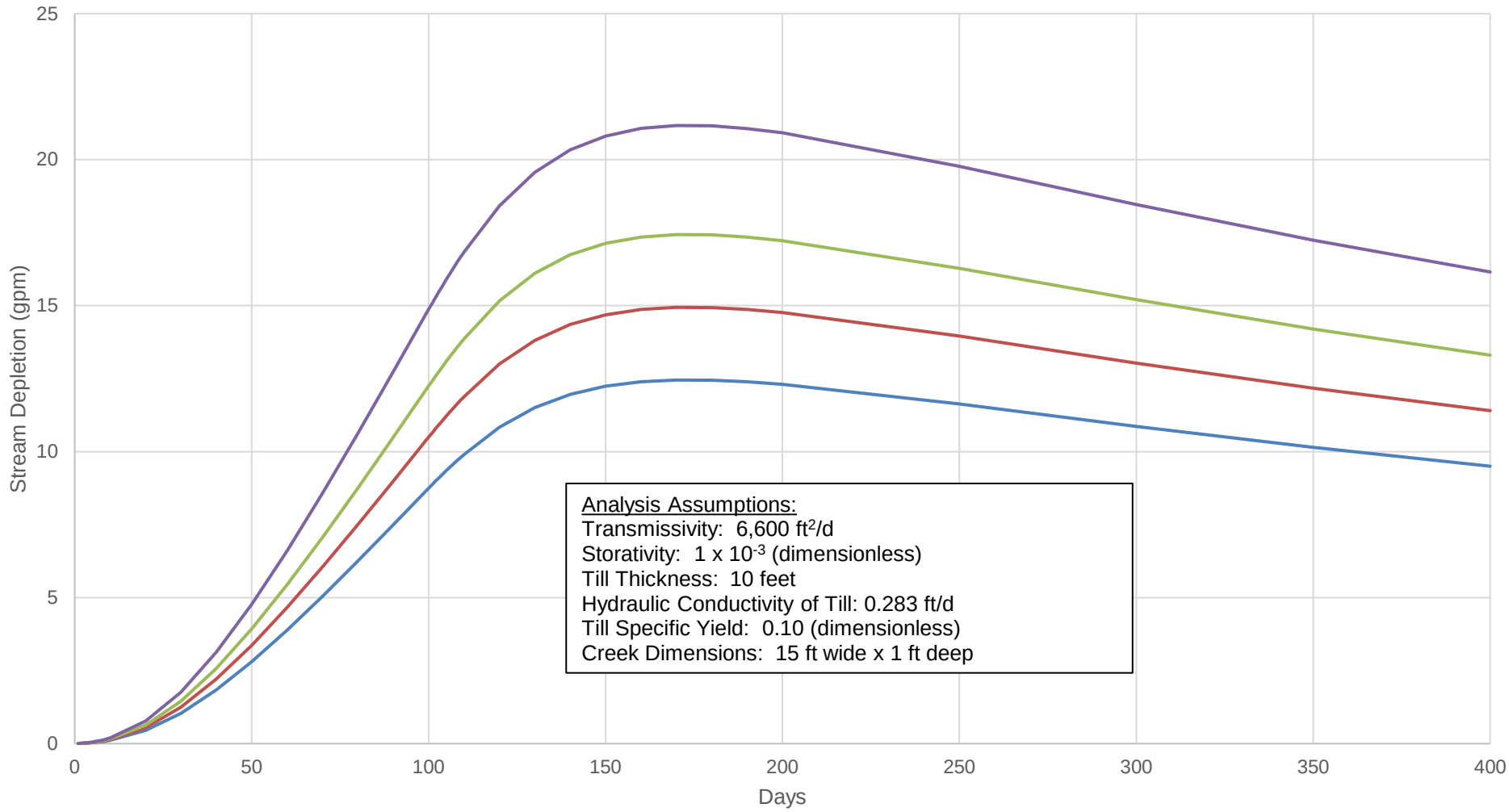
PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
HUNT (2003) ANALYTICAL MODEL CONCEPTUALIZATION
KELSEY CREEK STREAM DEPLETION

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	7



LEGEND

- Scenario 1a (500 gpm)
- Scenario 1b (600 gpm)
- Scenario 1c (700 gpm)
- Scenario 1d (850 gpm)

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PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
STREAM DEPELETION ANALYSIS - KELSEY CREEK
SINGLE WELL 100 DAYS PUMPING

PROJECT NO.	PHASE	REV.	FIGURE
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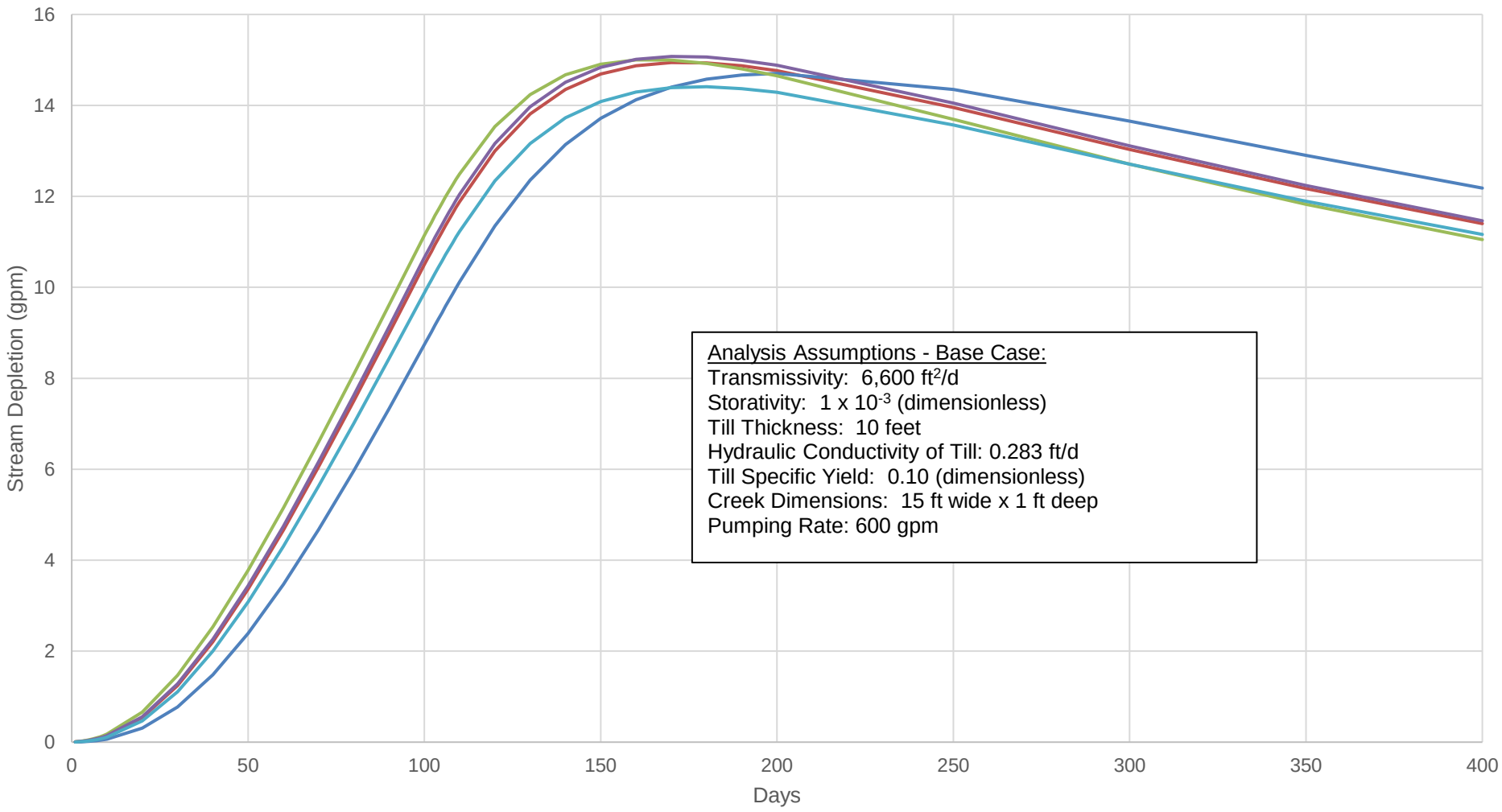

LEGEND

- Scenario 1b (baseline)
- Scenario 2 (low T - 5,000 ft2/d)
- Scenario 3 (high T - 7,400 ft2/d)
- Scenario 4 (low S 5 x 10-5)
- Scenario 5 (high S 5 x 10-3)

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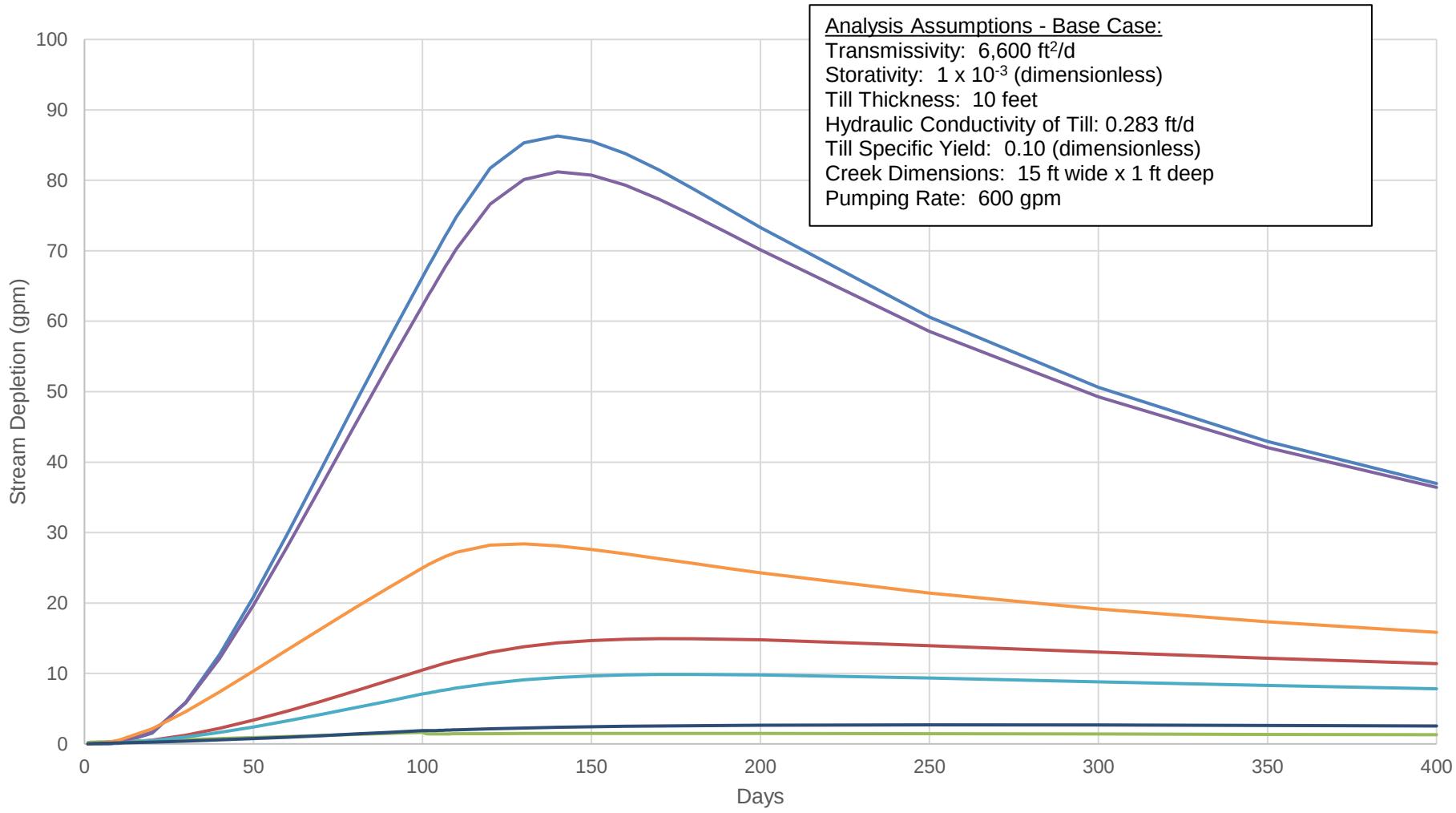
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
STREAM DEPELETION ANALYSIS - KELSEY CREEK
SENSITIVITY ANALYSIS - AQUIFER PARAMETERS

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	9



LEGEND
- Scenario 1b (baseline)
- Scenario 6 (high Till K -2.83 ft/d)
- Scenario 7 (low Till K - 2.83 x 10-2 ft/d)
- Scenario 8 (low Till thickness - 2 ft)
- Scenario 9 (high Till thickness - 15 ft)
- Scenario 10 (low till Sy - 0.05)
- Scenario 11 (high Till Sy - 0.15)

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PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
STREAM DEPELETION ANALYSIS - KELSEY CREEK
SENSITIVITY ANALYSIS - TILL PARAMETERS

PROJECT NO.	PHASE	REV.	FIGURE
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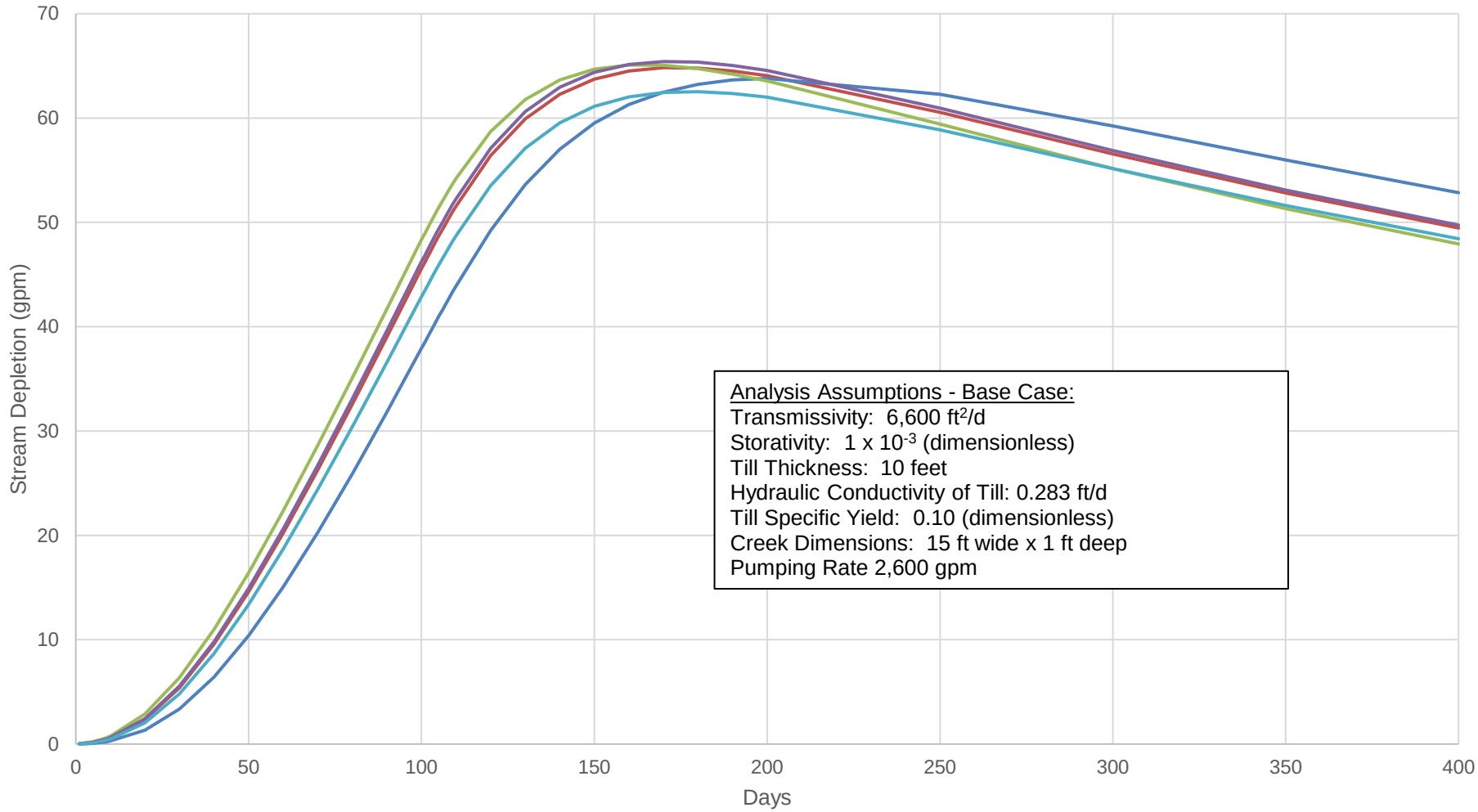

LEGEND

- Wellfield Scenario 1 (Base Case 2,600 gpm 4-well wellfield)
- Wellfield Scenario 2 (low T 5,000 ft2/d)
- Wellfield Scenario 3 (High T - 7,400 ft2/d)
- Wellfield Scenario 4 (low S - 5 x 10-5)
- Wellfield Scenario 5 (high S -5 x 10-3)

CLIENT
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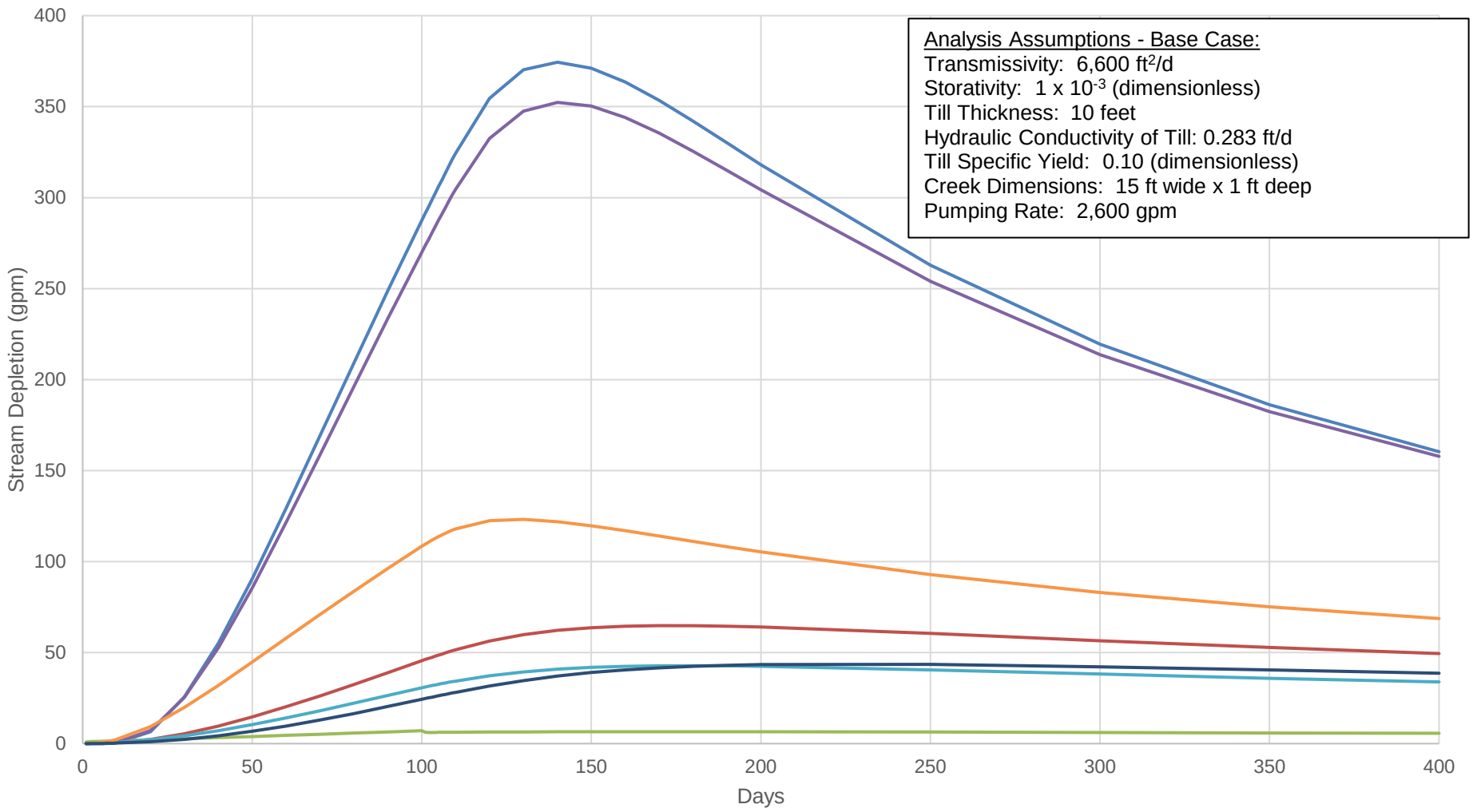
PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
STREAM DEPELETION ANALYSIS - KELSEY CREEK
WELLFIELD PUMPING AND AQUIFER PROPERTIES SENSITIVITY

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	11



LEGEND
- Wellfield Scenario 1 (Base Case 2,600 gpm 4-well wellfield)
- Wellfield Scenario 6 (high Till K 2.83 ft/d)
- Wellfield Scenario 7 (low Till K 2.83 x 10-2 ft/d)
- Wellfield Scenario 8 (low Till thickness 2 ft)
- Wellfield Scenario 9 (high Till thickness 15 ft)
- Wellfield Scenario 10 (low Till Sy 0.05)
- Wellfield Scenario 11 (high Till Sy 0.015)

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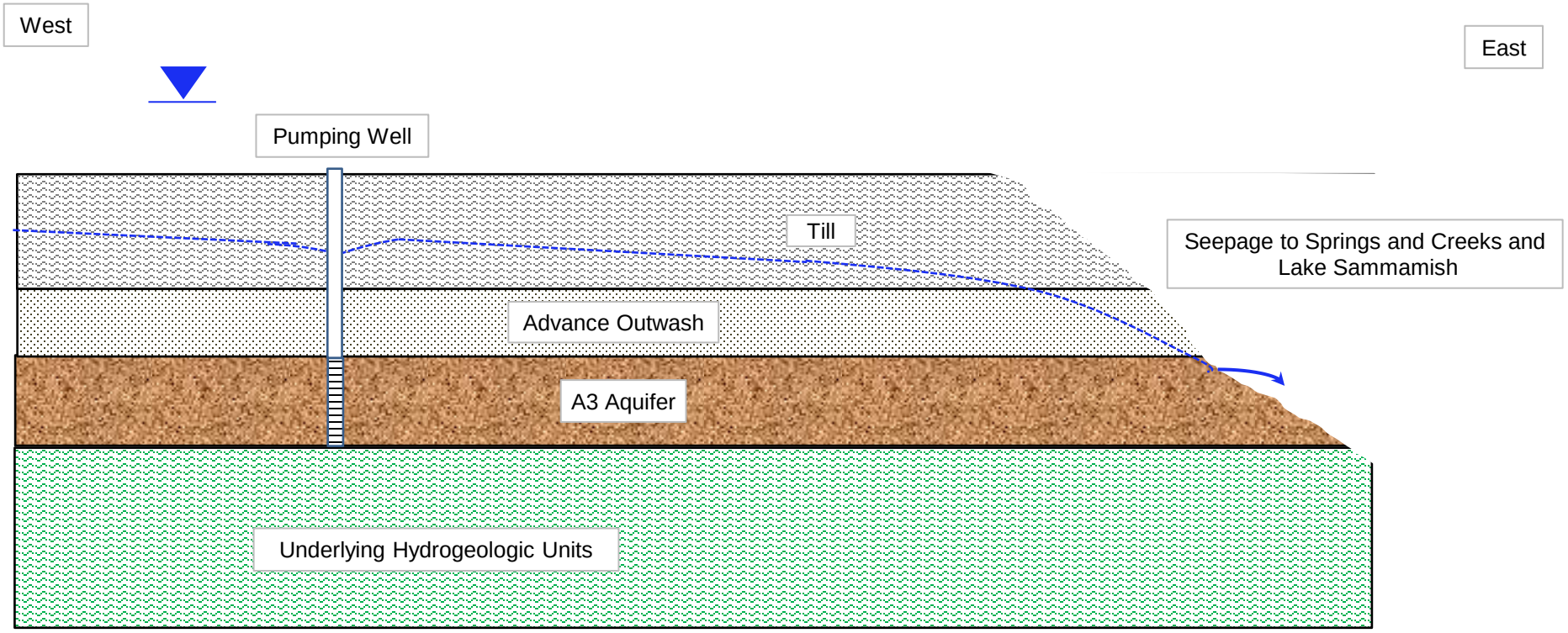
GOLDER

PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
STREAM DEPELETION ANALYSIS - KELSEY CREEK
WELLFIELD PUMPING AND TILL PARAMETERS SENSITIVITY

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	12



Conceptual Model:
Heterogeneous, non-infinite, isotropic aquifer
Confined to semi-confined aquifer
Seepage where A3 Aquifer exposed on hillslopes
Seepage locations in direct hydraulic continuity with aquifer

LEGEND

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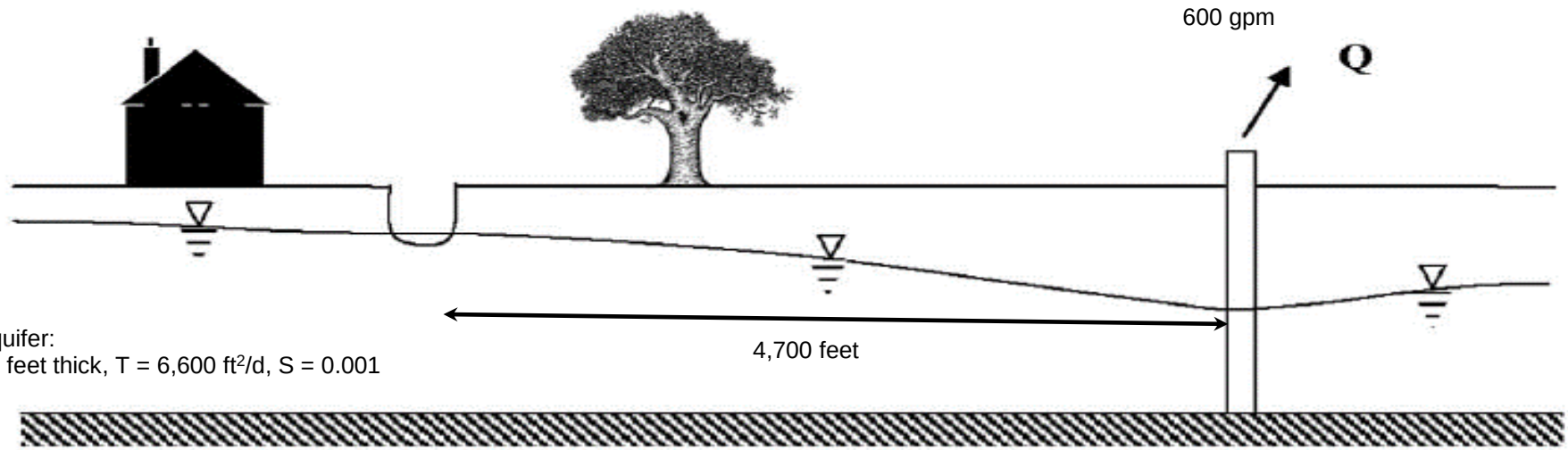
PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
CONCEPTUAL MODEL
FOR LAKE SAMMAMISH TRIBUTARIES DEPLETION

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	13

Streambed:
15 feet wide, 1 foot thick, K = 0.283 ft/d



Aquifer:
50 feet thick, T = 6,600 ft^2/d, S = 0.001

Analytical Model Conceptualization:
Homogeneous, infinite, isotropic
Unconfined aquifer
Stream partially penetrates aquifer and is infinitely long
Stream in direct hydraulic continuity with aquifer
No surface recharge

Data Input for Scenario 1b (see Table 2)

LEGEND

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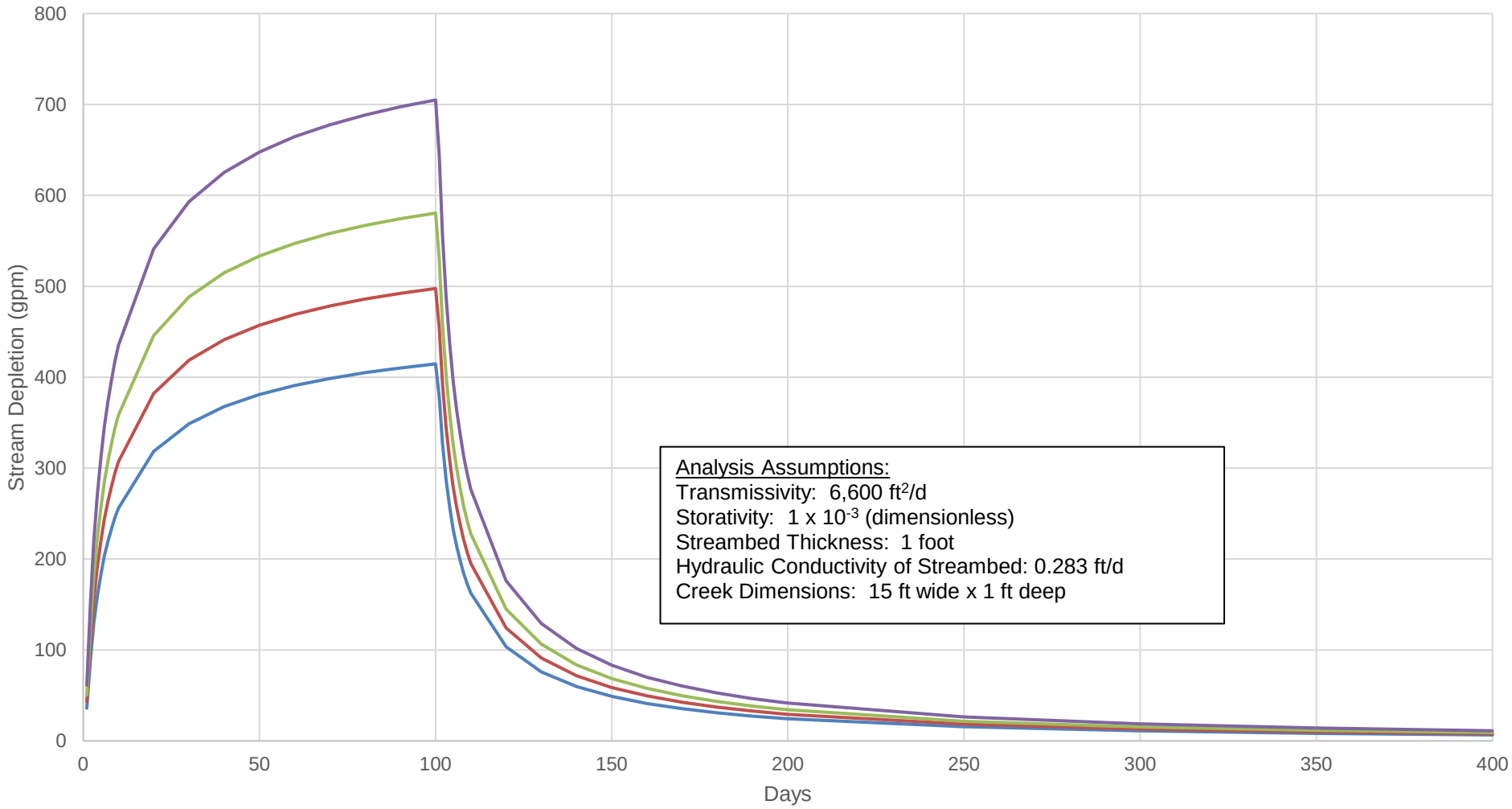
PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
HUNT (1999) ANALYTICAL MODEL CONCEPTUALIZATION
LAKE SAMMAMISH TRIBUTARIES

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	14



LEGEND

- Scenario 1a (500 gpm)
- Scenario 1b (600 gpm)
- Scenario 1c (700 gpm)
- Scenario 1d (850 gpm)

CLIENT
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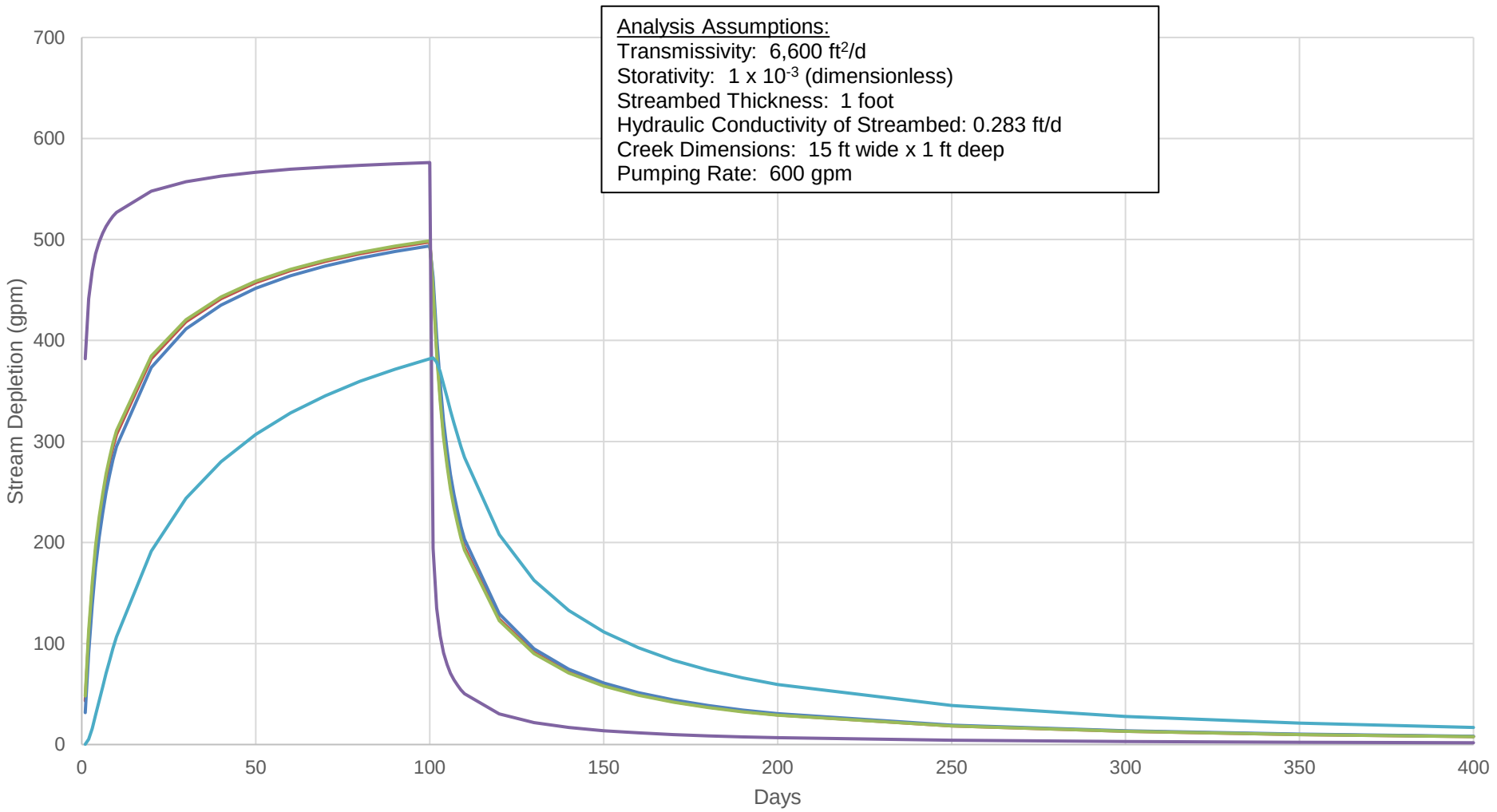
PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
STREAM DEPELETION ANALYSIS - LAKE SAMMAMISH TRIBUTARY
SINGLE WELL 100 DAYS PUMPING

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	15

PATH: C:\Users\mklisch\Documents | FILE NAME: Aquifer-Stream Figures.xlsx



LEGEND

- Scenario 1b (baseline)
- Scenario 2 (low T - 5,000 ft2/d)
- Scenario 3 (high T - 7,400 ft2/d)
- Scenario 4 (low S 5 x 10-5)
- Scenario 5 (high S 5 x 10-3)

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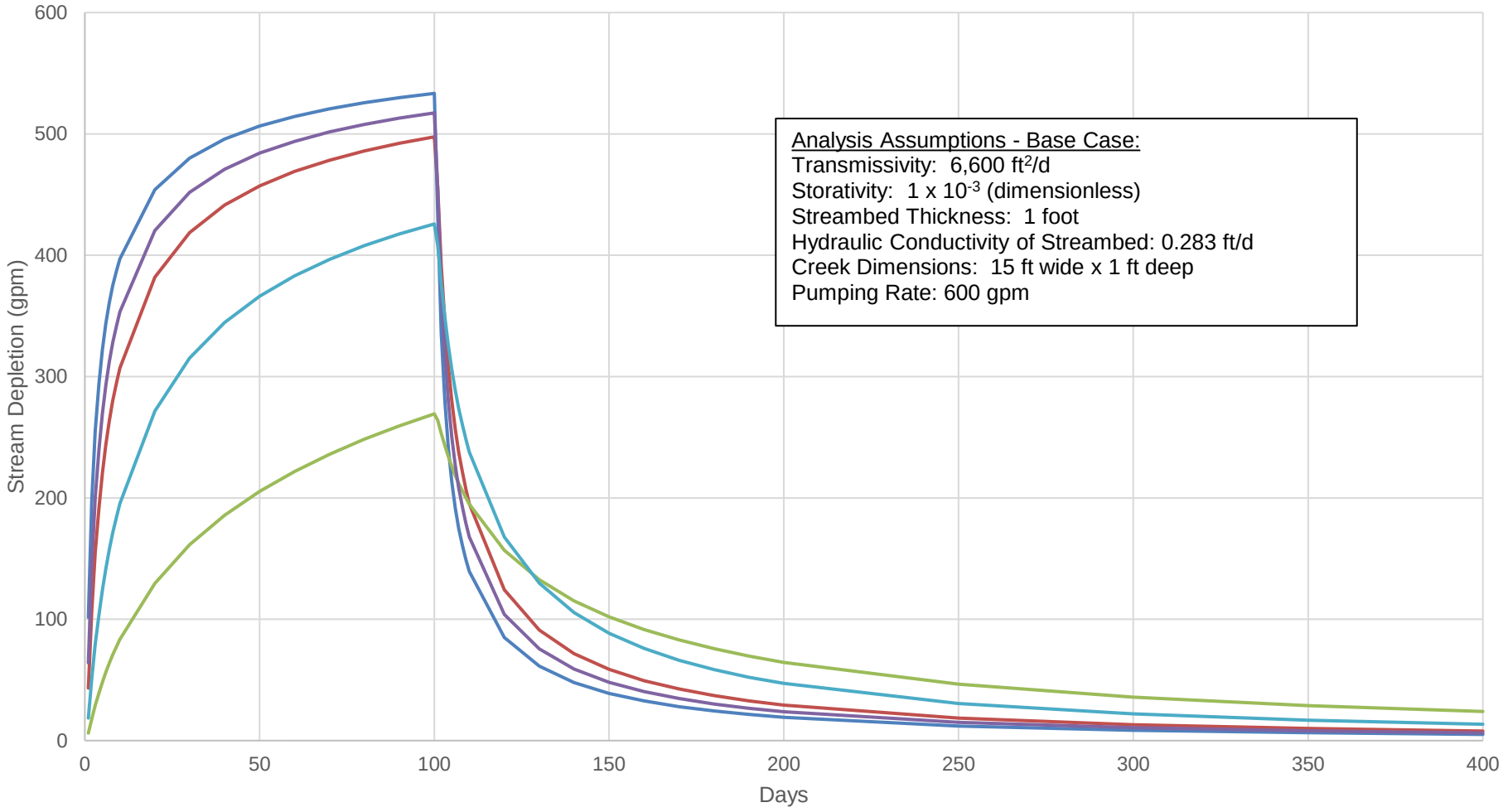
PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
STREAM DEPELETION ANALYSIS - LAKE SAMMAMISH TRIBUTARY
SENSITIVITY ANALYSIS - AQUIFER PARAMETERS

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	16



LEGEND
- Scenario 1b (baseline)
- Scenario 6 (high streambed K - 2.83 ft/d)
- Scenario 7 (low streambed K - 2.83 x 10-2 ft/d)
- Scenario 8 (low streambed thickness - 0.5 ft)
- Scenario 9 (high streambed thickness - 3 ft)

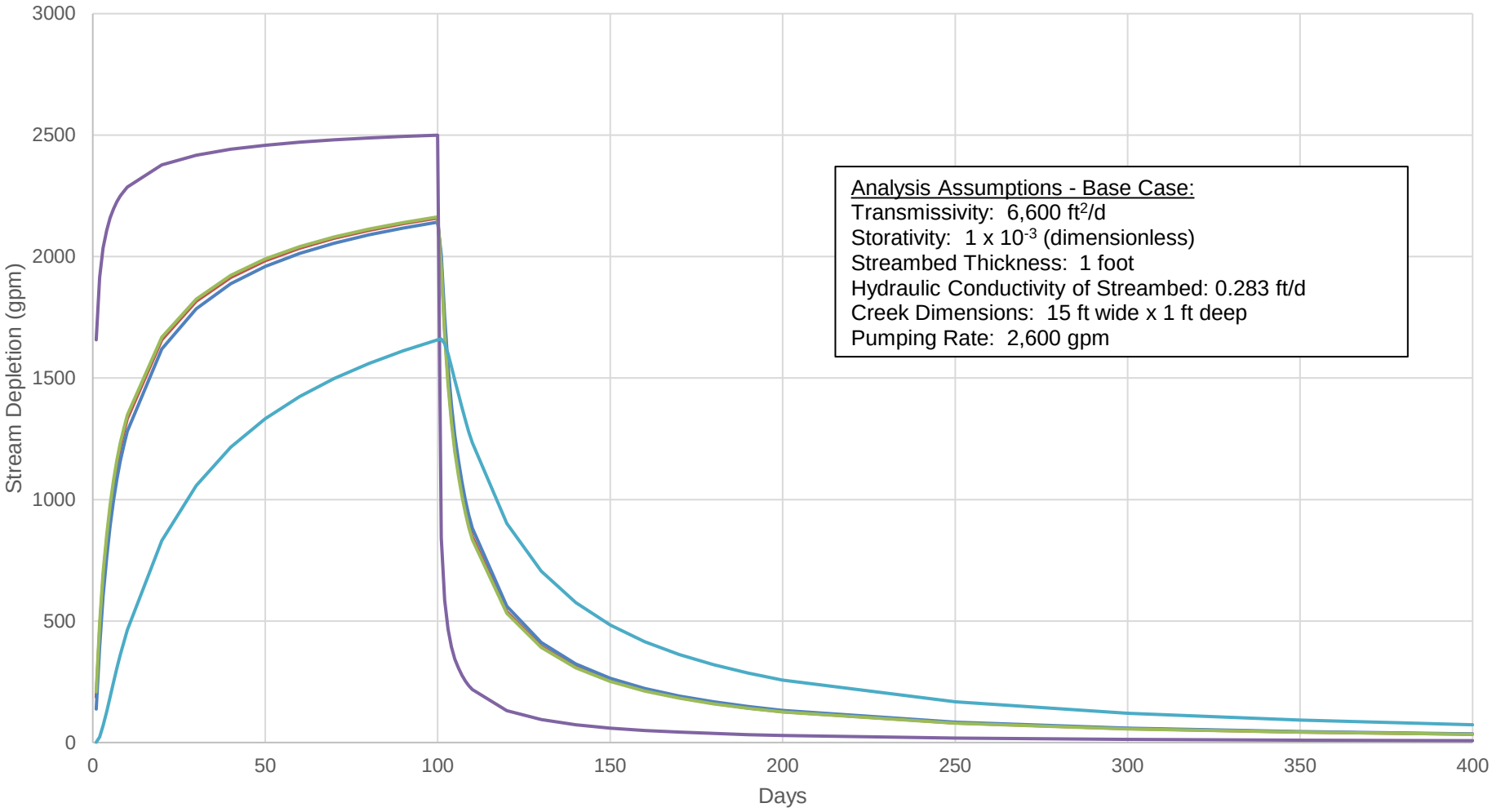
CLIENT
STANTEC

CONSULTANT
GOLDER

PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
STREAM DEPELETION ANALYSIS - LAKE SAMMAMISH TRIBUTARY
SENSITIVITY ANALYSIS - STREAMBED PARAMETERS

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	17



LEGEND

- Wellfield Scenario 1 (Base Case 2,600 gpm 4-well wellfield)
- Wellfield Scenario 2 (low T 5,000 ft2/d)
- Wellfield Scenario 3 (High T - 7,400 ft2/d)
- Wellfield Scenario 4 (low S - 5 x 10-5)
- Wellfield Scenario 5 (high S -5 x 10-3)

CLIENT
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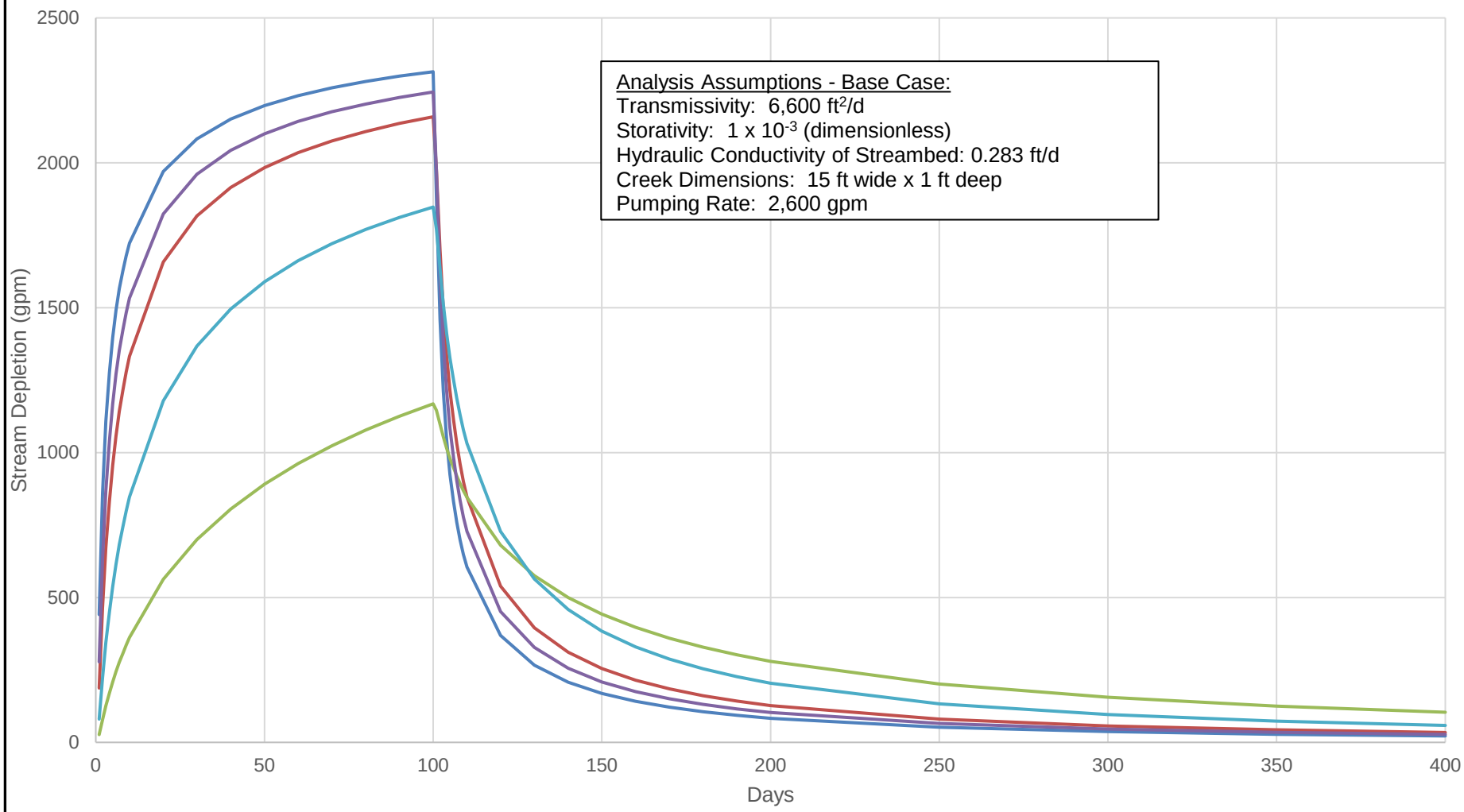
GOLDER

PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
STREAM DEPELETION ANALYSIS - LAKE SAMMAMISH TRIBUTARY
WELLFIELD PUMPING AND AQUIFER PROPERTIES SENSITVITY

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	18

PATH: C:\Users\mklisch\Documents | FILE NAME: Aquifer-Stream Figures.xlsx



LEGEND

- Wellfield Scenario 1 (Base Case 2,600 gpm 4-well wellfield)
- Wellfield Scenario 6 (high streambed K 2.83 ft/d)
- Wellfield Scenario 7 (low streambed K 2.83 x 10-2 ft/d)
- Wellfield Scenario 8 (low streambed thickness 0.5 ft)
- Wellfield Scenario 9 (high streambed thickness 3 ft)

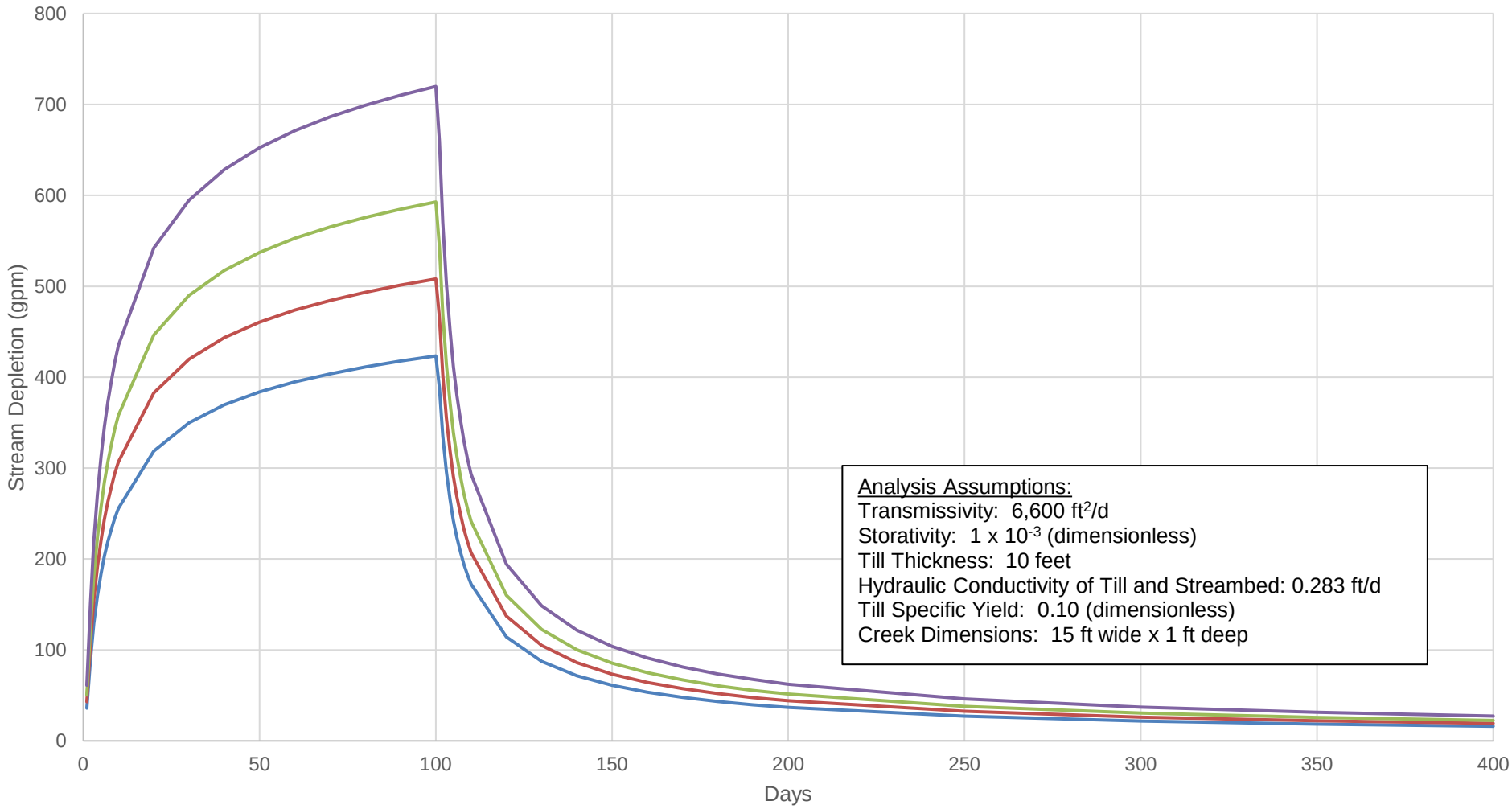
CLIENT
STANTEC

CONSULTANT
GOLDER

PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
STREAM DEPELETION ANALYSIS - LAKE SAMMAMISH TRIBUTARY
WELLFIELD PUMPING AND STREAMBED PARAMETERS SENSITIVITY

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	19



LEGEND

- Scenario 1a (500 gpm)
- Scenario 1b (600 gpm)
- Scenario 1c (700 gpm)
- Scenario 1d (850 gpm)

CLIENT
STANTEC

CONSULTANT
GOLDER

PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
COMBINED STREAM DEPELETION ANALYSIS
SINGLE WELL 100 DAYS PUMPING

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	20

Appendix F. Emergency Water Needs Assessment

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Technical Memorandum

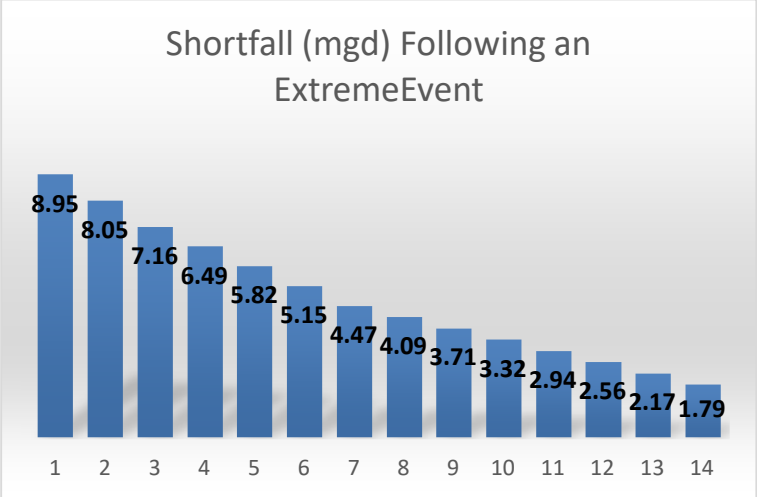
To:	Douglas Lane, P.E., City of Bellevue Laurie Fulton, P.E., Stantec
From:	Thomas Bell-Games, P.E., HDR
Date:	May 14, 2019
Subject:	Emergency Water Needs Assessment

Executive Summary

The City of Bellevue (the City) is in the process of evaluating existing and potential options for providing water following a major event that disrupts the normal drinking water supply. The purpose of this memorandum is to assess the probable needs for water following such an event, both in the short- and long-term. Having a sense of the degree of need will assist the City in response prioritization and in planning for improvements to mitigate potential impacts. This assessment is based on studies and policies for similar communities on the West Coast.

While Seattle Public Utilities (SPU), as the regional source and transmission of drinking water, has a long-term goal of restoring water to wholesale meters within 14 days, it is also recognized that a severe event (e.g. a local crustal earthquake) could result in a water outage of 45 to 60 days or longer (equivalent to recent events in Kobe and Christchurch). Until significant improvements are in place, restoration of service will likely fall short of stated goals. This is true for both transmission of water to the City of Bellevue as well as distribution within the City itself.

A reasonable expectation of domestic water demands in Bellevue's service area following a major disaster is approximately 9 million gallons per day (mgd). Assuming a total loss of water supply following a significant event this shortfall would need to be made up with alternative or emergency supplies. If the City sets a goal of 80% recovery within 14 days, similar to the Oregon Resilience Plan g, the following graph presents the likely shortfall in potable water supply.



It is generally impractical for both technical and economic reasons to upgrade all components of a water system to fully resist the impacts of a disruptive event like a significant earthquake. Therefore, post-event service levels will necessarily be below normal performance. A prudent approach to this issue would be to anticipate the need for some amount of water to supplement the normal supply.

Recommendations

- Performance goals should be established which identify and prioritize appropriate levels of service in such an event.
- This planning should be coordinated with the regional planning efforts of regional water providers such as those represented by the Water Supply Forum.
- Public outreach and messaging to encourage self-reliance for an extended period of time following a disruptive event. The Washington State Emergency Management Division currently recommends two weeks of self-sufficient preparedness for individuals.
- Establish a capital improvements plan to harden existing facilities and develop emergency water sources, such as wells, over time. The plan should prioritize emergency water for critical needs facilities such as hospitals and health care facilities.

1. Scope

This memorandum summarizes an evaluation of anticipated water demands following a disaster which significantly disrupts the normal supply. In performing this evaluation, reviews were conducted of the geographic distribution of normal water demands as well as the quantity and type of water demands experienced in the system. A comparison of emergency level of service goals for other utilities in the region was used to establish a reasonable benchmark for the City.

Other studies and policies within the region are used as benchmarks for the current state of planning, evaluation, and goal setting for performance. Assumptions of this analysis are presented along with a high level overview of the existing water infrastructure. Critical needs are identified and a means of prioritizing those needs is presented. A review of relatively recent past events within and outside of the region is discussed as a means of evaluating possible behavior with respect to continuity of business and residential occupancy immediately after the event and longer term post-event. Conclusions and general recommendations are similarly presented.

It is recognized that an event that disrupts the drinking water infrastructure is likely to have far ranging impacts affecting many, if not all, public sectors. Other impacted public sectors would most likely include transportation, power, wastewater collection and treatment, first responders, and communications. Disruption of these services would have a compounding effect on the ability of the City to bring essential services back up to pre-event performance. The scope of this memorandum is focused solely on a high-level estimation of needs associated with drinking water following a disruptive event. By limiting the assessment to drinking water needs, the City can focus on this one aspect of the community's broader range of services.

2. Review of Benchmark Studies and Policies

The following is a summary of the findings and recommendations developed by a number of regional entities including planning commissions, utilities, and state agencies. In most cases, these studies and policy statements strive to identify current conditions and outcomes of significant disruptive events (typically earthquakes) on performance of drinking water facilities, in addition to other infrastructure and services. Goals are established for the time required to restore these systems to a stated level of service relative to normal performance. In most cases these goals cannot currently be met, but rather, are goals to be achieved following implementation of physical or operational improvements to mitigate the effects of events that could result in system outages.

Mercer Island Emergency Drinking Water Supply Well

The City of Mercer Island applied for and received a permit, including emergency water rights, for an emergency groundwater source through the Washington Department of Ecology. The Department of Ecology permit (GI-2842P) was issued in 2009 for a total withdrawal of up to 400 gallons per minute (gpm) for a duration of up to 90 days with an annual limit of 66.3 acre-feet. This permit was based on the assumption that two wells would eventually be installed, one on the north end of the island and one on the south. If the disruption of normal drinking water supply extends beyond 90 days, provisions are in place to consider a request for an extension of the use of the emergency wells. The Mercer Island 2015 Water System Plan indicates the North Well, currently installed, is intended to supply water for up to seven days, providing five gallons

of water per person per day. This is projected to support a population of 26,000 while operating ten hours per day at a rate of approximately 220 gpm. The current population estimate (2016) for Mercer Island is just over 25,000. The seven day duration is an assumption with the permit allowing for much longer use. The facilities are designed as a non-potable system with no chlorination feed system. The emergency well is not connected to the distribution system. Emergency use would involve drive-up or walk-up service as well as loading of bulk tanks or trucks for distribution elsewhere in the City. Staffing plans include the use of trained volunteers in addition to City personnel. The City intends to distribute information regarding the need to disinfect the water and will provide chlorine tablets along with instructions on proper disinfection practices with the water.

Oregon Resilience Plan

The Oregon Resilience Plan is a report presented to the 77th Legislative Assembly by the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) in February 2013. The plan is specifically focused on risk reduction and improved recovery following a Cascadia subduction zone earthquake and associated tsunami event. The Plan divides areas of concern between the coastal zone and the valley zone. Of these two, the valley zone is more directly relevant to Bellevue's situation as it does not include the impact of a tsunami following the incident.

The Plan recommends identification of a phased approach to system recovery in which a primary backbone of the distribution system (e.g. transmission mains, reservoirs, and pump stations) would be given higher priority in repair, thus bringing the system back online in a somewhat organized manner. This does not alleviate water outages immediately following the event, but does provide a structured approach to post-event recovery that is intended to improve restoration times. Projected water needs are addressed by functional use categories in developing target recovery timeframes.

The following table from the Oregon Resilience Plan presents the goals for percent return to current state for various components within the system. 90 percent operational is considered equivalent to the current (pre-event) state.

Table 1. Oregon Resilience Plan – Water System Recovery Goals

TARGET STATES OF RECOVERY: WATER		Target Timeframe for Recovery:							
		Current state (90% operational)							X
		Desired time to restore component to 80-90%							G
		Desired time to restore component to 50-60%							Y
		Desired time to restore component to 20-30%							R
	Event Occurs	0-24 hours	1-3 days	3-7 days	1-2 weeks	2 weeks - 1 month	1-3 months	3-6 months	6 months - 1 year
Domestic Water Supply	*								
Potable water available at supply source (WTP, wells, impoundment)	*	R	Y		G			X	
Main transmission facilities, pipes, pump stations, and reservoirs (backbone) operational	*	G					X		
Water supply to critical facilities available	*	Y	G				X		
Water for fire suppression - at key supply points	*	G		X					
Water for fire suppression - at fire hydrants	*			R	Y	G		X	
Water available at community distribution centers/points	*		Y	G	X				
Distribution system operational	*		R	Y	G			X	

Source: The Oregon Resilience Plan - February 2013

Disclaimer from the Oregon Resiliency Plan: "Estimates of recovery times assume the typical system has implemented comprehensive resilience improvements, including upgrades to its backbone system, over the 50-year planning horizon. It is further assumed that the resilient backbone is capable of withstanding the anticipated impact of a Cascadia subduction zone earthquake with minimal damage. It is recommended that those responsible for individual systems establish their own target recovery goals as part of a system-specific assessment to reflect the particular configuration of the individual system and the needs of the community it serves".

Other than water for fire suppression at key points and water for distribution centers, water supply would not be returned to a near normal state for one to six months based on this set of goals. However, the majority of water supply (80%) would be available within about two weeks.

Portland, Oregon and the Regional Water Providers Consortium

The City of Portland, Oregon has developed a number of reports addressing risk and potential mitigation of disruption to water and related infrastructure including "Big Steps before the Big One", City Club of Portland Bulletin, Vol. 99, No. 2, February 14, 2017 and "Earthquake Response Appendix to Basic Emergency Operations Plan (BEOP)", City of Portland, April 2012. Both of these documents develop an assessment of resiliency within the region and potential impact of a Cascadia subduction zone M 9.0 event. Portland has taken a holistic approach and has evaluated potential inter-related impacts to transportation, water, wastewater,

telecommunications, energy transmission and distribution, as well as critical infrastructure such as health and medical facilities, schools, and public safety radio communications infrastructure.

The BEOP identifies goals and objectives for several time periods following an event in very general terms with respect to water. The BEOP recognizes that residents may have to be self-sufficient for the first five days after a major event. Specific goals or expectations for return to service are not identified within these documents.

Portland is a member of the Regional Water Providers Consortium (RWPC) along with 19 other cities and utilities throughout the Portland metropolitan area. In 2014, the RWPC Board adopted a resolution to back the Oregon Resilience Plan, in essence, following the guidelines and goals of that plan. The RWPC has adopted a Regional Water Supply Plan, most recently updated in 2016. One of the main focal points of the work of the RWPC has been to promote and strengthen inter-agency capabilities. This has involved evaluation of deficiencies throughout the region resulting in development of additional interconnections between regional systems and purchase of mobile water treatment systems, portable piping systems, and emergency water distribution systems. One of the goals of the RWPC is to promote mutual-aid agreements between all neighboring water providers within the region. This has included promotion of the Oregon Water/Wastewater Agency Response Network (ORWARN), established in 2007 and modeled after similar WARN networks throughout the country. According to the Regional Water Supply Plan, "ORWARN facilitates rapid, short-term deployment of emergency services in the form of personnel, equipment, and materials that are required to restore critical operations to utilities that have sustained damage from natural or man-made events."

San Francisco Area Planning

The San Francisco Public Utilities Commission (SFPUC) is in the process of a $4.8 billion Water System Improvement Program (WSIP), as of August 2016. WISP is designed to repair, replace, and upgrade aging water infrastructure. A component of this work addresses issues regarding level of service and performance goals as they relate to potential system disruption due to a seismic event. SFPUC is committed to a basic Level of Service Criteria. The long term basic level of service goal is to be able to deliver average winter day demand of 215 million gallons per day mgd within 24 hours after a major event. This optimistic level of service is based on an assumption that they will deliver at least 70% of SFPUC's wholesale customers' turnouts and achieve a 90% confidence level of meeting this goal. With the ongoing improvements, SFPUC has a goal of meeting average-day demands of up to 300 mgd within thirty (30) days after a major event.

The WSIP level of service goal does not characterize the nature of the demand, rather, the level of service is generalized for the entire system as a percentage of full (pre-event) capacity. Performance goals with respect to seismic classification (Seismic Performance Class Standard, I; Important, II; and Critical, III) are assigned to structures that are components of the water infrastructure.

Seattle Public Utilities – Water System Advisory Committee

Seattle Public Utilities, Water System Advisory Committee developed draft recommendations for post-earthquake water system performance goals in November 2015. This set of

recommendations is based on review of previous events outside the region and was designed to establish post-event water system performance goals. A key feature of this work is the recommendation for publicly communicating the expected system performance so others will know what to expect and how best to prepare.

The Committee reviewed performance of water systems in past events as summarized below.

Table 2. Summary of Water System Performance Following Recent Significant Earthquakes

Event	Date	Water Main Breaks	Duration until Full Restoration of Water Service	Notes
Loma Prieta	1989	1,000	several days	M 6.9 Damage mostly in areas of poor soils.
Northridge	1994	>1,000	8-13 days +	M 6.7 Damage mostly in areas of poor soils. >100 fires
Kobe	1995	>1,700	60 days +	M 6.9, >100 fires
Christchurch	2011	1,645	45 days +	M 6.2
Tohoku	2011		45 days +	M 9.0, 345 fires

The Advisory Committee assumed SPU's water system performance would likely be similar to performance after the Kobe and Christchurch events. With respect to transmission, this draft evaluation projects three to seven days for partial restoration and one to two months for substantial restoration. Loss of pressure throughout the system was projected to be possible within eight to twelve hours after the event. Water distribution system service restoration was estimated to be about 50 percent after two weeks with 45 to 60 days required to reach near complete restoration. These estimations highlighted a discrepancy in public expectation versus likely post-event performance. Eighty percent of customers were noted as expecting service restoration within one week with more than half of these expecting service restoration in less than three days. This discrepancy points to the importance of public outreach and messaging to manage expectations.

The Advisory Committee recommended defining water availability and the time customers should expect before there is restoration of water service. The Advisory Committee presented a process for developing these performance goals based on stakeholder input. These would then be balanced against estimated cost to achieve the desired goals.

The Advisory Committee developed draft level of service goals for 2035 (twenty year planning period) based on service type as presented in Table 3.

Table 3. Seattle Public Utilities 20-Year Level of Service Goals

Supply Type		Immediately After	24 Hours	3 Days	7 Days	14 Days	1 Month
Water Supply at Wholesale Meters	Minimum Volume	Winter Demand	Winter Demand	Winter Demand	Winter Demand	Winter Demand	Normal
	Water Quality	Non-potable	Non-potable	Non-potable	Non-potable	Potable	Potable
	Water Availability	50% of Meters	50% of Meters	50% of Meters	75% of Meters	100% of Meters	100% of Meters
Fire Suppression Water at Designated Supply Points	Minimum Volume	300,000 Gallons per Location	150,000 Gallons per Location	Full Storage Capacity	Full Storage Capacity		
	Water Availability	90% of Supply Points	75% of Supply Points	75% of Supply Points	100% of Supply Points		
Water Supply at Hydrants and Retail Meters	Water Quality	Non-potable	Non-potable	Non-potable	Non-potable	Non-potable	Potable
	Water Availability	50%	50%	60%	75%	90%	100%
Water Supply for Critical Customers (e.g. Hospitals)	Water Quality	Non-potable	Non-potable	Non-potable	Non-potable	Non-potable	Potable
	Water Availability	50% of Critical Customers	50% of Critical Customers	100% of Critical Customers	100% of Critical Customers	100% of Critical Customers	100% of Critical Customers
Water Supply at Retail Customer Emergency Supply Points	Water Quality	Potable	Potable	Potable			
	Water Availability	0%	50%	100%			

A similar set of goals was established for 2065 (fifty year planning period). This later set of goals moves up full restoration to within 14 days or earlier depending on the type of supply. Improved performance goals are projected as a result of anticipated improvements in infrastructure resiliency over time.

Washington State Emergency Management Council

The Washington State Emergency Management Council, Seismic Safety Committee developed a high-level resiliency plan in 2012. This plan evaluates four areas of infrastructure within the State: critical services, utilities, transportation, and housing and economic development.

Health and medical care are among critical services identified within the plan. The plan estimates that health and medical care services should be 80 to 90 percent operational within three to seven days of a significant disruptive event. Under current conditions, these critical

services are estimated to not be capable of reaching this level of restoration for three months to one year following such an event. For the purposes of this plan, health and medical care include normal medical care such as elective procedures. Emergency care immediately following an event is included as part of emergency response. The goal for restoration of emergency response is one to three days following an event. In contrast, the estimated time needed for restoration of emergency response under current conditions is three to seven days.

With respect to water, the plan defines "supply" to include reservoirs, storage facilities, treatment facilities, and pump stations. For domestic water, the plan indicates a goal of time needed for recovery to 80 to 90 percent operational to be within one to three days for supply, transmission pipes, and distribution pipes. The plan differentiates estimated recovery based on the type of earthquake damage: within liquefaction and within non-liquefaction zones. Supply and transmission pipes are estimated to reach 80 to 90 percent operational within three to seven days in non-liquefaction zones and within three months to one year in liquefaction zones. Under current conditions, distribution pipes are estimated to require one week to one month to become 80 to 90 percent operational in non-liquefaction zones and three months to one year in liquefaction zones. Service lines connecting customers to water mains are not considered within the plan as these would be the responsibility of the customer to repair.

Water Supply Forum

The Water Supply Forum (Forum) is a consortium of utilities in the Central Puget Sound region. Membership includes representation by public water systems and local governments from King, Pierce, and Snohomish Counties ranging from large municipal systems to smaller water and sewer districts as well as regional water associations.

Among issues to be considered in setting level of service goals are the following:

- Water quantity
- Water quality
- Location of delivery
- Time to restore service to customers / duration of the outage
- Extent of damage following the event
- Economic impact of outages
- Cost to upgrade the water system to reduce the impact of customer outages
- Regulatory requirements
- Stakeholder expectations, risk acceptance, and willingness to commit resources to reduce risk
- Level of service goals established by utilities of similar size and susceptibility

The Forum evaluated water availability and time required for restoration of supply to customers. The availability of water immediately following an event is emphasized as important as this is likely to be required for firefighting. 90 percent of the average water demand in winter was selected as equivalent to return of service. Average winter demand is thought likely to best represent more critical uses such as drinking water, bathing, and sanitation and is expected to exclude non-critical uses such as irrigation. This is a commonly used value throughout the studies reviewed by the Forum.

In the April 11, 2016 Earthquake Vulnerability Assessment Technical Memorandum, the Forum summarizes estimated post-earthquake system performance for Seattle Public Utilities/Cascade Water Alliance, Tacoma Water, and Everett Public Works. Performance for each of these systems is estimated for each of four potential events including Cascadia Subduction Zone, South Whidbey Island Fault, Seattle Fault, and Tacoma Fault. Based on a high-level evaluation, each system estimates minimal disinfection within 24 hours for all events with the exception of Tacoma Water (Cascadia Subduction Zone and Tacoma Fault) and Everett Public Works (South Whidbey Island Fault), in which case minimal disinfection is estimated to occur within 72 hours. Full treatment is projected to occur anywhere from 24 hours to 7 days or longer following an event. In reviewing major earthquake events such as interplate subduction and shallow earthquake scenarios, this study found that full restoration of water service has typically taken 30 to 60 days.

In this same memorandum, these utilities anticipate restoration of water service to 90 percent of customers' taps at average winter day demand in a range of 7 to 60 days, depending on the utility and the event. In some cases, more than 90 percent of customers are expected to have water service immediately following an event (e.g. Everett Public Works following an event on the Tacoma Fault).

Estimates within this document were generally based on a high-level analysis without the benefit of detailed seismic studies. The Forum conducted a literature search of post-earthquake level of service goals for seven West Coast water agencies and the American Water Works Association (AWWA) General Performance Goals.

Summary Discussion

These policy statements, plans, and guidance documents exhibit an array of recovery expectations and goals. These do not lend themselves to comparison on a common set of criteria. However, some general trends and points of commonality can be identified.

- Recognition that the existing state is inadequate and long term recovery goals are required.
- Prioritization based on usage type (e.g. goals for critical uses such as health and safety are more aggressive).
- Recognition that restoration to normal service may take six months or longer.
- Performance of water systems at recent events, in particular Christchurch and Tohoku, used as a reference to anticipated level of disruption and recovery.
- Use of some percentage of winter average daily demand as a benchmark for anticipated need.
- Most have set a goal of two weeks or longer for significant return of supply.
- Trend toward recommending individual self-sufficiency for longer than the previously suggested three days.

Due to a likely discrepancy between public expectation of system recovery and the probable duration of an extensive outage, public outreach and messaging prior to and during a disruptive event will be required to effectively manage expectations.

3. Existing Water Infrastructure

The City of Bellevue water utility service area includes the City of Bellevue and numerous outlying communities including Clyde Hill, Medina, Hunts Point, and Yarrow Point, plus a small number of houses in Kirkland. Bellevue also wheels water through its system to portions of Issaquah and Redmond. Water is contractually supplied to the City of Bellevue system through Cascade Water Alliance, but the ultimate source of this water is SPU's Tolt and Cedar treatment facilities.

As documented in the 2016 Water System Plan, the existing infrastructure includes the following:

- 600 miles of pipe
- 6,000 fire hydrants
- 10,500 main isolation valves
- 37,500 customer accounts
- 41,000 customer meters
- 25 active reservoirs
- 22 pump stations
- 145 pressure reducing valve stations

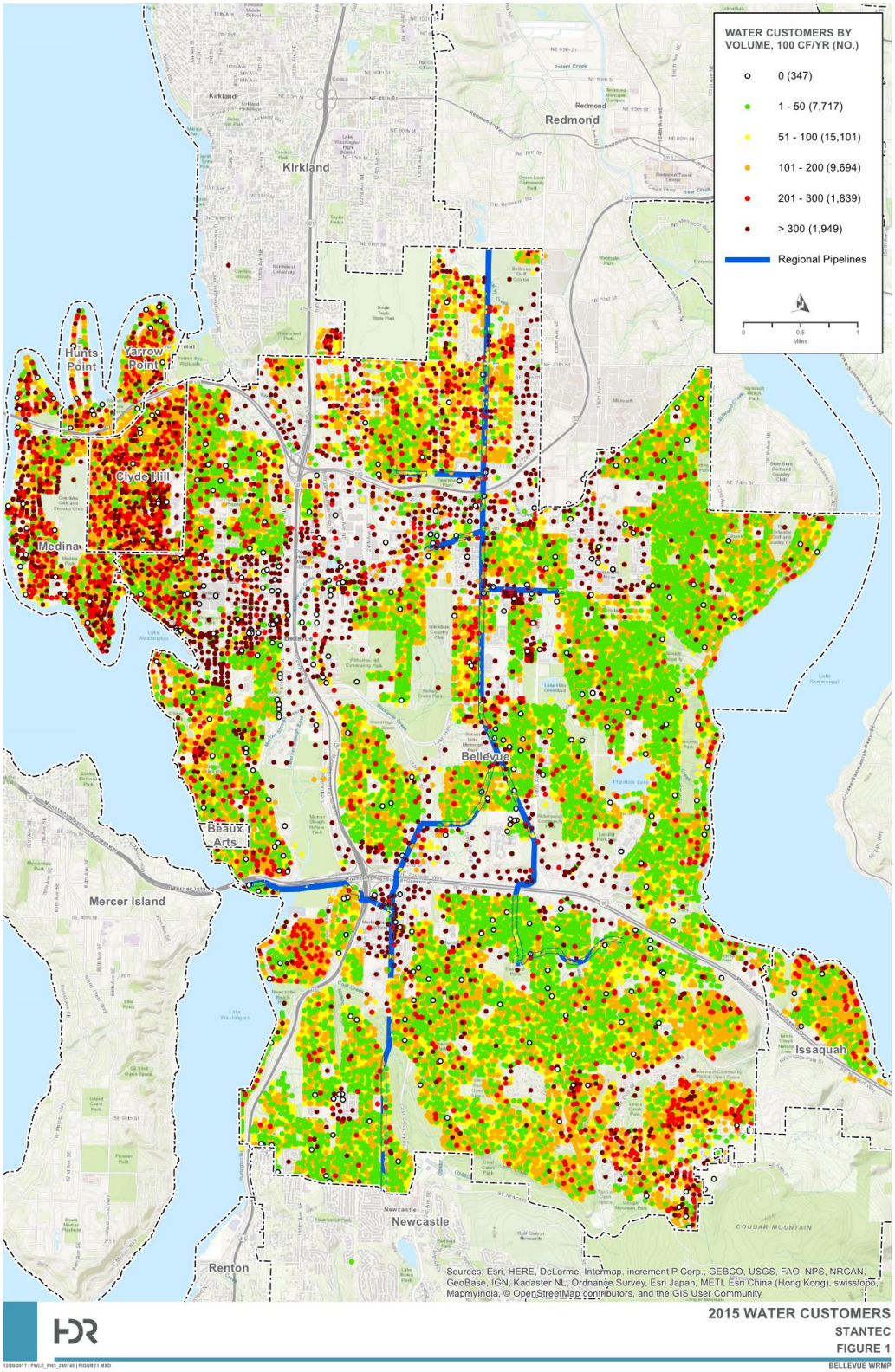
Water comes into the Bellevue system through 12 active inlets, one inactive inlet that is available for providing back-up flow, three inlets operated by adjacent utilities, and four additional inlets no longer in service, but available by re-commissioning if needed. Furthermore, the system is heavily interconnected with adjacent utilities through a series of interties, some of which are capable of bi-directional flow.

Bellevue maintains and operates 22 pump stations in addition to five pump stations that are joint-use with other utilities including Coal Creek Utility District, Cascade Water Alliance, Redmond, and Seattle Public Utilities.

Recent annual average day demand has fluctuated between approximately 15 and 17 mgd. Current projections are for an increase in average day demand to between 21 and 27 mgd within twenty years. Storage available to Bellevue includes active reservoirs, and portions of water in reservoirs that are currently owned and maintained by neighboring utilities. Total available storage within the distribution system is approximately 43.5 million gallons or just under three days of average demand.

Distribution of annual average annual water demand by general order of magnitude is shown in Figure 1. This figure presents 2015 data and does not include irrigation water that is metered separately. It is assumed that use of water for irrigation will not be permitted during a system-wide water emergency. It should be noted that this data reflects high water usage in some areas that are predominately single-family dwellings. This observation may be indicative of high usage due to irrigation. Figure 1 also shows, schematically, the main transmission line running through the City to present the geographic relationship of demands to the primary source of supply for the distribution system.

Figure 1. Distribution of Bellevue Average Annual Water Demand



4. Characterization of Impacts

While this Emergency Water Needs Assessment Technical Memorandum is focused on needs associated with potable water supply in an emergency, all of the benchmark studies reviewed emphasize the inter-dependency of services and the compounding impact of disruption across services as a result of a disruptive event. An event that results in a significant loss of water supply is likely going to similarly degrade communication, transportation, power, wastewater collection and treatment, safety, and the movement of key personnel, repair materials, and supplies throughout the region.

As noted in many of the benchmark studies, water outages could be expected to range between several days to several months or longer, depending on the nature and severity of the disruptive event. Using the American Lifelines Alliance estimate of 0.58 breaks per mile of pipeline for typical distribution systems with an earthquake, Bellevue could expect somewhere around 350 breaks. A process of overlaying distribution system characteristics (e.g. pipe material and size) over mapped areas more susceptible to liquefaction could be used to characterize areas of the distribution system most susceptible to damage. This process could also help identify the areas of highest risk to water delivery should damage occur.

It should be noted that in reviewing some recent events (Chile, 2010; Christchurch, 2010-2011; Japan, 2011), Water Research Foundation Report 4408 found that damage to large diameter transmission pipes was quantified as “many”. Damage to small diameter distribution lines including cast-iron, asbestos cement, ductile iron, and PVC ranged into the thousands. Damage to wells ranged from unknown to widespread in liquefaction zones. Damage to at-grade water tanks ranged from “none” to “some”. In the February 22, 2011 event, Christchurch experienced 1.9 breaks per mile of asbestos cement pipe and 2.1 breaks per mile of cast iron pipe. Both were significantly higher than the American Lifeline Alliance estimate for typical distribution systems.

The 2011 magnitude 9.0 Tohoku-oki event in eastern Japan reduced capacity of the drinking water pipelines in Sendai City to 60 percent of normal capacity on the day of the event (2017, Post-Disaster Reconstruction Department, City Planning Policy Bureau, City of Sendai). This capacity dropped to 50 percent for the four days following the event. Water supply capacity was restored to over 80 percent in approximately eight days following the event. It should be noted that the City of Sendai estimated that at the time of the event, over 84 percent of the pipelines were already “earthquake-resilient”. Sendai City was impacted by both the earthquake and the subsequent tsunami. In this same event, Urayasu City was primarily impacted by liquefaction which required 27 days for restoration of water pipelines (Matsuzaki, 2018).

Groundwater wells are not immune to impacts of earthquakes. In the recent Christchurch event, out of 174 wells, 20 wells needed to be re-drilled, 82 needed some degree of repair, and 72 were unaffected (Bears, 2012).

5. Critical Needs and Prioritization of Service

The benchmark studies reviewed identify critical services and facilities. Most typically, these include the following:

- Medical facilities including hospitals, urgent care facilities, and nursing homes
- Command and control centers

- Industries essential to recovery and restoration of services
- Schools and other public buildings
- Fire and police facilities

The assumption is that each of these critical facilities would be given priority for water in order to maintain continuity of services. The following discussion addresses several of these types of facilities specific to Bellevue.

Medical Facilities

Table 4 shows five year average annual demands (2012-2016) for major healthcare facilities within the City of Bellevue's service area. These demands have been fairly consistent throughout this period. These demands do not include water that is metered separately for irrigation.

Table 4. Five-year Average Annual Demands for Bellevue Major Healthcare Facilities

Facility	Average Demand (gpd)[1]
Overlake Hospital	126,900[2]
Group Health	12,600
Seattle Children's	5,000
US Health Works	400
Mission Healthcare	15,300
DaVita Bellevue Dialysis	7,200
Lake Washington Kidney Center	600
UW Medicine, Eastside Center	600
Total	**168,600**

[1] *All demands rounded up to nearest 100 gpd.*

[2] *Increased by 40 percent to account for planned expansion of 180,000 sf.*

Since some of these facilities are not hospitals, not all are required to stay open during a city-wide emergency; however, it is assumed that services would shift to urgent care for all. Dialysis services would need to continue. Water would continue to be needed for sanitation and sterilization, among other needs. The assumption is that all would have a significant role in a coordinated emergency response, making a goal of providing 100 percent of current average demand appropriate. These critical facilities are recommended to further identify essential functions and actual minimum water needs with respect to safety and well-being of staff and patients with the objective of developing baseline operating assumptions (CDC & AWWA, 2012).

The current standard of the Joint Commission, the accrediting organization for hospitals, is that a hospital's emergency operations plan be designed to provide services most applicable for an emergency related to utility disruption for at least four days (96 hours). This may include an organized curtailment of some services. Recent studies and surveys have pointed out the difficulty in stockpiling the necessary

volume of water, even with curtailed usage, beyond that needed for direct consumption. This is typically a small fraction of the overall water demand for these types of facilities.

Currently, none of these facilities have significant stockpiles or other sources for emergency water.

Command and Control Centers

These centers for Bellevue include the following:

- City of Bellevue Emergency Operations Center at City Hall
- North East King County Regional Public Safety Communication Agency, NORCOM (City Hall); 911 dispatch
- Bellevue Service Center (utility operations and telemetry center)
- Washington State Patrol District 2 and King County 911 call center (2803 156 Ave SE)
- Puget Sound Energy backup Emergency Operations Center (355 110th Ave NE)
- Bellevue School District Emergency Operations Center (12241 Main Street)

Industries Essential to Recovery and Restoration of Services

The Washington State Department of Transportation (WSDOT) Maintenance Operations Program has a Regional Bridge Office at 10833 Northup Way NE in Bellevue. In addition to being a base for regional bridge maintenance, WSDOT also could be expected to base some emergency operations out of this facility. This is a backup Emergency Operations Center in case the primary EOC in Shoreline has a problem.

Additional industries in this category include Coca Cola bottling facility which would convert to bottling water in the event of a disruptive event.

Schools and Other Public Buildings

Following a significant event resulting in disruption in water service, schools would be expected to close. The City and the Bellevue School District have signed a memorandum of understanding regarding the use of schools as shelters and/or points of distribution (PODs) for emergency supplies. This agreement addresses emergency assistance in the form of resources, such as equipment, supplies, facilities, and personnel.

Middle schools and high schools would be more likely to be used as shelters due to the availability of facilities such as showers, assuming an emergency supply of water is available.

Elementary schools would be more likely to be used as PODs. These schools are able to accommodate incoming and outgoing traffic and are generally well distributed geographically. With respect to water distributed at a POD, this could be addressed through tanker trucks or portable reservoirs filled by tanker trucks.

Firefighting

For the purpose of firefighting, the Bellevue Fire Department has the ability to draft water from available surface water in the region if required. Potential sources of this water include lakes, streams, dump tanks, and swimming pools. Water can be pumped to a fire within 1,000 to 2,000 feet of the point

of drafting. If the fire is more remote, up to 500 gallons of water would be drafted onto the fire engine and then transported to the site of the fire.

Community Points of Distribution

In December 2011, the City of Bellevue developed a draft Community Points of Distribution (CPOD) Annex. The purpose of this document is to establish the authorities, capabilities, responsibilities, and supporting procedures for commodity distribution operations during a disaster.

The following are some noted features of the draft CPOD plan:

- CPODs are characterized as Type 1, 2, or 3. Features factored into this include equipment, resources, and intended number of people served (ranging from 5,000 for Type 3 up to 20,000 for Type 1).
- Multiple CPODs of varying types and sizes are anticipated to be required, depending on the nature and extent of the disruptive event.
- Resources to open a CPOD will likely not be available for the first 72 hours following a disruptive event.
- CPODs are anticipated to be very temporary, lasting only one to three weeks.
- With respect to water, distribution may include one gallon of water per person per day.
- The City of Bellevue is divided into five geographic regions with a total of seven pre-determined CPOD sites. Additional CPOD sites would be opened as needs are identified.

6. Typical Consumption

As reported in the 2016 Bellevue Water System Plan, potable water consumption has declined in recent years, as is typical throughout the region. Per capita consumption in low demand years is roughly 80 percent of that in high demand years. This suggests some elasticity in the consumption of water. The Water System Plan shows a ten year average daily consumption of roughly 70 gallons per capita. However, the Water Research Foundation reports that domestic household use has decreased by 22 percent between 1999 and 2016; average per capita use has decreased 16 percent during this same period to 58.6 gallons per capita per day (gpd/capita) (DeOreo et al., April 2016). The Water Research Foundation Report 4309b focuses solely on residential use. An approximate comparison can be made with Bellevue's winter day demand (which excludes irrigation) which averages approximately 52 gpd/capita (2014-2016).

For purposes of evaluating emergency water needs, only water used for consumption and sanitation should be considered. This would include residential indoor and critical facilities usage. This is best reflected as some percentage of winter average demands as typical in some of the benchmark studies and policies. Winter average demand for the Bellevue Service Area is approximately 12.57 mgd based on usage between 2005 and 2014. This is about 75 percent of overall average demand.

7. Possible Impacts of Water Conservation and Outreach Post-Event

The potential impacts of water conservation efforts following a disruptive event are difficult to predict. The effectiveness of these efforts are likely to be impacted by the ability to communicate the extent of conservation needed immediately following a disruptive event.

It may be more feasible to institute conservation measures at some later point in time while the potable water infrastructure is in the lengthy process of repair. As an example, the Christchurch event occurred

on February 22, 2011. This was followed by a long series of aftershocks. Nine months after the initial event, the Christchurch City Council instituted Level 3 water restrictions (Bears, 2012) in anticipation of the upcoming summer demands. Level 3 water restrictions are not onerous as they permit alternate day hand-held hose use for outdoor watering. The effectiveness of these measures is not known. However, at that point in time, the population had a general awareness of the damage to the system, and compliance was anticipated to be good. The goal was a 32 percent decrease in peak demand.

In response to drought conditions in California, the State imposed mandatory water restrictions state-wide with an overall goal of 25 percent reduction (Nagourney, 2015). In April 2017, the State Water Board rescinded the mandatory conservation standards for urban water suppliers. On December 28, 2017, the California Environmental Protection Agency State Water Resources Control Board published cumulative savings between June 2015 and November 2017 for the 384 water purveyors reporting. Statewide water savings reached 11 percent in November 2017. This overall reduction trends fairly closely throughout 2017 compared to baseline 2013.

8. Probable Needs

One of the shortcomings in using the policies and guidelines developed by other regional utilities reviewed herein as general benchmarks is that these generally characterize the percentage recovery goals by usage type (e.g. fire suppression or water supply for critical customers). The difficulty in assigning a corresponding need is that utilities generally do not track average usage by these categories. However, Bellevue has identified probable needs for major medical facilities as previously noted in the discussion regarding critical needs. The actual needs throughout the system will vary depending on the severity and extent of the disruptive event. The majority of studies and plans acknowledge that customers will need to be self-sufficient for the initial three days to one week in severe events. Moreover, the Washington State Emergency Management Division has recently increased this recommendation to two weeks of self-sufficient preparedness for individuals.

Initial needs for emergency water may increase in the short term as water is lost through damaged reservoirs, pipelines, and pumping stations in the days immediately following the event. Functionality of portions of the system can be expected to be returned over time, and associated needs for emergency water can be expected to decrease accordingly. In the case where restoration of the system takes a longer period of time, water consumers may move out of the region, either temporarily or permanently, thus lessening the water demands.

More significantly, the studies reviewed generally identify level of service goals following a disruptive event, not necessarily the actual level of service attainable by the current state of facilities within the utility.

Recognizing these uncertainties, the following estimated needs and characteristics of emergency water conditions for Bellevue are summarized. The difference between the anticipated consumption and the estimated level of service represents the probable need for a temporary emergency source of water.

As previously discussed, winter average consumption can be used as the basis of estimating water demand following a disruptive event as this would be reflective of more critical water consumption, excluding outside watering and other non-essential uses. Based on a ten year average (2005 – 2014), the winter average demand for the Bellevue system is approximately 12.57 mgd.

The Water Research Foundation Report 4309b, *Residential End Uses of Water, Version 2* (DeOreo, et al., 2016) evaluated indoor versus outdoor use as well as use by fixture type. This report indicates showers and clothes washers account for an average of 36 percent of annual indoor water use. Taking this into account, 80 percent of the winter average day demand (ADD) would be a reasonable estimate for essential use as routine showering, laundry, and similar uses could be expected to be somewhat reduced. In addition, people may move out of the affected area, thereby further reducing demand. As an example, following the 2015 Gorkha Earthquake (albeit a less developed area), water demand decreased by a little over 15 percent. Using the recent experience of California in mandated water conservation efforts, an additional 11 percent reduction could reasonably be expected. These impacts are summarized in Table 5.

Table 5. Estimated Needs for Bellevue following a Disruptive Event

Characteristic	Percent Reduction	Need (mgd)
Winter ADD		12.57
Winter ADD Reduction	20%	10.06
Conservation	11%	8.95
Total Discounted Winter ADD		**8.95**

The net effect would be a remaining need of approximately 9 mgd immediately after an event.

Looking at this another way, the Water Research Foundation Report 4309b (DeOreo et al., 2016) indicates that indoor water use represents approximately half of all annual residential water use. However, it is also noted that outside water use varies greatly by region. The overall annual average use for Bellevue during the 2005-2014 period was 16.11 mgd. Half of this would be about 8.05 mgd. Because the Bellevue area has a mild climate, outdoor water use could reasonably be expected to represent a smaller percentage of overall use and the essential indoor use is likely higher making the discounted winter ADD estimate of 8.95 mgd a reasonable estimate.

Using Oregon Resilience Plan Approach

If Bellevue decides to implement the Oregon Resilience Plan goal of having the distribution system 20 percent operational within three days, 50 percent within one week, and 80 percent within two weeks, the supplies shown in Table 6 would be needed for the first two weeks following a disruptive event. This uses a conservative assumption that no water is available immediately following the event and that there would be a uniform increase in capacity through each period (i.e., three days, one week, and two weeks).

Table 6. Oregon Resilience Plan Goal Scenario

Day	Percent Functional	Available Supply (mgd)		Shortfall
1	0%	0.00		8.95
2	10%	0.90		8.05
3	20%	1.79		7.16
4	27.5%	2.46		6.49
5	35%	3.13		5.82
6	42.5%	3.80		5.15
7	50%	4.48		4.47
8	54.3%	4.86		4.09
9	58.6%	5.24		3.71
10	62.9%	5.63		3.32
11	67.1%	6.01		2.94
12	71.4%	6.39		2.56
13	75.7%	6.78		2.17
14	80%	7.16		1.79

This scenario does not take into account disruption of typical water demand due to public reaction to the event. It may be that water demand could rise dramatically immediately following a disruptive event as people attempt to stockpile what water they can. Also, more significant reduction in demand through conservation beyond 11 percent might be possible as the extent of the situation and limitation of supply become well communicated and understood, particularly in the case where a longer term recovery is required and a portion of the population moves out of the impacted area.

Until major capital improvements are implemented, the Oregon Resilience Plan level of service appears to be unachievable by Bellevue (via independent supplies) for the near term if SPU supplies were disrupted. Under current conditions, a more prolonged recovery period and extended shortfall could be expected.

Using Mercer Island Approach

An alternative approach to determining potential need would be to assume complete failure of the existing system and emergency water supplied at the rate established by Mercer Island's plan of 5 gallons per day per person. This is equivalent to the upper range referenced by USEPA (*Planning for an Emergency Drinking Water Supply,* 2011). The 2017 Bellevue Water Quality Report indicates 223,900 as an average daytime population served. Using 5 gallons per day per person corresponds to a net need of 1.12 mgd (780 gpm), assuming no water availability in the distribution system. This is equivalent to less than 13 percent of the Total Discounted Winter ADD noted in Table 5.

This need represents only water required for personal use and is not reflective of water required for fire suppression. It is assumed that water for fire suppression could be provided through drafting of surface water sources. Further, this does not include water required for critical healthcare facilities. As previously noted, the five-year average water usage for these facilities has been estimated at 168,600 gallons per day. Adding this to the 5 gallons per day per person brings the total estimated need to 1.29 mgd. This could conceivably be achieved through the existing emergency supply wells, though distribution to the population would be difficult as these wells are located on only two sites in the City.

9. General Planning

It is generally impractical for both technical and economic reasons to upgrade all components of a water system to resist the impacts of a disruptive event like a significant earthquake. Therefore, post-event service levels will necessarily be below normal performance. A prudent approach to this issue would be to anticipate the need for some amount of water to supplement the normal supply. Performance goals should be established which identify and prioritize appropriate levels of service in such an event.

The Water Research Foundation Web Report 4408, Recent Earthquakes: Implications for US Water Utilities (Eidinger and Davis, 2012), outlines an approach to developing performance goals for water utilities.

- Establish "target" performance goals as part of an overall utility-wide seismic vulnerability assessment.
- Evaluate these tentative "target" goals. Costs associated with achieving these goals will not be known initially and it will be necessary to determine what goals are reasonably achieved.
- Conduct a vulnerability analysis to establish the "as-is" susceptibility of the utility. Analysis may be probabilistic (likelihood of occurrence) or deterministic (scenario based).
- Evaluate potential mitigation and response activities to determine capital improvements required.
- Rank the performance goals with respect to ability of capital improvements or mitigative measures to meet the target goals. Economic analysis should be used to establish suitability of the goals.
- After review, finalize "target" goals and develop a suitable multi-year capital program necessary to meet these goals.

One of the near-term outcomes of the Water Supply Forum will be development of regionally coordinated level of service goals for utilities in the Puget Sound area. Further assessment of the consequence, likelihood, and vulnerability of the City's system should be conducted. With this risk information, the City policy makers can make informed decisions regarding the extent to which the City integrates the Water Supply Forum suggested level of service goals, thus giving Bellevue some consistency with regional assessment goals.

10. Recommendations

While the Mercer Island approach of five gallons per person per day is currently achievable with existing emergency wells, this would be at the low end of the level of service the City may desire. The Oregon Resilience Plan Goal presents an aggressive strategy for return of service that is not necessarily achievable in the near future for Bellevue. It may be more appropriate to assume a total loss of water in the near term and a longer period of recovery such as the 45 to 60 days noted by Seattle Public Utilities. Using the assumption of total loss of water in the near term, a total need for about 9 mgd of emergency

water supply could be assumed immediately following an event. It is recommended that the more conservative approach of providing 9 mgd in emergency water be pursued.

In addition, the City should continue to monitor the work of the Water Supply Forum so that emergency water planning is coordinated with other utilities in the region.

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APPENDIX A

ADDITIONAL INFORMATION

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The following presents additional detailed information on benchmark studies and policies reviewed for this memorandum.

Oregon Resilience Plan

The Plan notes the interdependencies of aspects of infrastructure on a utility provider's ability to respond and restore water service following an event. Damage to transportation corridors is noted as having potential to significantly impact the ability of repair and response crews to access damaged portions of the system and the transport of materials needed for repairs into affected areas. Damage to power and fuel supplies is expected to impact the ability of pump stations and treatment facilities. Disruption of the supply chain is projected to impact the ability to implement repairs or to continue normal operations. Damage throughout the region would impact work force availability in general. The Plan also points out that systems are financially dependent on consistent revenue streams to fund ongoing operations, not to mention extensive repair and replacement following such an event.

The following are brief summaries of the various water components associated with the various Water System Recovery Goals established in the Plan.

Potable Water Supply Source

In the case of Bellevue, the potable water supply source represents the first point where water comes into the distribution system, and it is dependent on resiliency of the source water system being operational. Depending on the degree of resiliency in the City's storage, longer recovery of the source could be accommodated while relying on stored water.

Main Transmission Facilities, Pipes, Pump Stations, and Reservoirs

The Plan identifies main transmission facilities, pipes, pump stations, and reservoirs as key features of the backbone of the system. Repair and restoration of these assets would receive high prioritization in order to minimize the overall recovery timeframe.

Water Supply to Critical Facilities

Critical facilities are identified within the Plan as hospitals, first-aid facilities, command and control centers, and industries essential to recovery and restoration of services. The Plan assumes critical facilities will be nearly operational due to either on-site storage or capacity of the local supply. For Bellevue, this assumption may not be appropriate.

Fire Suppression

Loss of storage and depressurization would impact fire suppression capabilities. The Plan anticipates firefighting strategies more commonly used in rural areas where water would be used from lakes, streams, and any surviving storage reservoirs. Water would be drafted by fire engines from these sites and tankers could move water to fires. Immediately after the event, the focus would likely be on life safety and containment of fires rather than attempting to extinguish all fires. As the distribution system is repaired, fire hydrants will become operational in a phased manner.

Potable Water at Community Distribution Points

Emergency supplies would be required for the first several weeks depending on location and condition of transportation. Water for healthcare facilities could be expected to be extremely limited. Emergency supplies would be initially for subsistence needs only. This would include

direct consumption. The Plan anticipates bulk water delivered to smaller tanks and portable bladders located throughout the affected area. People would carry water from these distributed locations to their homes. This situation could be expected to last one or two months. In the hardest hit areas, recovery could take much longer. Some portable water treatment units could be expected to be utilized, but the volume of treated water would be much less than the anticipated demand.

Water Available at Community Distribution Centers/Points

The use of community distribution points is recommended for heavily damaged areas. These would be located at strategic points along the backbone of the system. One month to one year is the estimated time required to restore all water and sewer service in the valley zone.

The Task Group that developed the Plan assessed system performance based on available data and experience from similar events. The Task Group superimposed pipelines and materials over mapping of a magnitude 9.0 Cascadia subduction zone earthquake scenario. Empirical data from the American Lifeline Alliance was used to predict breaks and leaks for typical distribution systems. Resulting pipeline and facility failures were estimated as a percentage of overall installed infrastructure. The total number of breaks were projected to be approximately one for every 1.73 miles of pipeline. Service line breaks on the utility side were estimated at two percent of the total number of services and five percent of total services on the customer side.

Water Structures

A preliminary assessment of reservoirs, tanks, and pump stations was developed based on available data on construction and age of critical water facilities. The Task Group evaluated existing facilities based on the building code seismic requirements in place at the time of construction. Water bearing structures in the study's valley zone including reservoirs, tanks, and pumping stations are expected to perform to varying degrees depending on the age of construction. Structures prior to 1990 and near the epicenter will most likely fail; structures constructed after 2000 are anticipated to remain intact and functional.

It should be noted that while goals for recovery following a disruptive event were identified, the assessment of existing conditions by the Task Group found notable performance gaps which would require improvements in order to achieve the desired performance goals. The following were among recommendations for potential improvements.

- Harden existing transmission facilities where possible.
- Replace vulnerable transmission facilities where hardening is not possible.
- Install additional line valves to facilitate isolation of damaged sections.
- Stockpile critical replacement pieces.
- Harden valve and control facilities.
- Provide vacuum relief valves to prevent potential pipeline collapse.
- Install earthquake shutoff valves at selected storage facilities and in vulnerable areas of the distribution system.
- Replace pumping stations constructed prior to 1970; harden pumping stations constructed after 1970.

- Rebuild/redesign transitions between soft piping (e.g. mains) and hard piping at tanks and pump stations.
- Replace 80 to 90 percent of transmission facilities and 20 to 30 percent of the distribution systems using more earthquake resistant materials and design standards.
- Replace tankage constructed prior to 1960 and harden tankage constructed after 1960.
- Incorporate seismic resilience objectives into future capital improvement projects.

San Francisco Area Planning

The U.S. Department of Homeland Security, Federal Emergency Management Agency Region IX, and the California Governor's Office of Emergency Services have developed a Concept of Operations Plan (CONPLAN) for San Francisco Bay Area Earthquake Readiness Response (2008, Interim). The CONPLAN identifies project impacts, objectives and courses of action, response capabilities, and response actions. While this document is primarily focused on emergency operations, it does provide some insight into the anticipated needs of the communities potentially affected by a catastrophic event. For this particular document, a moment magnitude (Mw) 7.7 to 7.9 event was assumed (similar in magnitude to the 1906 San Andreas event).

A methodology developed by FEMA to estimate expected damage to buildings, HAZUS analysis, was used to project anticipated impacts with respect to water supply, distribution, and demand. The projected major impacts included 500 fire ignitions and the following number of households without potable water. An estimate of the percentage of households impacted is shown using 2010-2014 Census Data for population of the counties involved and estimating an average of 2.7 people per household.

- Day 1: 1,828,000 65%
- Day 7: 1,279,000 45%
- Day 30: 256,000 9%

Major water and sewer facilities are anticipated to require significant repairs. Damage to water distribution is likely to take months, requiring temporary systems. Within this region, the Hetch-Hetchy water system supplies water to 2.4 million people in the Bay Area. Projected outages include:

- Pump stations 2 days
- Water treatment plants 3 to 6 days
- Storage tanks 25 to 30 days
- Tunnels 30 to 60 days
- Pipelines up to 40 days

As mentioned, the CONPLAN is focused on emergency operations response. The study breaks this up into three phases post-event:

- Immediate impact Event to E+72 hours
- Sustained response E+72 hours to E+14 days
- Relief E+60 days

Using these phases, the CONPLAN identifies the following objectives:

Event to E+72 hours

- Establish interoperable emergency communications
- Save lives and ensure public safety
- Treat those requiring medical care
- Establish lines of supply and transportation

E 72 hours to E+14 days

- Provide care and shelter for displaced population
- Reestablish medical system
- Reduce hazards to the population
- Conduct mass fatality operations
- Provide interim housing for displaced population
- Restore utilities, infrastructure, and public services
- Establish temporary transportation capabilities

The relief phase objectives have been redacted from the public release version of this report. The CONPLAN recommends an initial estimate of the status of critical infrastructure and facilities within six hours with updates every 12 hours. Critical infrastructure and facilities are identified as:

- Potable and non-potable water and wastewater treatment plants/distribution systems
- Medical facilities including hospitals and nursing homes
- Schools and other public buildings
- Fire and police facilities
- Levees and dams

The CONPLAN also points out that the event itself and evacuation of people out of the area and deploying response teams into the area will have far-reaching impacts throughout the region. Most of the locally stored water supplies held in tanks and small reservoirs can be expected to be depleted within 48 to 72 hours. This would be due to physical damage as well as use for fire, medical, and other critical services.

Possible points of distribution (POD) are identified in CONPLAN (redacted in the publicly available version) based on potential requirements within the area. PODs are anticipated for both water and food, as well as other critical commodities. The actual location of PODs are proposed to be identified by local officials working with FEMA and the California Governor's Office of Emergency Services, post-event. The event is expected to severely impact modes of transporting water and related commodities as well as impede the ability of those in need to reach PODs thus requiring flexibility in choosing locations for the PODs. The Bay Area Urban Areas Security Initiative conducted POD training in 2014 in conjunction with FEMA Region IX and the California Governor's Office of Emergency Services. This workshop included discussion of POD site identification, site staffing, and planning.

Temporary systems including above ground temporary lines for distribution and chemicals for POD water treatment are also anticipated to be required.

Water Supply Forum

In assessing the issues considered for setting level of service goals, the Forum documented planned level of service goals following an earthquake from the following organizations:

- American Water Works Association (AWWA) General Performance Goals
- Contra Costa Water District
- East Bay Municipal Utility District
- City of Everett Public Works
- Oregon Resilience Plan
- San Francisco Public Utilities Commission
- Washington State Resiliency Plan

In addition to the information collected from these entities, the Forum also recognizes the importance of customer expectations and the financial ability to meet these expectations. Both factor into the establishment of goals for post-event level of service. In their literature review, the Forum noted that many agencies acknowledged the relationship between the return to normal level of service goals and the severity of a seismic event. Goals for treatment ranged from untreated or raw water, to minimally disinfected, to full treatment. Water that is introduced into the distribution system would, at a minimum, be disinfected. Distribution system level of service goals were differentiated by customer class such as hospitals, commercial and industrial, and residential customers.

To date, the Forum has not established post-event level of service goals. However, the Forum has identified information that will factor into the development of these goals, including the following:

- Expected system damage following an earthquake
- Time to restore service to customers
- Number of customers with water outages and duration of outages
- Economic impact of loss of water
- Cost to upgrade facilities to reduce the impact of outages
- Regulatory requirements
- Stakeholder input including expectations, risk acceptance, and willingness to commit resources to reduce risk
- Post-event level of service goals established by similarly sized utilities and in areas with comparable seismic activity and by expert opinion

Appendix G. Bellevue Emergency Water Alternatives Analysis

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Technical Memorandum

To:	Douglas Lane, PE City of Bellevue
	Laurie Fulton, PE Stantec
From:	Tom Bell-Games, PE
	Beth Mende, EIT
	Joy Terry, PE
Project:	Bellevue Emergency Water Planning
Date:	2/18/2019 (revised 12/20/2019)
Subject:	Emergency Water Alternatives Analysis

1.0 Introduction

The City of Bellevue is in the process of evaluating existing and potential ground water sources for the purpose of providing water should a major event disrupt the existing water system. The purpose of this memorandum is to evaluate three alternatives for provision of emergency water in the City of Bellevue. The three alternatives are as follows (Robinson Noble, Emergency Well Evaluation, Technical Memoranda 3 and 4, 2015):

1. Drive-up / Emergency use of wells only, for filling trucks or other containers.
2. Wells disconnected under normal operating conditions, but plumbed for quick connection to the distribution system in an emergency.
3. Full-time continuous use of the well waters as permanent sources for the water system.

This technical memorandum evaluates the emergency water alternatives and identifies potential treatment needs and monitoring requirements, along with staffing needs and operation and maintenance requirements both during routine standby mode and during emergency operations. Conceptual design drawings and estimated costs are also included. Each alternative will require property acquisition and site improvements, which are included in the conceptual cost opinion. Net present worth is calculated for two emergency scenarios: a short-term two-week event and a longer term three-month event. Two weeks is assumed to be sufficiently disruptive that emergency water supplies would be required to meet immediate needs. For a longer term event, three months was assumed as a reasonable degree of need, beyond which more permanent relocation and changes in water needs could be expected.

2.0 Emergency Water Demand

The Emergency Water Needs Assessment (Needs Assessment, HDR June 25, 2018), estimates an emergency daily potable water demand for Bellevue of 8.95 million gallons per day (mgd). This is based on 80 percent of the average winter water demand with an additional 11 percent reduction due to conservation. This accounts for all non-essential usage that might be anticipated during a disruptive event. The existing emergency water wells have a combined capacity of 3.82 mgd, based on 24 hour operation. During an emergency, it may only be possible to operate during daylight hours, say 12 hours per day. This would reduce the capacity of these wells to 1.91 mgd. Assuming a total loss of normal water supply following a significant event and the use of all existing emergency wells, a net shortfall of approximately 7.04 mgd could be expected (1.91 mgd existing emergency supply minus 8.95 mgd demand results in 7.04 mgd shortfall) if the full 8.95 mgd is supplied.

WHO has recommended a minimum supply of 15 liters/capita/day (4 gallons/capita/day) in an emergency (WHO Technical Notes on Drinking-water, Sanitation and Hygiene in Emergencies, July 2013). More or less comparable to the WHO recommendation and as noted in the Needs Assessment, a reasonable approach would be to provide 5 gallons/capita/day, similar to what is planned for Mercer Island. The 2017 Bellevue Water Quality Report indicates that Bellevue provides water service to an average daytime population of 223,900. At a minimum of 5 gallons/capita/day, this represents a minimum emergency water demand of at least 1.12 mgd. This would be for only absolutely essential use by residential users. Critical water users such as hospitals would require a greater per capita supply.

2.1 Number of Sites Required

Based on the average capacity for the existing wells, individual well capacity has been estimated to be 650 gallons per minute (gpm) for each of the theoretical emergency wells considered in this evaluation.

For Alternative 1, a point of distribution (POD) would be established at each well site. During an emergency, it is assumed that the PODs would likely only operate 12 hours per day due to security concerns. Security of the equipment during off-hours could be incorporated into the design of the facilities. Such elements could include interlocks on power generation and intrusion alarms. If necessary, this could be augmented with security staffing. Assuming an operation of 12 hours per day at 650 gpm, the total water supply at a single well site POD would be 468,000 gallons per day. At 5 gallons/capita/day, 93,600 customers could theoretically be served per site. To supply the average daytime population of 223,900, approximately 3 sites would be needed based on these assumptions. There are four existing wells (Crossroads Wells 5, 6, 7, at one site and Samena Well 3 at a second site). Wells 5, 6, and 7 are very close to each other and would not be expected to be operated simultaneously. With this in mind, at least one additional well site would likely be needed, at a minimum.

However, the logistics of moving this many people through a given POD site would not be reasonable. The site would require a fairly significant local distribution network to enable the estimated 7,800 people per hour to move through the site, collect water, and leave the site (considering a 12-hour period of operation). Additionally, in an emergency, it is likely that the transportation system would not be entirely functional so a limited number of sites may be less desirable.

To reduce the number of people moving through a POD site and to improve the geographic distribution of POD sites throughout the City, a total of 6 sites are assumed for Alternative 1. This alternative addresses only residential use and does not address the needs of critical customers. For Alternatives 2 and 3, which involve connection to the existing distribution system, operations could be expected 24 hours per day during an emergency. In either case, connection to a compromised distribution system is likely to be problematic with respect to maintaining the required minimum pressures and chlorine residual. However, if the distribution system to be served is intact and can be appropriately isolated from damaged portions of the distribution system, Alternatives 2 and 3 could be an appropriate approach to providing emergency water to critical needs facilities such as hospitals and other health care facilities. In these cases, the base need of 40 gallons/capita/day is assumed for customers planned to be served. Assuming 650 gpm per well, 24 hours per day operation, and adequate on-site storage, up to 23,400 people could be served per well site.

3.0 Water Supply Alternatives

This section evaluates the three water supply alternatives in terms of facilities required, potential treatment needs, and monitoring requirements, along with staffing needs and operation and maintenance requirements. Property acquisition is also considered, and it generally represents the single largest capital cost in each of these alternatives. For this reason, it is anticipated that the City

will try to minimize up-front capital costs by locating as many of the sites as possible on property either already owned by the City or owned by other public entities such as school districts.

Two approaches can be considered with respect to treatment of the emergency supply of water: treatment to achieve potable water standards or, alternatively, no treatment. With the no treatment option, water would be non-potable suitable for sanitary use. This would require boiling and possible addition of disinfectant prior to consumption. Mercer Island is using this approach and plans to distribute calcium hypochlorite tablets for disinfection by users. All alternatives would require significant public notification. This would be particularly important in the no treatment option in which non-potable water would be provided. Non-potable water could also be supplemented with distribution of bottled water for consumption if transportation to points of distribution is possible. The technical memorandum, Water Quality Analysis (Confluence Engineering Group LLC, February 28, 2018) developed a summary of potable water treatment recommendations which are presented in Table 1. As previously mentioned, Alternative #1 could also be considered as part of a no treatment option in which chlorine in the form of calcium hypochlorite tablets could be distributed for disinfection of the water by residential users.

Table 1. Summary of Treatment Recommendations

	Treatment Recommendation		
Treatment Objective	**Alternative #1 (Drive Up)**	**Alternative #2 (Temporary Connection)**	**Alternative #3 (Permanent Connection)**
Disinfection (with chlorine)	Chlorine residual required but 4-log virus inactivation not necessary		4-log virus inactivation recommended
Ammonia removal	Breakpoint chlorination required to achieve stable free chlorine residual		
Fe/Mn removal	Not required	Recommended to avoid loading Fe/Mn to distribution system	
pH Adjustment	Not required	Likely not justified based on cost/complexity	Consider based on results of future corrosion control study

To meet water quality standards, all emergency wells must be disinfected and maintain at least a 0.5 mg/L chlorine residual at the time of delivery to ensure adequate microbial control throughout the distribution system. This would be accomplished by breakpoint chlorination to ensure a stable residual is maintained. A minimum chlorine contact time (CT) of 6 mg/L-min is required prior to the first end user. Maintaining a free chlorine residual of 0.5 mg/L would achieve the minimum required CT after 12 minutes. Bench-scale chlorine demand and decay testing should be performed once wells are developed to determine actual chlorine dosing required.

It is assumed that disinfection will be achieved using either liquid sodium hypochlorite (12.5%) or granular calcium hypochlorite (65%) with a saturator. Long-term storage is not recommended for sodium hypochlorite as it degrades, losing strength over time. As a consequence, sodium hypochlorite would need to be purchased and shipped to each site following a disruptive event, if this was the chemical selected for disinfection. A disadvantage of this approach is that obtaining and delivering sodium hypochlorite might delay response time, depending on the extent of the disruption. Alternatively, calcium hypochlorite tablets could be stored on-site. For the purposes of identifying infrastructure needs and estimating probable costs, calcium hypochlorite is assumed to be the preferred chemical for Alternatives 1 and 2 (temporary usage). For Alternative 3 (permanent usage), liquid sodium hypochlorite is assumed to be the preferred chemical as it is readily available in bulk and would eliminate the need for hypochlorite saturators. This could be brought on site in 55 gallon drums, totes (275 or 330 gallons capacity), or in bulk (approximately 4,000 gallons).

3.1 Alternative 1 – Drive-Up Bulk Water Supply

Alternative 1 is to use emergency wells to provide the public with bulk water supply at fill stations. These fill stations would be located at the well sites for efficiency, with either drive-up or walk-up access provided for collection. Depending on conditions at the time of the emergency event, these facilities could also be used to fill totes or tanker trucks for delivery to neighborhoods around the well site.

A concept for the potable water fill stations site plan is shown in Figure 1. This general layout is based on Federal Emergency Management Agency (FEMA) United States Corps of Engineers (USCOE) IS-26, Guide to Points of Distribution (PODs) (2008). PODs are centralized points used for delivery and distribution where the public travels to the site to pick up commodities and water. IS-26 presents various general site layouts for PODs based primarily on the number of people served per site and the general flow of traffic. For this alternative, a Type 1 POD has been assumed for each site. These are designed to serve 20,000 people per day. Although this memorandum is focused on just emergency water, the FEMA/COE POD guidelines are designed to address distribution of multiple types of commodities including food, water, ice, and other supplies.

A buffer of at least 100 feet around the well would need to be controlled (owned) by the City. This results in a minimum site of about one acre (200 feet by 200 feet). This includes a 100 ft setback from potential sources of well contamination as well as space for stormwater control, on-site storage and equipment, and other permanent structures. Traffic lanes and laydown areas for loading points would not necessarily be located within this area and could be adjacent to the well site utilizing parking lots, surface streets, or open space, depending on the specific site. Figure 1 shows a conceptual layout for the overall site. Figure 2 shows more detail for the immediate area around the well. The well house and chlorine building would be fully enclosed by security fencing and separated from the water filling stations. Chlorine would be injected into the line between the well and a 14,000 gallon hydropneumatic tank. The tank would provide residual pressure to a small localized distribution system for multiple loading points on the site. The site would be paved to facilitate chemical deliveries and movement of equipment on and off site.

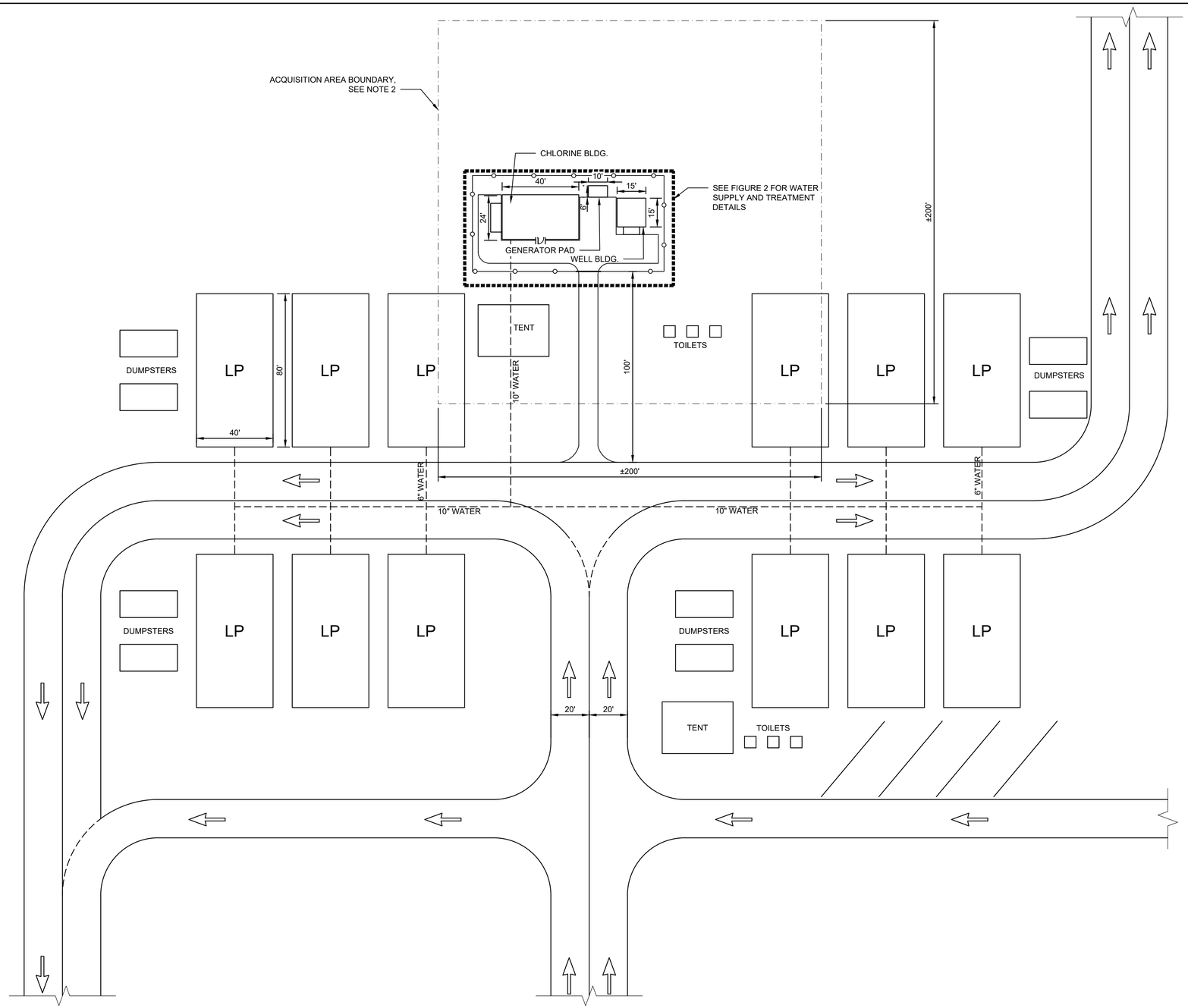
Additional treatment may be required depending on the specific well water quality; however, based on available water quality data and the recommendation presented in Table 1, no further treatment is assumed other than disinfection for the evaluation of this alternative.

Treatment in the form of disinfection would take place at the site of the emergency well. The facilities would include the following structures and equipment:

- Well House
  - Well
  - Well pump
- Chlorine Building
  - Calcium hypochlorite storage and feed system
  - Hydropneumatic tank
  - Flow meter and chlorine residual analyzer, both downstream of the hydropneumatic tank
- Localized distribution between the hydropneumatic tank and fill stations on site
- Truck filling station
- Standby power generator with integral fuel storage
- Portable toilets

Permitting requirements for Alternative 1 include the following:

- Obtaining approval from Washington Department of Health (DOH) and Washington Department of Ecology (DOE) for emergency use of the sources



OVERALL LAYOUT - ALTERNATIVE 1
SCALE: 1"= 30'-0"

NOTES:

1. ALTERNATIVE 1 INCLUDES PIPING AND APPURTENANCES FOR A DRIVE-UP/WALK-UP POINT OF DISTRIBUTION. BULK DELIVERY FOR REMOTE POINTS OF DISTRIBUTION ALSO INCLUDED.
2. THE APPROXIMATE AREA NEEDED FOR THE ALTERNATIVE 1 IS 40,000 SQ.FT. (0.92 ACRES)

LEGEND

- DIRECTION OF TRAFFIC
- LP LOADING POINT
- ACQUISITION AREA BOUNDARY

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BELLEVUE EMERGENCY WATER MASTER PLAN
OVERALL LAYOUT FOR ALTERNATIVE 1

DRIVE-UP

DATE
10-09-2018

FIGURE
1

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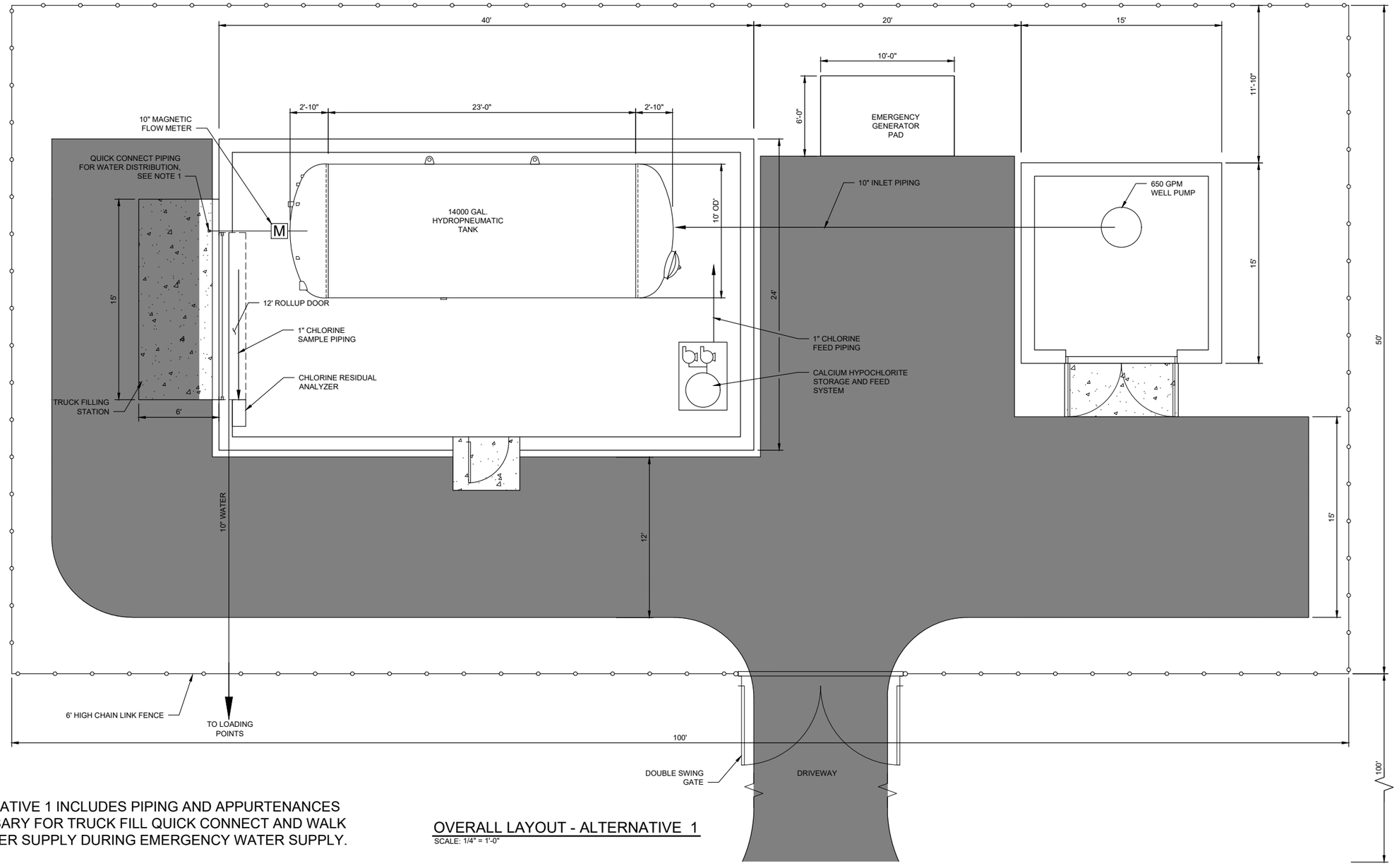

NOTES:

1. ALTERNATIVE 1 INCLUDES PIPING AND APPURTENANCES NECESSARY FOR TRUCK FILL QUICK CONNECT AND WALK UP WATER SUPPLY DURING EMERGENCY WATER SUPPLY.

OVERALL LAYOUT - ALTERNATIVE 1

SCALE: 1/4" = 1'-0"

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BELLEVUE EMERGENCY WATER MASTER PLAN FOR ALTERNATIVE 1

DRIVE-UP

DATE 10-09-2018

FIGURE 2

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- Obtaining emergency water rights approval from DOE
- Submit an Engineering Report to DOH complying with WAC 246-290
- If the water is intended to be treated to potable standards (i.e. maintaining a required free chlorine residual), negative bacteriological testing confirmed by an independent third party lab would be required. Until this testing is confirmed, the emergency water would need to be considered non-potable, requiring boiling before consumption. DOH may require additional, more frequent testing depending on the nature of the emergency.

The following assumptions were made for the maintenance and operational needs for Alternative 1:

- Staffing of the POD during an event would be by City employees, emergency services staff, or certified volunteers. Training of all staff could be incorporated into annual emergency planning and has been estimated to involve four to eight hours, performed annually. The FEMA/COE IS-26 Guide suggests a staff of 78 per day although this is dependent on the number of different types of commodities to be distributed, the routing of traffic, and other site specific features. This staffing is not included in the cost estimate.
- Staff for the well and treatment facility operation and maintenance during an event is assumed to be one person per 12-hour day.
- The City will maintain the wells and pumps and keep them in operable condition by exercising them at least once per month for up to 5 hours with one hour per month for additional maintenance. The duration of testing could be reduced, based on the City's experience and manufacturers' requirements.
- The City will have 30 days storage of calcium hypochlorite stored at each site. The storage life of calcium hypochlorite is considered somewhat indefinite if the material is stored in dry, protected conditions per manufacturers' recommendations. Particular care needs to be taken to protect the dry chemical from exposure to moisture and humidity.
- The equipment life-time is 20 years, and the annual maintenance equipment repair cost is 2% of the total equipment cost.
- Wells will be tested annually for VOC, coliform, and nitrate.
- Operation during an emergency event would be 12 hours a day for the duration of the event, operated by a standby generator.
- Average chlorine dose of 1.5 mg/L.
- 14,000 gallon hydropneumatic tank.
- Residents would supply their own storage containers for walk-up or drive-up collection of water.

3.1.1 Alternative 1 - Additional Considerations

This alternative relies on the ability for people to reach each of the POD sites and addresses the needs of residential users. It will not support commercial needs or high priority emergency use such as first responders, hospitals, or the Fire Department. Depending on the extent of disruption to City infrastructure, this may or may not be feasible for all sites. The more sites that are developed, the greater the likelihood that the public and individuals staffing the site will be able to reach the POD. Also, if POD sites are designed to serve smaller numbers of people, smaller physical sites would be required.

This alternative is somewhat more resilient than Alternatives 2 and 3 as it is independent of the condition of the distribution system following a disruptive event. This alternative requires more staffing for each POD than Alternatives 2 and 3.

3.2 Alternative 2 - Standby Temporary Connection to Distribution System

Alternative 2 is the use of emergency wells to provide water to the existing distribution system in an emergency. This alternative would consist of a plumbed system from the emergency well that is

normally not connected to the distribution system but is ready to be connected quickly during an emergency. Temporary connecting piping can be stored on site and could be expected to be plumbed within a matter of hours provided the local distribution system is modified to facilitate this installation, staff are available, and the site is accessible. A concept for the emergency well site and temporary connection is shown in Figure 3. As with Alternative 1, a buffer of at least 100 feet around the well would be required to be controlled by the City. This area would be fenced and would include the well house, a hydropneumatic tank, a small building to house pumps and water treatment equipment. A valve vault would be provided to enable quick connection to the distribution system in the event of an emergency.

To meet water quality standards, all emergency wells must be disinfected and maintain at least a 0.5 mg/L chlorine residual at the time of delivery to ensure adequate microbial control throughout the distribution system. This would be accomplished by breakpoint chlorination to ensure a stable residual is maintained. Based on the recommendations summarized in Table 1, iron and manganese removal and pH adjustment would be recommended to avoid introducing oxidized iron and manganese into the distribution system. However, additional treatment may be needed depending on the specific well water quality. For the purpose of this evaluation, it was assumed that treatment in the form of iron and manganese removal through the use of pyrolusite or manganese greensand filtration would be needed. Water quality in existing wells in the area exceeds secondary standards for both iron and manganese. It is not recommended that water with elevated levels of iron or manganese be injected into the distribution system as this could cause longer term water quality problems for the distribution system. This would need to be confirmed at each site once the well is constructed and the water quality for each well is verified.

Water from the well would be directed to two pressure filters operated in parallel within the treatment building. Residual pressure in the filtered water would be boosted by two filtered water booster pumps. The discharge from these pumps would be directed to a hydropneumatic tank which would provide a constant pressure feed into the distribution system. This is shown in more detail in Figure 5.

Treatment by disinfection and removal of iron and manganese (filtration) would take place at the site of the emergency well. The facilities would include the following structures and equipment:

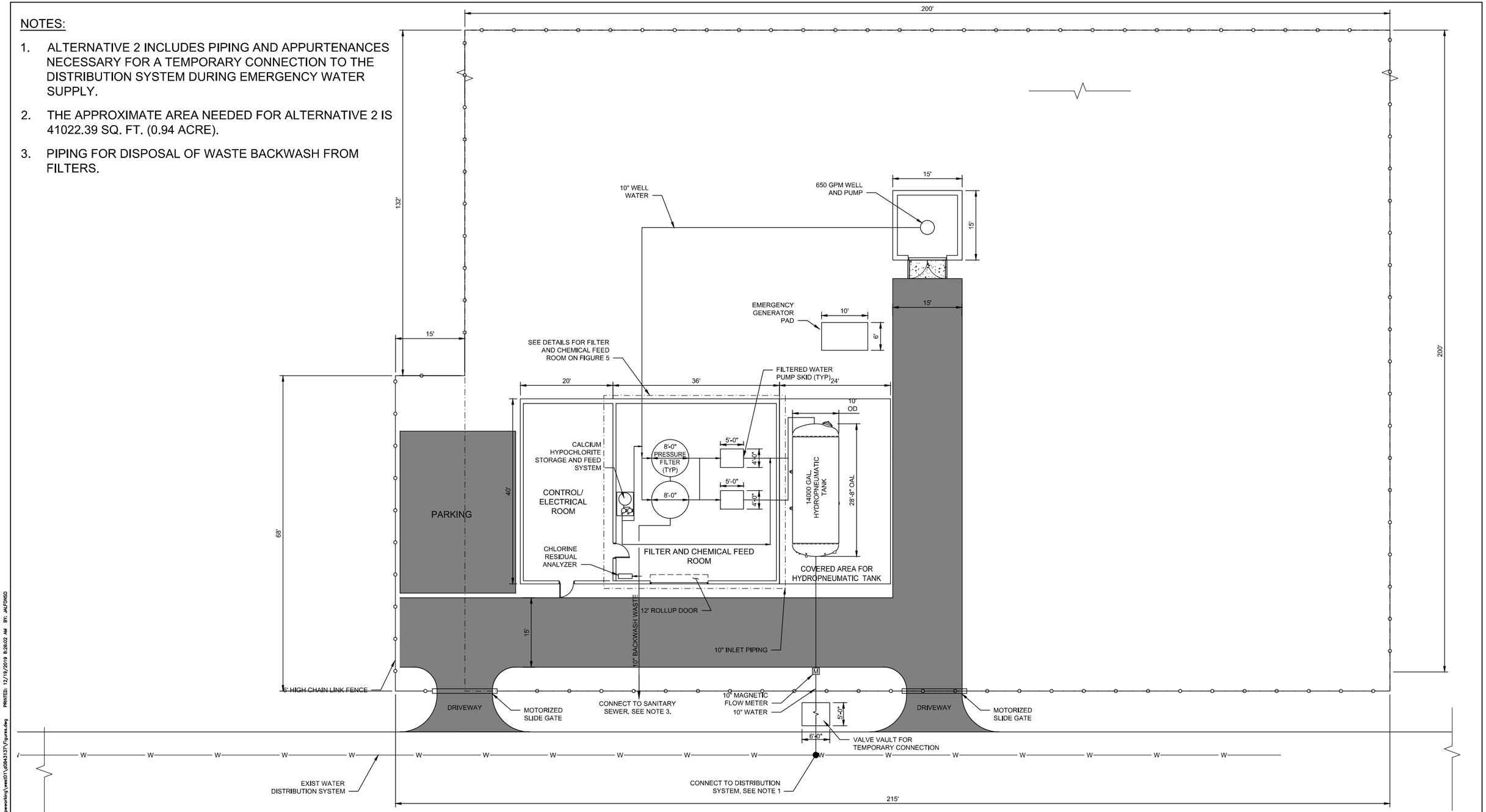
- Well house
    - Well
    - Well pump
- Disinfection storage and feed building
    - Calcium hypochlorite storage and feed system (also used for oxidation of iron and manganese)
    - Hydropneumatic tank
    - Chlorine residual analyzer
- Additional treatment for iron and manganese removal
    - Pressure filters (pyrolusite or manganese greensand)
- Temporary piping for connection with booster pumps downstream of the treatment system
- Permanent piping for disposal of waste backwash water from filters
- Standby power generator

Permitting requirements for Alternative 2 include the following:

- Obtaining approval from DOH and DOE for emergency use of the sources
- Obtaining emergency water rights approval from DOE
- Submit an Engineering Report to DOH complying with WAC 246-290

NOTES:

1. ALTERNATIVE 2 INCLUDES PIPING AND APPURTENANCES NECESSARY FOR A TEMPORARY CONNECTION TO THE DISTRIBUTION SYSTEM DURING EMERGENCY WATER SUPPLY.
2. THE APPROXIMATE AREA NEEDED FOR ALTERNATIVE 2 IS 41022.39 SQ. FT. (0.94 ACRE).
3. PIPING FOR DISPOSAL OF WASTE BACKWASH FROM FILTERS.



OVERALL LAYOUT - ALTERNATIVE 2

SCALE: 1/4" = 1'-0"

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BELLEVUE EMERGENCY WATER MASTER PLAN
OVERALL LAYOUT FOR ALTERNATIVE 2

TEMPORARY CONNECTION

DATE 10-09-2018

FIGURE 3

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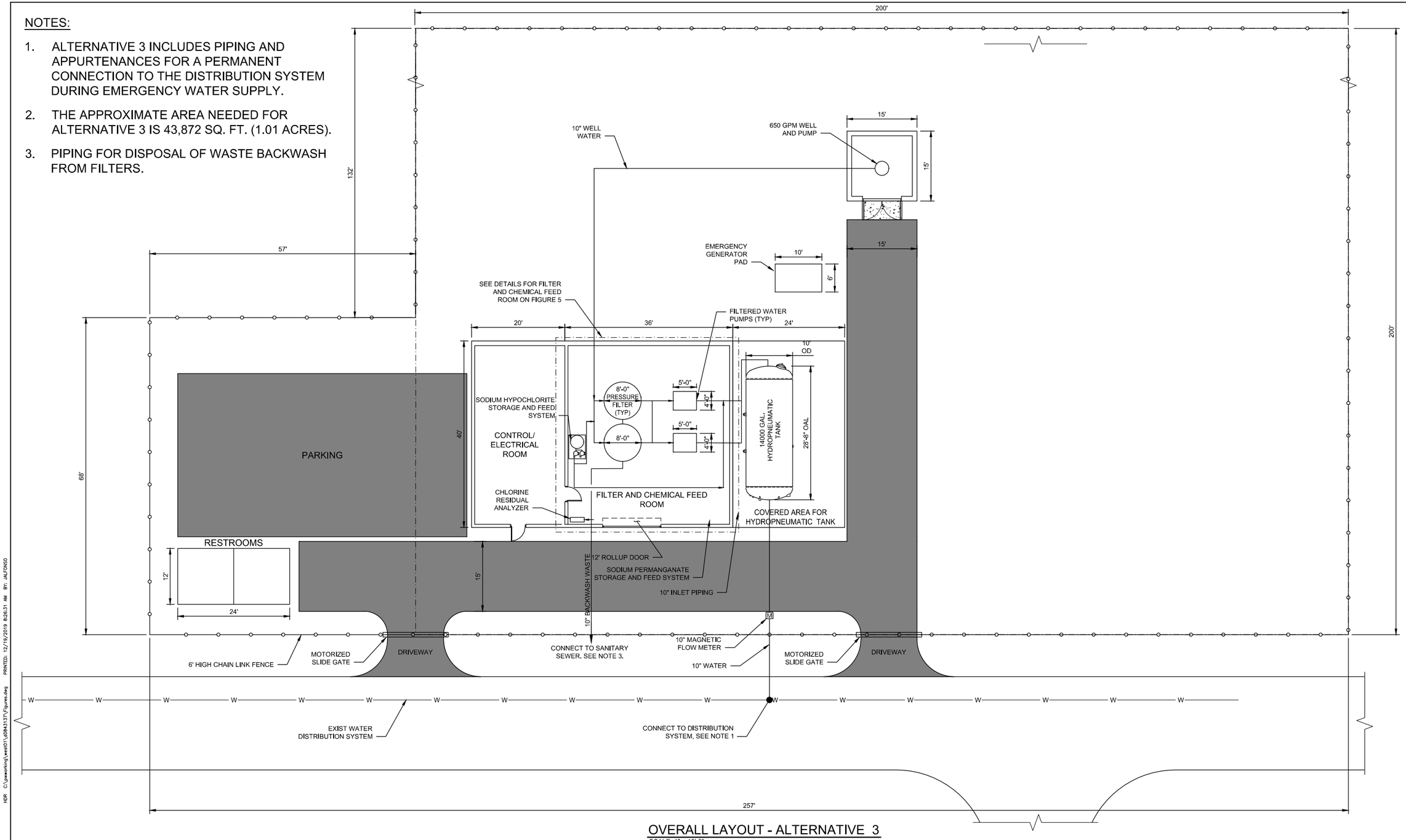
NOTES:

1. ALTERNATIVE 3 INCLUDES PIPING AND APPURTENANCES FOR A PERMANENT CONNECTION TO THE DISTRIBUTION SYSTEM DURING EMERGENCY WATER SUPPLY.
2. THE APPROXIMATE AREA NEEDED FOR ALTERNATIVE 3 IS 43,872 SQ. FT. (1.01 ACRES).
3. PIPING FOR DISPOSAL OF WASTE BACKWASH FROM FILTERS.



OVERALL LAYOUT - ALTERNATIVE 3

SCALE: 1" = 10'-0"

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BELLEVUE EMERGENCY WATER MASTER PLAN
OVERALL LAYOUT FOR ALTERNATIVE 3

PERMANENT CONNECTION

DATE
10-09-2018

FIGURE
4

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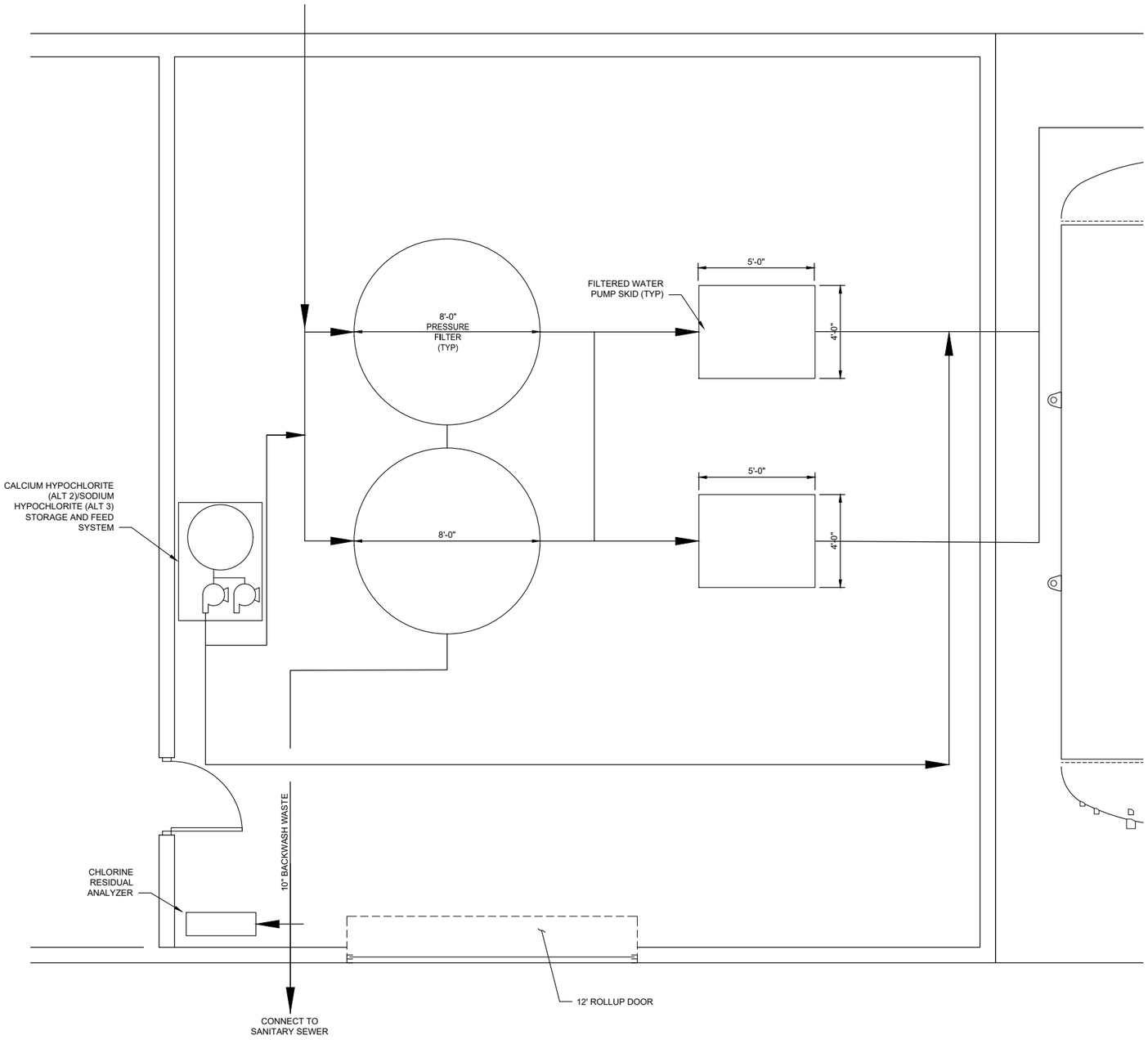

OVERALL LAYOUT - ALTERNATIVE 2 & 3

SCALE: 3/8" = 1'-0"

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BELLEVUE EMERGENCY WATER MASTER PLAN
FILTER AND CHEMICAL FEED ROOM
FOR ALTERNATIVE 2 & 3

BOTH TEMPORARY & PERMANENT CONNECTION

DATE
10-09-2018

FIGURE
5

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The following assumptions were made for the maintenance and operational needs for Alternative 2:

- The City will maintain the wells and keep them in operable condition by exercising the wells and the filtration equipment at least once a month for up to 5 hours.
- The City will have at least 30 days storage of calcium hypochlorite stored on-site.
- The equipment life-time is 20 years, and the annual maintenance equipment repair cost is 2% of the total equipment cost.
- Wells will be tested annually for VOC, coliform, and nitrate.
- Operation of the well during an emergency event would be 24 hours a day for the duration of the event, operated by a standby generator.
- Maximum chlorine dose of 1.5 mg/L.
- 14,000 gallon hydropneumatic tank.

3.2.1 Alternative 2 - Additional Considerations

This alternative relies on the local distribution system to remain intact in the area of each well. If the distribution system is damaged, some wells may not be useful for replenishing portions of the distribution system. If the distribution system can be isolated, this is an appropriate approach to providing an emergency source of water for critical users such as hospitals and related health care facilities and to allow occupancy of nearby buildings (e.g. schools, community centers) that rely on fire sprinkler systems. There may be opportunities with such facilities for the City to partner with critical customers on installation of such an emergency source, recognizing the mutual benefits of improved reliability. An ancillary benefit of Alternative 2 is that other customers in the local, isolated area of the system would have water service. Depending on the needs of the facilities, it might be possible for such a source to also serve as a modified POD for Alternative 1 (drive up) type distribution.

3.3 Alternative 3 - Permanent Connection to Distribution System

Alternative 3 is to use new wells as a permanent water supply to the City. This alternative would consist of a new permanent connection to the City's existing distribution system. A concept for the emergency well site and permanent connection is shown in Figure 4. The overall layout is similar to Alternative 2 with the addition of restrooms and a permanent connection to the distribution system. The detail in Figure 5 applies to Alternative 3 as well.

Based on the recommendations presented in Table 1, disinfection treatment that achieves 4-log virus inactivation (6 mg/L-min) will be needed for this alternative. Additionally, iron and manganese removal will also be required to prevent aesthetic issues and water discoloration episodes. Iron and manganese will be removed using pressure filters with pyrolusite or manganese greensand media. pH adjustment may also be needed for corrosion control depending on the water quality of the well. A full corrosion study has been recommended to be performed if this alternative is selected (Confluence Engineering Group LLC, February 28, 2018).

Treatment would take place at the site of the emergency well and would include the following structures and equipment:

- Disinfection storage and feed building
    - Sodium hypochlorite storage and feed system (also used for oxidation of iron and manganese)
    - Hydropneumatic Tank
    - Chlorine residual analyzer
- Permanent connection to distribution system with booster pumps downstream of the Treatment system
- Additional treatment for iron and manganese removal
    - Pressure filters (pyrolusite or manganese greensand)
- Permanent connection to sanitary sewer for disposal of waste backwash water from filters

- Standby power generator

Permitting requirements for Alternative 3 include the following:
- Obtaining approval from DOH and DOE for permanent use of the sources
- Obtaining water rights approval from DOE

The following assumptions were made for the maintenance and operational needs for Alternative 3:
- The City will collect baseline water quality and bench-scale testing data.
- The City will keep at least 30 days of sodium hypochlorite storage for disinfection on-site at all times. This is equivalent to one tote.
- The equipment life-time is 20 years, and the annual maintenance equipment repair cost is 2% of the total equipment cost.
- Wells will be tested annually for VOC, coliform, and nitrate.
- Operation of wells would be 24 hours a day and would be permanently connected to an existing power source.
- The facility would require oversight by a treatment plant operator.
- Maximum chlorine dose of 1.5 mg/L.
- 14,000 gallon hydropneumatic tank.

3.3.1 Alternative 3 - Additional Considerations

This alternative requires additional bench-scale testing of the long-term impacts of blending groundwater with existing treated surface water to verify water stability. Additional treatment may be required.

This alternative also relies on the ability to rehabilitate existing wells and re-purpose those sites, or to transfer existing water rights as new municipal (non-emergency) water rights are no longer available. Permitting through the Department of Ecology is likely to be difficult and uncertain with respect to these additional water rights. Additionally, the Department of Health may not allow full-time use of existing wells due to historical site contamination, or may have extensive requirements for well-head protection.

As with Alternative 2, this alternative relies on the distribution system to remain intact in the area of each well. If the distribution system is damaged, some wells may not be useful for replenishing portions of the distribution system.

4.0 Conceptual Cost Opinion

This section provides a summary of the life cycle cost comparison (50 year period) for each of the alternatives presented, given the previously listed assumptions, capital costs, and operations and maintenance costs. Life cycle costs were based upon two water supply disruption scenarios; one that lasts for two weeks and another that lasts three months. For the purpose of this analysis, the water supply disruption event was assumed to take place in the year 2030.

Electrical improvements are estimated as 20 percent of all other capital costs. The following are additional costs factored as a percentage of the subtotal of direct costs:
- General Conditions, mobilization, demobilization: 7%
- Bond and All Risk Insurance: 1.5%
- General Contractor overhead and profit: 12%
- Sales Tax: 10.0%
- Undefined scope of work: 20%
- Construction escalation: 2.5%

- Construction change order contingency: 20%

The life cycle cost estimate uses the following baseline factors for calculation:

- Escalation rate: 3.5%
- Discount rate: 2.5%

Lifecycle costs for a two week emergency event and three month emergency event are presented in Table 2 and Table 3, respectively. Costs presented in these tables include engineering (planning, design, and services during construction) and permitting as 39% of total construction cost.

Table 2. Cost Summary for Water Supply Alternatives Per Site for Two Week Emergency Event

	Alternative 1	**Alternative 2**	**Alternative 3**
Capital Construction Costs	$3,253,000	$5,147,000	$5,394,000
Operation and Maintenance Costs (During Emergency Year)	$30,500	$52,100	$110,400
Operation and Maintenance Costs (During Non-Emergency Year)	$24,200	$42,400	$105,200
Total NPV	$4,940,400	$6,727,100	$7,711,000
Total Land Acquisition Costs	$2,300,000	$2,350,000	$2,525,000

Table 3. Cost Summary for Water Supply Alternatives per Site for Three Month Emergency Event

	Alternative 1	**Alternative 2**	**Alternative 3**
Capital Construction Costs	$3,253,000	$5,147,000	$5,394,000
Operation and Maintenance Costs (During Emergency Year)	$53,200	$94,100	$140,200
Operation and Maintenance Costs (During Non-Emergency Year)	$24,200	$42,400	$105,200
Total NPV	$4,966,000	$6,774,300	$7,744,400
Total Land Acquisition Costs	$2,300,000	$2,350,000	$2,525,000

Some options for reducing the overall up front capital costs include the possibility of financial support through funding for emergency equipment to proactively mitigate disaster impacts. As an example, FEMA now offers grants for emergency generators under the Hazard Mitigation Grant Program (HMGP). HMGP funding is available if the generator protects a critical facility (e.g., police and fire stations, hospitals, and water and sewer treatment facilities). Generators that are components of a larger project are also eligible. Generators and related equipment can also be funded as part of a Pre-Disaster Mitigation (PDM) Program. Funding and requirements of the HMGP and PDM Programs vary by fiscal year.

As previously mentioned, Alternatives 2 and 3 costs might also be partially offset through partnering agreements with critical facilities to be served.

5.0 Summary and Recommendations

Three alternatives have been considered to augment the water supply following an event that disrupts the existing potable water supply.

- Alternative 1 – Wells that are independent of the distribution system and would supply localized PODs. Disinfection would be provided. No treatment for aesthetic water quality issues (iron or manganese).
- Alternative 2 – Wells that would be temporarily connected to the distribution system. Disinfection and treatment for iron and manganese would be provided.
- Alternative 3 – Wells that would be permanently connected to the distribution system. Disinfection, treatment for iron and manganese, and potential water stability treatment would be provided.

Alternative 1 is recommended as the best approach for addressing residential use for the following reasons. Capital costs for Alternative 1 wells are lowest. Net present worth for Alternative 1 wells is also the lowest. This approach also has the advantage of being independent of the existing distribution system which may be compromised following a major disruptive event. Staffing would likely consist of a combination of City personnel and ad hoc volunteers. This approach would require the greatest number of people to staff the facilities. Permitting would be most streamlined for Alternative 1. Permitting would be most difficult for Alternative 3 as water rights would need to be obtained for these new permanent sources.

The number of wells required is a more subjective evaluation and is directly related to the amount of water proposed to be supplied per person per day and the anticipated volume of water that can be generated per site per day. The goal for the amount of water to be supplied per person is a policy decision that will need to be established by the City. Based on WHO guidelines and the approach of other utilities in the region, a minimum of 5 gallons/capita/day could be considered. At the high end, based on the estimated essential use, discounted by conservation efforts, as much as 40 gallons/capita/day might be considered for critical users (e.g., hospitals). For the purpose of this evaluation, 5 gallons/capita/day is recommended for Alternative 1 (i.e. drive-up) sites. This equates to a rate of 1.12 mgd emergency water needed for an estimated daytime population of 223,900.

Alternative 2 is recommended as an approach to addressing the emergency water needs of critical facilities (e.g., hospitals) in fixed locations.

The disposition of the existing emergency wells is another factor in estimating the number of additional emergency wells required. Three of the four (Crossroads Wells 5, 6, and 7) are all located on the same site within relatively close proximity to each other. Operation of all three simultaneously may impact their productivity. Further, in terms of logistics, it may not be feasible for the site of these three wells to be utilized for drive-up/walk-up by the same number of people were these wells to be located on three separate sites.

Assuming all four existing wells can be used simultaneously, the four existing emergency wells have a combined capacity of 3.82 mgd over 24 hours. Operating on a twelve hour day during an emergency, these would have a combined capacity of 1.91 mgd. Using Alternative 1, each new emergency well would contribute about 0.468 mgd.

A risk-based approach should be used when the City performs a siting study. This can factor in geographic distribution considerations to address the overall estimated domestic needs throughout the City by way of Alternative 1 type sites. This approach can also be used in identifying the appropriate number and location of Alternative 2 type sites.

In conjunction with a siting study, agreements with contractors for such services as maintenance of temporary sanitary facilities and fuel delivery for emergency generators should be crafted for negotiation in advance of need.

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BASIS OF ESTIMATE – Concept Planning Phase

Project Name	**Emergency Water Supply Planning**
Project Number. CIP Plan #	
CIP Program Number	
Date Prepared	*December 20, 2019*
Requested by	
Prepared by	*Tom Bell-Games, PE, HDR*
Estimate Classification	*Concept Planning, AACE Class 5*
Estimate Purpose/ Milestone	*Charter, Gate, CIP Planning, Project Prioritization, 60% Design, etc.*
Total Cost Estimate and Range	*Alternative 1 $3,253,000 -50% to +100%; per site* *Alternative 2 $5,147,000 -50% to +100%; per site* *Alternative 3 $5,394,000 -50% to +100%; per site*
Total Approved Budget and Date	
Gate Budget and Date	
Approved Change Mgmt. Date	
Change Mgmt. New Total Cost Projection and Range	
Planned Year of Construction	*2020/2021 (est.)*
Project Manager	*Doug Lane, PE*
Cc or Distribution List	

Project Name	**Emergency Water Supply Planning**		
Project Number:		Date:	12/20/2019

1.0 Purpose/ Project Driver/ Problem to be Solved

The City of Bellevue is in the process of evaluating existing and potential ground water sources for the purpose of providing water should a major event disrupt the existing water system. The purpose of this Class 5 cost estimate is to evaluate three alternatives for provision of emergency water in the City of Bellevue. The three alternatives evaluated include:

1. Drive-up / Emergency use of wells only, for filling trucks or other containers.
2. Wells disconnected under normal operating conditions, but plumbed for quick connection to the distribution system in an emergency.
3. Full-time continuous use of the well waters as permanent sources for the water system.

2.0 Project Scope Definition

This project includes the development of a conceptual cost opinion for three alternatives for the provision of emergency supply of water in the City of Bellevue. Each of the three alternatives is evaluated based on potential treatment needs and monitoring requirements, along with staffing needs and operation and maintenance requirements both during routine standby mode and during emergency operations. Additionally, property acquisition requirements and site improvements are included as part of the evaluation.

The net present worth is calculated for each alternative for two emergency scenarios: a short-term two-week event and a longer term three-month event. Two weeks is assumed to be sufficiently disruptive that emergency water supplies would be required to meet immediate needs. For a longer term event, three months was assumed as a reasonable degree of need, beyond which more permanent relocation and changes in water needs could be expected. This section describes the scope of work for each alternative. All references to figures are those found in the main body of the Technical Memorandum, Emergency Water Alternatives Analysis (HDR, 2/18/2019).

Alternative 1 – Drive- Up Bulk Water Supply

Alternative 1 is to use emergency wells to provide the public with bulk water supply at fill stations. These fill stations would be located at the well sites for efficiency, with either drive-up or walk-up access provided for collection. Depending on conditions at the time of the emergency event, these facilities could also be used to fill totes or tanker trucks for delivery to neighborhoods around the well site.

A concept for the potable water fill stations site plan is shown in Figure 1. This general layout is based on Federal Emergency Management Agency (FEMA) United States Corps of Engineers (USCOE) IS-26, Guide to Points of Distribution (PODs) (2008). PODs are centralized points used for delivery and distribution where the public travels to the site to pick up commodities and water. IS-26 presents various general site layouts for PODs based primarily on the number of people served per site and the general flow of traffic. For this alternative, a Type 1 POD has been assumed for each site. These are designed to serve 20,000 people per day. Although this memorandum is focused on just emergency water, the FEMA/COE POD guidelines are designed to address distribution of multiple types of commodities including food, water, ice, and other supplies.

A buffer of at least 100 feet around the well would need to be controlled (owned) by the City. This results in a minimum site of about one acre (200 feet by 200 feet). This includes a 100 ft setback from potential sources of well contamination as well as space for stormwater control, on-site storage and equipment, and other permanent structures. Traffic lanes and laydown areas for loading points would not necessarily be located

within this area and could be adjacent to the well site utilizing parking lots, surface streets, or open space, depending on the specific site. Figure 1 shows a conceptual layout for the overall site. Figure 2 shows more detail for the immediate area around the well. The well house and chlorine building would be fully enclosed by security fencing and separated from the water filling stations. Chlorine would be injected into the line between the well and a 14,000 gallon hydropneumatic tank. The tank would provide residual pressure to a small localized distribution system for multiple loading points on the site. The site would be paved to facilitate chemical deliveries and movement of equipment on and off site.

Additional treatment may be required depending on the specific well water quality; however, based on available water quality data and the recommendation presented in Table 1, no further treatment is assumed other than disinfection for the evaluation of this alternative.

Treatment in the form of disinfection would take place at the site of the emergency well. The facilities would include the following structures and equipment:

- Well House
  - Well
  - Well pump
- Chlorine Building
  - Calcium hypochlorite storage and feed system
  - Hydropneumatic tank
  - Flow meter and chlorine residual analyzer, both downstream of the hydropneumatic tank
- Localized distribution between the hydropneumatic tank and fill stations on site
- Truck filling station
- Standby power generator with integral fuel storage
- Portable toilets

Permitting requirements for Alternative 1 include the following:

- Obtaining approval from Washington Department of Health (DOH) and Washington Department of Ecology (DOE) for emergency use of the sources
- Obtaining emergency water rights approval from DOE
- Submit an Engineering Report to DOH complying with WAC 246-290
- If the water is intended to be treated to potable standards (i.e. maintaining a required free chlorine residual), negative bacteriological testing confirmed by an independent third party lab would be required. Until this testing is confirmed, the emergency water would need to be considered non-potable, requiring boiling before consumption. DOH may require additional, more frequent testing depending on the nature of the emergency.

This alternative relies on the ability for people to reach each of the POD sites and addresses the needs of residential users. It will not support commercial needs or high priority emergency use such as first responders, hospitals, or the Fire Department. Depending on the extent of disruption to City infrastructure, this may or may not be feasible for all sites. The more sites that are developed, the greater the likelihood that the public and individuals staffing the site will be able to reach the POD. Also, if POD sites are designed to serve smaller numbers of people, smaller physical sites would be required.

This alternative is somewhat more resilient than Alternatives 2 and 3 as it is independent of the condition of the distribution system following a disruptive event. This alternative requires more staffing for each POD than Alternatives 2 and 3.

Alternative 2 – Standby Temporary Connection to Distribution System
Alternative 2 is the use of emergency wells to provide water to the existing distribution system in an emergency. This alternative would consist of a plumbed system from the emergency well that is normally not connected to the distribution system but is ready to be connected quickly during an emergency. Temporary connecting piping can be stored on site and could be expected to be plumbed within a matter of hours provided the local distribution system is modified to facilitate this installation, staff are available, and the site is accessible. A concept for the emergency well site and temporary connection is shown in Figure 3. As with Alternative 1, a buffer of at least 100 feet around the well would be required to be controlled by the City. This area would be fenced and would include the well house, a hydropneumatic tank, a small building to house pumps and water treatment equipment. A valve vault would be provided to enable quick connection to the distribution system in the event of an emergency.

To meet water quality standards, all emergency wells must be disinfected and maintain at least a 0.5 mg/L chlorine residual at the time of delivery to ensure adequate microbial control throughout the distribution system. This would be accomplished by breakpoint chlorination to ensure a stable residual is maintained. Based on the recommendations summarized in Table 1, iron and manganese removal and pH adjustment would be recommended to avoid introducing oxidized iron and manganese into the distribution system. However, additional treatment may be needed depending on the specific well water quality. For the purpose of this evaluation, it was assumed that treatment in the form of iron and manganese removal through the use of pyrolusite or manganese greensand filtration would be needed. Water quality in existing wells in the area exceeds secondary standards for both iron and manganese. It is not recommended that water with elevated levels of iron or manganese be injected into the distribution system as this could cause longer term water quality problems for the distribution system. This would need to be confirmed at each site once the well is constructed and the water quality for each well is verified.

Water from the well would be directed to two pressure filters operated in parallel within the treatment building. Residual pressure in the filtered water would be boosted by two filtered water booster pumps. The discharge from these pumps would be directed to a hydropneumatic tank which would provide a constant pressure feed into the distribution system. This is shown in more detail in Figure 5.

Treatment by disinfection and removal of iron and manganese (filtration) would take place at the site of the emergency well. The facilities would include the following structures and equipment:

- Well house
    - Well
    - Well pump
- Disinfection storage and feed building
    - Calcium hypochlorite storage and feed system (also used for oxidation of iron and manganese)
    - Hydropneumatic tank
    - Chlorine residual analyzer
- Additional treatment for iron and manganese removal
    - Pressure filters (pyrolusite or manganese greensand)
- Temporary piping for connection with booster pumps downstream of the treatment system
- Permanent piping for disposal of waste backwash water from filters
- Standby power generator

Permitting requirements for Alternative 2 include the following:

- Obtaining approval from DOH and DOE for emergency use of the sources
- Obtaining emergency water rights approval from DOE
- Submit an Engineering Report to DOH complying with WAC 246-290The following assumptions were made for the maintenance and operational needs for Alternative 2:

This alternative relies on the local distribution system to remain intact in the area of each well. If the distribution system is damaged, some wells may not be useful for replenishing portions of the distribution system. If the distribution system can be isolated, this is an appropriate approach to providing an emergency source of water for critical users such as hospitals and related health care facilities and to allow occupancy of nearby buildings (e.g. schools, community centers) that rely on fire sprinkler systems. There may be opportunities with such facilities for the City to partner with critical customers on installation of such an emergency source, recognizing the mutual benefits of improved reliability. An ancillary benefit of Alternative 2 is that other customers in the local, isolated area of the system would have water service. Depending on the needs of the facilities, it might be possible for such a source to also serve as a modified POD for Alternative 1 (drive up) type distribution.

Alternative 3 – Permanent Connection to Distribution System
Alternative 3 is to use new wells as a permanent water supply to the City. This alternative would consist of a new permanent connection to the City's existing distribution system. A concept for the emergency well site and permanent connection is shown in Figure 4. The overall layout is similar to Alternative 2 with the addition of restrooms and a permanent connection to the distribution system. The detail in Figure 5 applies to Alternative 3 as well.

Based on the recommendations presented in Table 1, disinfection treatment that achieves 4-log virus inactivation (6 mg/L-min) will be needed for this alternative. Additionally, iron and manganese removal will also be required to prevent aesthetic issues and water discoloration episodes. Iron and manganese will be removed using pressure filters with pyrolusite or manganese greensand media. pH adjustment may also be needed for corrosion control depending on the water quality of
the well. A full corrosion study has been recommended to be performed if this alternative is selected (Confluence Engineering Group LLC, February 28, 2018).

Treatment would take place at the site of the emergency well and would include the following structures and equipment:

- Disinfection storage and feed building
    - Sodium hypochlorite storage and feed system (also used for oxidation of iron and manganese)
    - Hydropneumatic Tank
    - Chlorine residual analyzer
- Permanent connection to distribution system with booster pumps downstream of the Treatment system
- Additional treatment for iron and manganese removal
    - Pressure filters (pyrolusite or manganese greensand)
- Permanent connection to sanitary sewer for disposal of waste backwash water from filters
- Standby power generator

Permitting requirements for Alternative 3 include the following:

- Obtaining approval from DOH and DOE for permanent use of the sources
- Obtaining water rights approval from DOE

Project Name	**Emergency Water Supply Planning**		
Project Number:		Date:	12/20/2019

This alternative requires additional bench-scale testing of the long-term impacts of blending groundwater with existing treated surface water to verify water stability. Additional treatment may be required.

This alternative also relies on the ability to rehabilitate existing wells and re-purpose those sites, or to transfer existing water rights as new municipal (non-emergency) water rights are no longer available. Permitting through the Department of Ecology is likely to be difficult and uncertain with respect to these additional water rights. Additionally, the Department of Health may not allow full-time use of existing wells due to historical site contamination, or may have extensive requirements for well-head protection.

As with Alternative 2, this alternative relies on the distribution system to remain intact in the area of each well. If the distribution system is damaged, some wells may not be useful for replenishing portions of the distribution system.

Project Name	Emergency Water Supply Planning		
Project Number:		Date:	12/20/2019

3.0 Design Basis

This basis of estimate evaluates the emergency water alternatives and identifies potential treatment needs and monitoring requirements, along with staffing needs and operation and maintenance requirements both during routine standby mode and during emergency operations. Conceptual design drawings and estimated costs are also included. Each alternative will require property acquisition and site improvements, which are included in the conceptual cost opinion.

Emergency Water Demand

The basis for emergency water demand for three alternatives was based off of the following assumptions:

- Emergency Water Needs Assessment (HDR, 2018) estimates emergency daily potable demand of 8.95 mgd
- Existing emergency wells have combined capacity of 3.82 mgd based on 24 hour operation.
- During an emergency, it may only be possible to operate during daylight hours, say 12 hours per day. This would reduce the capacity of these wells to 1.91 mgd.
- Assuming total loss of normal water supply during emergency, there is a net shortfall of 7.04 mgd.
- WHO recommended minimum supply is 4 gallons/capita/day, we will use 5 gallons/capita/day similar to Mercer Island.
- The 2017 Bellevue Water Quality Report indicates water service to an average daytime population of 223,900.
- At 5 gallons/capita/day, minimum emergency water demand is at least 1.12 mgd. This only includes essential use by residential users. Critical water users would require greater supply per capita.

Treatment Objectives

Two approaches can be considered with respect to treatment of the emergency supply of water: treatment to achieve potable water standards or, alternatively, no treatment. With the no treatment option, water would be non-potable suitable for sanitary use. This would require boiling and possible addition of disinfectant prior to consumption. Mercer Island is using this approach and plans to distribute calcium hypochlorite tablets for disinfection by users. All alternatives would require significant public notification. This would be particularly important in the no treatment option in which non-potable water would be provided. Non-potable water could also be supplemented with distribution of bottled water for consumption if transportation to points of distribution is possible. The technical memorandum, Water Quality Analysis (Confluence Engineering Group LLC, February 28, 2018) developed a summary of potable water treatment recommendations which are presented in Table 1. As previously mentioned, Alternative #1 could also be considered as part of a no treatment option in which chlorine in the form of calcium hypochlorite tablets could be distributed for disinfection of the water by residential users.

Project Name	**Emergency Water Supply Planning**		
Project Number:		Date:	12/20/2019

Treatment Objective	Treatment Recommendation		
	Alternative #1 (Drive Up)	**Alternative #2 (Temporary Connection)**	**Alternative #3 (Permanent Connection)**
Disinfection (with chlorine)	Chlorine residual required but 4-log virus inactivation not necessary		4-log virus inactivation recommended
Ammonia removal	Breakpoint chlorination required to achieve stable free chlorine residual		
Fe/Mn removal	Not required	Recommended to avoid loading Fe/Mn to distribution system	
pH Adjustment	Not required	Likely not justified based on cost/complexity	Consider based on results of future corrosion control study

To meet water quality standards, all emergency wells must be disinfected and maintain at least a 0.5 mg/L chlorine residual at the time of delivery to ensure adequate microbial control throughout the distribution system. This would be accomplished by breakpoint chlorination to ensure a stable residual is maintained. A minimum chlorine contact time (CT) of 6 mg/L-min is required prior to the first end user. Maintaining a free chlorine residual of 0.5 mg/L would achieve the minimum required CT after 12 minutes. Bench-scale chlorine demand and decay testing should be performed once wells are developed to determine actual chlorine dosing required.

It is assumed that disinfection will be achieved using either liquid sodium hypochlorite (12.5%) or granular calcium hypochlorite (65%) with a saturator. Long-term storage is not recommended for sodium hypochlorite as it degrades, losing strength over time. As a consequence, sodium hypochlorite would need to be purchased and shipped to each site following a disruptive event, if this was the chemical selected for disinfection. A disadvantage of this approach is that obtaining and delivering sodium hypochlorite might delay response time, depending on the extent of the disruption. Alternatively, calcium hypochlorite tablets could be stored on-site. For the purposes of identifying infrastructure needs and estimating probable costs, calcium hypochlorite is assumed to be the preferred chemical for Alternatives 1 and 2 (temporary usage). For Alternative 3 (permanent usage), liquid sodium hypochlorite is assumed to be the preferred chemical as it is readily available in bulk and would eliminate the need for hypochlorite saturators. This could be brought on site in 55 gallon drums, totes (275 or 330 gallons capacity), or in bulk (approximately 4,000 gallons).

Assumptions that were considered for each alternative when developing the cost estimate are summarized below:

Alternative 1 – Drive-Up Bulk Water Supply

Number of Sites Required:

- Individual emergency well capacity is assumed to be 650 gpm based on existing well average capacity.
- Assuming operation of 12 hours per day, the total water supply at a single well site POD would be 468,000 gallons per day.
- At 5 gallons/capita/day, 93,600 customers could theoretically be served per site.

- The logistics of moving this many people through a given point of distribution (POD) site would not be reasonable. The site would require a fairly significant local distribution network to enable the estimated 7,800 people per hour to move through the site, collect water, and leave the site (considering a 12-hour period of operation). Additionally, in an emergency, it is likely that the transportation system would not be entirely functional so a limited number of sites may be less desirable.
- To reduce the number of people moving through a POD site and to improve the geographic distribution of POD sites throughout the City, a total of 6 sites are assumed for Alternative 1.

Points of Distribution (PODs):

- This general layout is based on Federal Emergency Management Agency (FEMA) United States Corps of Engineers (USCOE) IS-26, Guide to Points of Distribution (PODs) (2008).
- IS-26 presents various general site layouts for PODs based primarily on the number of people served per site and the general flow of traffic. For this alternative, a Type 1 POD has been assumed for each site. These are designed to serve 20,000 people per day.
- A buffer of at least 100 feet around the well would need to be controlled (owned) by the City. This results in a minimum site size of about one acre. This includes a 100 ft setback from potential sources of well contamination as well as space for stormwater control, on-site storage and equipment, and other permanent structures.
- The well house and chlorine building would be fully enclosed by security fencing and separated from the water filling stations. Chlorine would be injected into the line between the well and a 14,000 gallon hydropneumatic tank. The tank would provide residual pressure to a small localized distribution system for multiple loading points on the site. The site would be paved to facilitate chemical deliveries and movement of equipment on and off site.
- Additional treatment may be required depending on the specific well water quality; however, based on available water quality data, no further treatment is assumed other than disinfection for the evaluation of this alternative.

Facilities and Equipment:

- Well House
  - Well
  - Well pump
- Chlorine Building
  - Calcium hypochlorite storage and feed system
  - Hydropneumatic tank
  - Flow meter and chlorine residual analyzer, both downstream of the hydropneumatic tank
- Localized distribution between the hydropneumatic tank and fill stations on site
- Truck filling station
- Standby power generator with integral fuel storage
- Portable toilets

Permitting requirements:

- Obtaining approval from Washington Department of Health (DOH) and Washington Department of Ecology (DOE) for emergency use of the sources
- Obtaining emergency water rights approval from DOE
- Submit an Engineering Report to DOH complying with WAC 246-290

- If the water is intended to be treated to potable standards (i.e. maintaining a required free chlorine residual), negative bacteriological testing confirmed by an independent third party lab would be required. Until this testing is confirmed, the emergency water would need to be considered non-potable, requiring boiling before consumption. DOH may require additional, more frequent testing depending on the nature of the emergency.

Maintenance and operational needs:

- Staffing of the point of distribution (POD) during an event would be by City employees, emergency services staff, or certified volunteers. Training of all staff could be incorporated into annual emergency planning and has been estimated to involve four to eight hours, performed annually. The FEMA/COE IS-26 Guide suggests a staff of 78 per day although this is dependent on the number of different types of commodities to be distributed, the routing of traffic, and other site specific features. This staffing is not included in the cost estimate.
- Staff for the well and treatment facility operation and maintenance during an event is assumed to be one person per 12-hour day.
- The City will maintain the wells and pumps and keep them in operable condition by exercising them at least once per month for up to 5 hours with one hour per month for additional maintenance. The duration of testing could be reduced, based on the City's experience and manufacturers' requirements.
- The City will have 30 days storage of calcium hypochlorite stored at each site. The storage life of calcium hypochlorite is considered somewhat indefinite if the material is stored in dry, protected conditions per manufacturers' recommendations. Particular care needs to be taken to protect the dry chemical from exposure to moisture and humidity.
- The equipment life-time is 20 years, and the annual maintenance equipment repair cost is 2% of the total equipment cost.
- Wells will be tested annually for VOC, coliform, and nitrate.
- Operation during an emergency event would be 12 hours a day for the duration of the event, operated by a standby generator.
- Average chlorine dose of 1.5 mg/L.
- 14,000 gallon hydropneumatic tank.
- Residents would supply their own storage containers for walk-up or drive-up collection of water.

Alternative 2 – Standby Temporary Connection to Distribution System

Site Layout

- As with Alternative 1, a buffer of at least 100 feet around the well would be required to be controlled by the City. This area would be fenced and would include the well house, a hydropneumatic tank, a small building to house pumps and water treatment equipment. A valve vault would be provided to enable quick connection to the distribution system in the event of an emergency.

Water Treatment

- To meet water quality standards, all emergency wells must be disinfected and maintain at least a 0.5 mg/L chlorine residual at the time of delivery to ensure adequate microbial control throughout the distribution system. This would be accomplished by breakpoint chlorination to ensure a stable residual is maintained.
- Iron and manganese removal and pH adjustment is recommended to avoid introducing oxidized iron and manganese into the distribution system. However, additional treatment may be needed depending on the specific well water quality. For the purpose of this evaluation, it was assumed that treatment in

the form of iron and manganese removal through the use of pyrolusite or manganese greensand filtration would be needed.
- Water quality in existing wells in the area exceeds secondary standards for both iron and manganese. It is not recommended that water with elevated levels of iron or manganese be injected into the distribution system as this could cause longer term water quality problems for the distribution system. This would need to be confirmed at each site once the well is constructed and the water quality for each well is verified.
- Water from the well would be directed to two pressure filters operated in parallel within the treatment building. Residual pressure in the filtered water would be boosted by two filtered water booster pumps. The discharge from these pumps would be directed to a hydropneumatic tank which would provide a constant pressure feed into the distribution system.

Facilities and Equipment:

- Well House
  - Well
  - Well pump
- Disinfection storage and feed building
  - Calcium hypochlorite storage and feed system (also used for oxidation of iron and manganese)
  - Hydropneumatic tank
  - Chlorine residual analyzer
- Additional treatment for iron and manganese removal
  - Pressure filters (pyrolusite or manganese greensand)
- Temporary piping for connection with booster pumps downstream of the treatment system
- Permanent piping for disposal of waste backwash water from filters
- Standby power generator

Permitting requirements:

- Obtaining approval from DOH and DOE for emergency use of the sources
- Obtaining emergency water rights approval from DOE
- Submit an Engineering Report to DOH complying with WAC 246-290

Maintenance and operational needs:

- The City will maintain the wells and keep them in operable condition by exercising the wells and the filtration equipment at least once a month for up to 5 hours.
- The City will have at least 30 days storage of calcium hypochlorite stored on-site.
- The equipment life-time is 20 years, and the annual maintenance equipment repair cost is 2% of the total equipment cost.
- Wells will be tested annually for VOC, coliform, and nitrate.
- Operation of the well during an emergency event would be 24 hours a day for the duration of the event, operated by a standby generator.
- Maximum chlorine dose of 1.5 mg/L.
- 14,000 gallon hydropneumatic tank.

Alternative 3 – Permanent Connection to Distribution System

Site Layout

- The overall layout is similar to Alternative 2 with the addition of restrooms and a permanent connection to the distribution system.

Water Treatment

- Disinfection treatment that achieves 4-log virus inactivation (6 mg/L-min) will be needed for this alternative
- Iron and manganese removal will also be required to prevent aesthetic issues and water discoloration episodes.
- Iron and manganese will be removed using pressure filters with pyrolusite or manganese greensand media.
- pH adjustment may also be needed for corrosion control depending on the water quality of the well. A full corrosion study has been recommended to be performed if this alternative is selected

Facilities and Equipment:

- Well House
  - Well
  - Well pump
- Disinfection storage and feed building
  - Sodium hypochlorite storage and feed system (also used for oxidation of iron and manganese)
  - Hydropneumatic Tank
  - Chlorine residual analyzer
- Permanent connection to distribution system with booster pumps downstream of the Treatment system
- Additional treatment for iron and manganese removal
  - Pressure filters (pyrolusite or manganese greensand)
- Permanent connection to sanitary sewer for disposal of waste backwash water from filters
- Standby power generator

Permitting requirements:

- Obtaining approval from DOH and DOE for permanent use of the sources
- Obtaining water rights approval from DOE

Maintenance and operational needs:

- The City will collect baseline water quality and bench-scale testing data.
- The City will keep at least 30 days of sodium hypochlorite storage for disinfection on-site at all times. This is equivalent to one tote.
- The equipment life-time is 20 years, and the annual maintenance equipment repair cost is 2% of the total equipment cost.
- Wells will be tested annually for VOC, coliform, and nitrate.
- Operation of wells would be 24 hours a day and would be permanently connected to an existing power source.
- The facility would require oversight by a treatment plant operator.
- Maximum chlorine dose of 1.5 mg/L.
- 14,000 gallon hydropneumatic tank.

Project Name	Emergency Water Supply Planning		
Project Number:		Date:	12/20/2019

4.0 Project Planning Basis (Schedule, Constructability, Special Construction Equipment, etc.)

Project delivery is assumed to be conventional design-bid-build with no pre-procurement of equipment. The overall project schedule and key milestones have not yet been identified. Permitting will require approval from both Washington Department of Health and Department of Ecology. Emergency use water rights will need to be obtained from the Department of Ecology. In the event of Alternative 3, permanent water rights will need to be established. Building permits and stormwater related permits will be required.

Constructability issues and the need for specialized construction equipment is not anticipated at this time. Due to the highly urbanized environment, sensitivity to surrounding residences and businesses will likely need to be factored into design and construction activities.

4.1 Stakeholders

Local neighborhood stakeholders will depend on the proposed location(s) which are yet to be determined. The Emergency Operations Center will be an interested stakeholder. The Muckleshoot tribe will have an interest in potential groundwater/surface water impacts. The Snoqualmie tribe will have an interest if there are potential impacts to Lake Sammamish. If a Park is identified as a potential POD or if the Crossroads wells site is redeveloped, the Parks Department will have an interest. The Police and Fire Departments will have an interest as this will have impacts on their roles during emergencies. City Utilities will have an interest as this has potential to impact staffing and modification to the drinking water distribution system. The Washington Departments of Health and Ecology will have an interest from a regulatory perspective.

5.0 Proposal/ Unit Price Source Data

Life cycle costs were based upon two water supply disruption scenarios; one that lasts for two weeks and another that lasts three months. For the purpose of this analysis, the water supply disruption event was assumed to take place in the year 2031. A combination of similar project costs, historical data, RS Means and vendor quotations were used to establish direct costs.

This includes cost information provided by subject matter experts, RS Means or determined based on similar elements and their costs from the Mercer Island Booster Chlorination Project. The construction costs are considered a Class 5 cost estimate as defined by the Association for the Advancement of Cost Engineering (AACE) International.

Cost Item	Source	Notes
Site acquisition		
Site improvements		Includes but is not limited to: - Site clearing - Landscaping - Drainage
Excavation	RS Means	Includes but is not limited to: - Excavation for piping

Project Name	**Emergency Water Supply Planning**		
Project Number:		Date:	12/20/2019

Cost Item	Source	Notes
Paving	RS Means	Includes: - Asphalt paving for site area
Fencing and security	RS Means	Includes: - Chain link fencing around site - Access gates
Equipment pads	Past project estimates including the following projects:	Includes but is not limited to: - Chemical tank and equipment pads - Generator storage pad
Well Building	Past project estimates including the following projects: - Olympic View Water and Sewer District New Well Facility	Includes but is not limited to: - Associated well accessories and equipment - Ductile iron water piping - Masonry building
Well	Past project estimates including the following projects: - Olympic View Water and Sewer District New Well Facility	Includes but is not limited to: - Drilling and installing casing for 650 gpm well
Chemical Feed and Bladder Tank Building	Past project estimates including the following projects: - Mercer Island Booster Chlorination Project - Olympic View Water and Sewer District New Well Facility	Includes but is not limited to: - Masonry building - Ductile iron water piping - Chemical feed systems equipment and piping - Safety equipment - Hydropneumatic tanks - Calcium hypochlorite system and startup and training

Project Name	**Emergency Water Supply Planning**		
Project Number:		Date:	12/20/2019

The following multipliers were used to determine total project costs:

- Electrical and Instrumentation: 20 percent
  - Includes all electrical and instrumentation work.
- General Conditions, mobilization, demobilization: 7 percent
  - Site office facilities adequate for staff required to manage project site
  - Field office staff vehicles and equipment
  - SWPPP and minor maintenance of SWPPP measures
  - Project consumables
  - Temporary utilities
  - Temporary facilities
  - Set up and removal of all temporary facilities, including contractor field office
  - Equipment necessary for self-performed work
- Bond and All Risk Insurance: 1.5 percent
  - Bonds and insurance include the following:
    - 0.75% - Bonds
    - 0.75% - General liability
- General Contractor overhead and profit: 12 percent
  - Field OH includes, but is not limited to the following:
    - Field project staff and standard burden
    - Procurement
    - Project controls/scheduling
    - QA/QC manager
    - Safety manager
  - Profit based on
    - Local market conditions
    - Size and scope of project
- Sales Tax: 10.0 percent
  - Includes tax on labor, material, equipment, sub-contractor, profit and bond/insurance
- Undefined scope of work: 20 percent
- Construction escalation: 2.5 percent
- Construction change order contingency: 20 percent
- Engineering (planning, design, and services during construction) and Permitting: 39 percent

6.0 Allowances for Indeterminates (AFI)

Allowances for indeterminates include construction change order contingency as 20% of estimated total bid cost and an additional undefined scope of work as 20% of total direct costs, as noted above.

6.1 Quantity Take-off Factors

The factors and conversions used in the hard cost estimate to estimate quantities and convert to the units of measurement in the bid tab have not been identified at this phase.

Project Name	**Emergency Water Supply Planning**		
Project Number:		Date:	12/20/2019

7.0 Inclusions

Assumptions include an adequate labor supply being available and adequate funding available.

8.0 Exclusions

The following are not included in the estimates: land acquisition, site conditions, removal of hazardous wastes, financing costs, inflation, or construction cost escalation.

9.0 Exceptions

No exceptions noted.

10.0 Risks (Threats and Opportunities)

Risks to the accuracy of these estimates include inflation and unknowns associated with property acquisition. Opportunities may exist for mitigating property costs if the City is able to utilize property already owned.

11.0 Contingency

Contingencies are as noted in Sections 5.0 and 6.0, above.

12.0 Management Reserve

No management reserve is proposed at this time.

13.0 Reconciliation or Trend Analysis

This is an initial concept-level set of estimates. Therefore, there is no basis for a trend.

14.0 Benchmarking (Check to see if Cost Estimate is reasonable)

Benchmarking has not been performed at this time.

Project Name	**Emergency Water Supply Planning**		
Project Number:		Date:	12/20/2019

15.0 Attachments

Attachment A: Project Cost Estimate Breakdown

A breakdown of estimates for site development for each alternative (one site, each) is included as Attachment A.

Attachment B: Estimate Deliverables Checklist

Attach the completed Estimate Deliverables Checklist indicating the project and engineering deliverables to be supplied for the associated estimate classification, and whether they were in fact available during preparation of the estimate.

Attachment C: Reference Documents

Assumptions and cost references are noted in the cost estimate breakdowns included in Attachment A.

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Attachment A: Project Cost Estimate Breakdown, Alternatives 1, 2, and 3

City of Bellevue Water Supply Alternatives
Alternative Construction Cost Estimate
Alternative 1 - Drive-Up Bulk Water Supply
Project Number:

Item No.	Item Description	Quantity	Units	Unit Cost	Item Cost	Cost Source / Notes
	General Site Work					
1	Site Acquisition	0.92	AC	$ 2,500,000	$ 2,300,000	Property acquistion not included in estimate
2	Site improvements (includes site clearing, landscaping and drainage)	1	LS	$ 15,000	$ 15,000	$1,675 per acre for site clearing. Assumed $7,000 for landscaping
3	Excavation	15	CY	$ 5.00	$ 75	Excavation for well discharge piping
4	Asphalt Paving	46,000	SF	$ 5.18	$ 238,280	RS Means 32 12 16.14 1180 6" thick
5	6' High Chain Link Fence	300	LF	$ 33.23	$ 9,969	RS Means 6' high fence Line number 32311320020(
6	6' High Chain Link Swing Gate	1	LS	$ 1,194.21	$ 1,194	RS Means 6' high swing gate 12' opening, Line number 323113205060, includes excavatio
7	Emergency Generator Storage Pad	1	EA	$ 5,000.00	$ 5,000	
	Well Building					
8	Drill and install casing for 650 gpm well	1	LS	$ 200,000.00	$ 200,000	Assumed 300' in depth
9	Equip well - 650 gpm pump and associated piping	1	LS	$ 70,000.00	$ 70,000	
10	15' X 15' Masonry Well Building	225	SF	$ 220.00	$ 49,500	
	Chemical Feed and Bladder Tank Bldg					
11	40' X 20' Masonry Chemical Feed Building	800	SF	$ 220.00	$ 176,000	
12	10" DI Water Piping	650	FT	$ 132.56	$ 86,164	RS Means Total O&P cost for DI pipe. Line Number: 331113.15 2080
13	6" DI Water Piping	360	FT	$ 40.50	$ 14,580	For distribution to loading points
14	Calcium hypochlorite system	1	LS	$ 8,000.00	$ 8,000	Vendor quote - Includes freight and startup and training, and 297 gal tote for storage
15	1" PVC Chlorine Feed and Sample Piping	60	FT	$ 36.39	$ 2,183	RS Means Total O&P cost for 1" Sch 80 PVC pipe. Line Number: 221113741090
16	Chlorine Residual Analyzer	1	EA	$ 5,000.00	$ 5,000	Hach chlorine analyzer
17	10" Magnetic Flow Meter	1	EA	$ 8,000.00	$ 8,000	USA Blue Book
18	14,000 gal 125 psi hydropneumatic tank	1	EA	$ 120,000.00	$ 120,000	
19	Emergency Shower and Eyewash Station	1	EA	$ 5,300.97	$ 5,301	RS Means 2245138000
20	Secondary Containment Pallet for Calcium Hypochlorite	1	EA	$ 1,500.00	$ 1,500	
	Electrical and Instrumentation					
21	Electrical and Instrumentation (20%)	1	LS	$ 149,245.67	$ 149,246	Excluding general sitework
22	Emergency Generator	1	LS	$ 20,000.00	$ 20,000	

SUBTOTAL DIRECT COSTS		**$**	**1,184,992**
GC Mobilization/Demobilization	7%	$	82,949.46
Subtotal Costs		$	1,267,942
Bond & All Risk Insurance	1.5%	$	19,019
Subtotal Costs		$	1,286,961
General Contractor Overhead and Profit	12%	$	154,435
Subtotal Costs		$	1,441,396
Washington State Sales Tax (City of Federal Way)	10%	$	144,140
Subtotal Costs		$	1,585,536
Undefined Scope of Work	20%	$	317,107.15
Subtotal Costs		$	1,902,643
Total Construction Escalation	2.5%	$	47,566
ESTIMATED TOTAL BID COST		**$**	**1,950,209**
Construction Change Order Contigency	20%	**$**	**390,042**
ESTIMATED TOTAL CONSTRUCTION COST		**$**	**2,340,251**
Engineering (Planning, Design, Services during Construction) and Permitting	39%	$	912,697.80
TOTAL ESTIMATED CAPITAL COST		**$**	**3,252,949**

City of Bellevue Water Supply Alternatives
Alternative Construction Cost Estimate
Alternative 2- Standby Temporary Connection to Distribution System
Project Number:

Item No.	Item Description	Quantity	Units	Unit Cost	Item Cost	Cost Source / Notes
	General Site Work					
1	Site Acquisition	0.94	AC	$ 2,500,000.00	$ 2,350,000	Property acquisition not included in estimate
2	Site improvements (includes site clearing, landscaping and drainage)	1	LS	$ 7,000	$ 7,000	
3	Excavation	30	CY	$ 5.00	$ 150	
4	Asphalt Paving	4,500	SF	$ 5.18	$ 23,310	RS Means 32 12 16.14 1180 6" thick
5	6' High Chain Link Fence	550	LF	$ 33.23	$ 18,277	RS Means 6' high fence Line number 323113200200
6	6' High Chain Link Swing Gate	1	LS	$ 1,194.21	$ 1,194	RS Means 6' high swing gate 12' opening, Line number 323113205060, includes excavation
7	Emergency Generator Storage Pad	1	EA	$ 5,000.00	$ 5,000	
	Well Building					
8	Drill and install casing for 650 gpm well	1	LS	$ 200,000.00	$ 200,000	Assumed 300' in depth
9	Equip well - 650 gpm pump and associated piping	1	LS	$ 70,000.00	$ 70,000	
10	15' X 15' Masonry Well Building	225	SF	$ 220.00	$ 49,500	
	Filter and Control Bldg					
11	56' x 40' Filter and Control Masonry Building	2,240	SF	$ 220	$ 492,800	
12	Filter Building 4" Process Piping and Appurtenances	1	LS	$ 20,000	$ 20,000	
13	Iron and Manganese Removal System (includes four 8' Dia Pressure Filters, valves piping, controls, and appurtenances)	1	LS	$ 335,000	$ 335,000	Quote from Loprest
14	Calcium hypochlorite system	1	LS	$ 8,000	$ 8,000	Vendor quote - Includes freight and startup and training, and 297 gal tote for storage
15	10" Magnetic Flow Meter	1	EA	$ 8,000.00	$ 8,000	USA Blue Book
16	Chlorine Residual Analyzer	1	LS	$ 5,000.00	$ 5,000	Hach Chlorine Analyzer
17	Emergency Shower and Eyewash Station	1	EA	$ 5,300.97	$ 5,301	RS Means 2245138000
18	Secondary Containment Pallet for Calcium Hypochlorite	1	EA	$ 1,500.00	$ 1,500	
	Hydro Tank Covered Area					
19	24' X 40' Covered Area adjacent to Filter & Control Building	960	SF	$ 60.00	$ 57,600	
20	14,000 gal 125 psi hydropneuamtic tank	1	EA	$ 120,000.00	$ 120,000	USA Blue Book
21	Piping and Appurtenances for tank	1	LS	$ 10,000.00	$ 10,000	
	Yard Piping					
22	10" DI Yard Piping (Well to Hydro Tank)	200	FT	$ 132.56	$ 26,512	RS Means Total O&P cost for DI pipe. Line Number: 331113.15 2080
23	10" DI Water Piping	300	FT	$ 132.56	$ 39,768	RS Means Total O&P cost for DI pipe. Line Number: 331113.15 2080
24	10" DI Valves and Fittings	1	LS	$ 15,907	$ 15,907	Assumed 40% of DI piping
25	4" DI Water Piping	140	FT	$ 69.31	$ 9,703	RS Means 331414152020
26	10" DI Backwash Piping	150	LF	$ 67.50	$ 10,125	
27	1" PVC Chlorine Feed and Sample Piping	60	FT	$ 34.00	$ 2,040	RS Means Total O&P cost for 1" Sch 80 PVC pipe. Line Number: 221113741090
28	Permanent Piping Connection to Distribution System	1	LS	$ 5,000.00	$ 5,000	
	Electrical and Instrumentation					
29	Electrical and Instrumentation (20%)	1	LS	$ 298,351	$ 298,351	Excluding General Site Work
30	Emergency Generator	1	LS	$ 30,000	$ 30,000	

SUBTOTAL DIRECT COSTS		**$**	**1,875,039**
GC Mobilization/Demobilization	7%	$	131,252.70
Subtotal Costs		$	2,006,291
Bond & All Risk Insurance	1.5%	$	30,094
Subtotal Costs		$	2,036,386
General Contractor Overhead and Profit	12%	$	244,366
Subtotal Costs		$	2,280,752
Washington State Sales Tax (City of Federal Way)	10%	$	228,075
Subtotal Costs		$	2,508,827
Undefined Scope of Work	20%	$	501,765
Subtotal Costs		$	3,010,593
Total Construction Escalation	2.5%	$	75,265
ESTIMATED TOTAL BID COST		**$**	**3,085,857**
Construction Change Order Contigency	20%	**$**	**617,171**
ESTIMATED TOTAL CONSTRUCTION COST		**$**	**3,703,029**
Engineering (Planning, Design, Services during Construction) and Permitting	39%	$	1,444,181
TOTAL ESTIMATED CAPITAL COST		**$**	**5,147,210**

Excluding land acquisition

City of Bellevue Water Supply Alternatives
Alternative Construction Cost Estimate
Alternative 3 - Permanent Connection to Distribution System
Project Number:

Item No.	Item Description	Quantity	Units	Unit Cost	Item Cost	Cost Source / Notes
	General Site Work					
1	Site Acquisition	1.01	AC	$ 2,500,000.00	$ 2,525,000	Property acquistion not included in estimate
2	Site improvements (includes site clearing, landscaping and draingage)	1	LS	$ 7,000.00	$ 7,000	
3	Excavation	30	CY	$ 5.00	$ 150	
4	Asphalt Paving	5,000	SF	$ 5.18	$ 25,900	RS Means 32 12 16.14 1180 6" thick
5	Sewer piping and connection	1	LS	$ 25,000.00	$ 25,000	
6	12' X 24" Masonry Flush Toilets Building	288	SF	$ 220.00	$ 63,360	
7	6' High Chain Link Fence	600	LF	$ 33.23	$ 19,938	RS Means 6' high fence Line number 323113200200
8	6' High Chain Link Swing Gate	2	LS	$ 1,194.21	$ 2,388	RS Means 6' high swing gate 12' opening, Line number 323113205060, includes excavation
9	Emergency Generator Storage Pad	1	EA	$ 5,000.00	$ 5,000	
	Well Building					
10	Drill, develop, and install casing for 650 gpm well	1	LS	$ 200,000.00	$ 200,000	
11	Equip well - 650 gpm pump and associated piping	1	LS	$ 70,000.00	$ 70,000	
12	15' X 15' Masonry Well Building	225	SF	$ 220.00	$ 49,500	
	Hydro Tank Covered Area					
13	24' X 40' Covered Area adjacent to Filter & Control Building	960	SF	$ 60.00	$ 57,600	
14	3000 gal 125 psi hydropneuamtic tank	1	EA	$ 120,000.00	$ 120,000	USA Blue Book
15	Piping and Appurtenances for tank	1	LS	$ 10,000.00	$ 10,000	
	Filter and Control Bldg					
16	56' x 40' Filter and Control Masonry Building	2,240	SF	$ 220.00	$ 492,800	
17	Filter Building 4" Process Piping and Appurtenances	1	LS	$ 20,000.00	$ 20,000	
18	Filters, valves piping, controls, and appurtenances)	1	LS	$ 335,000.00	$ 335,000	Quote from Loprest
19	Sodium Hypolchlorite Feed & Storage System - Dual Pump Skid	1	LS	$ 13,000.00	$ 13,000	Vendor quote - Includes freight and startup and training, and 297 gal tote for storage
20	Backwash Tank and Appurtenances	1	LS	$ 10,000.00	$ 10,000	
21	10" Magnetic Flow Meter	1	EA	$ 8,000.00	$ 8,000	USA Blue Book
22	Chlorine Residual Analyzer	1	LS	$ 5,000.00	$ 5,000	Hach Chlorine Analyzer
23	Emergency Shower and Eyewash Station	1	EA	$ 5,300.97	$ 5,301	RS Means 2245138000
24	Secondary Containment Pallet for Sodium Hypochlorite	1	EA	$ 1,500.00	$ 1,500	
	Yard Piping					
25	10" DI Yard Piping (Well to Hydro Tank)	200	FT	$ 132.56	$ 26,512	RS Means Total O&P cost for DI pipe. Line Number: 331113.15 2080
26	10" DI Water Piping	300	FT	$ 132.56	$ 39,768	RS Means Total O&P cost for DI pipe. Line Number: 331113.15 2080
27	10" DI Valves and Fittings	1	LS	$ 15,907	$ 15,907	Assumed 40% of DI piping
28	1" PVC Chlorine Feed and Sample Piping	50	FT	$ 34.00	$ 1,700	RS Means Total O&P cost for 1" Sch 80 PVC pipe. Line Number: 221113741090
29	Permanent Piping Connection to Distribution System	1	LS	$ 7,000	$ 7,000	
	Electrical and Instrumentation					
30	Electrical and Instrumentation (20%)	1	LS	$ 297,717.63	$ 297,718	
31	Emergency Generator	1	LS	$ 30,000.00	$ 30,000	

	SUBTOTAL DIRECT COSTS		**$ 1,965,042**	Excluding land acquisition
	GC Mobilization/Demobilization	7%	$ 137,552.96	
	Subtotal Costs		$ 2,102,595	
	Bond & All Risk Insurance	1.5%	$ 31,539	
	Subtotal Costs		$ 2,134,134	
	General Contractor Overhead and Profit	12%	$ 256,096	
	Subtotal Costs		$ 2,390,230	
	Washington State Sales Tax (City of Federal Way)	10%	$ 239,023	
	Subtotal Costs		$ 2,629,253	
	Undefined Scope of Work	20%	$ 525,851	
	Subtotal Costs		$ 3,155,104	
	Total Construction Escalation	2.5%	$ 78,878	
	ESTIMATED TOTAL BID COST		**$ 3,233,981**	
	Construction Change Order Contigency	20%	**$ 646,796**	
	ESTIMATED TOTAL CONSTRUCTION COST		**$ 3,880,778**	
	Engineering (Planning, Design, Services during Construction) and Permitting	39%	$ 1,513,503.32	
	TOTAL ESTIMATED CAPITAL COST		**$ 5,394,281**	

Project Name	**Emergency Water Supply Planning**		
Project Number:		Date:	12/20/2019

Attachment B – Cost Estimate Checklist

Project Information clearly stated.

Sources of data clearly identified.

All estimate assumptions and allowances are completely explained.

Quantity Take-off calculations are provided at each submittal of the cost estimate

Major changes from previous estimate versions identified.

All add-on values are provided, and justifications explained.

Estimate detail fully reflects project scope of work, and scope presented in other submitted documents.

Estimate level matches or exceeds the detail level of other submitted documents.

Total estimated cost is within budget and scope.

Costs presented are reasonable and within context for the project.

Estimate has documented application of appropriate cost factors.

Estimate has been reviewed and signed off by Consultant reviewer or as delegated.

Any major scope of work questions or other items of concern by the estimator are clearly identified.

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March 30, 2022

City of Bellevue Emergency Water Supply Master Plan

Survey Report

PRR

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01

Introduction

Purpose

The City of Bellevue Utilities Department is responsible for providing the high-quality drinking water that residential and business customers rely on every day. We take pride in making sure our water service is dependable, a good value, and delivered with the customer in mind.

After a severe earthquake, Bellevue's water supply may be completely unavailable for 3 weeks, followed by a long recovery period with only partial local service for several months. To prepare for this threat, the City is developing an Emergency Water Supply Master Plan. The Master Plan will guide how we improve our system over the coming decades, to shorten recovery time and reduce earthquake impacts to the community.

As the City develops the Master Plan, we wanted to hear from the community. It is important that the City's plan matches our community's priorities. The City of Bellevue hired PRR to conduct a survey to hear the community's thoughts and concerns to help inform how we move forward.

What will the Master Plan accomplish?

To prepare for these threats to Bellevue's water system and supply, the Master Plan will help the City accomplish the following objectives:

- Identify water system risks and potential impacts to the community
- Establish long-term goals for improved water system performance, and minimum levels of service after an event
- Propose mitigation actions and investment levels to improve resiliency over the next 50-years

Potential improvements may include adding more emergency groundwater wells, constructing a resilient "backbone" of more resilient pipes, adjusting the City's existing program to replace aging water mains, and other potential improvements.

For more information about the Emergency Water Supply Master Plan, go to: https://bellevuewa.gov/city-government/departments/utilities/utilities-projects-plans-standards/capital-projects/emergency

Data Collection

Recruitment and Fielding

A random sample of 5,000 residents received two postcard invitations, arriving about one week apart, to take the online survey. The City of Bellevue also advertised the survey on social media, in their newsletter, with flyers, with online ads, through Community Based Organizations, and on the City website. The survey was available online in English, Chinese (simplified), Russian, Korean, Spanish, and Vietnamese, and invitations included all six languages.

Participants who completed the survey were eligible to enter a drawing to win one of five $100 gift cards.

SURVEY PERIOD

Dec. 2, 2021 to
Jan. 3, 2022

1,079 SURVEY RESPONSES

1,015
Residential customers took the survey

23
Commercial customers took the survey

41
additional respondents took the survey*

* Note: 41 people who are not a City of Bellevue water customer (includes residents of Hilltop, Trail's End and Beaux Arts) responded to the survey. We included their responses with the residential customers as they did not significantly influence the results.

Data Analysis

Charts

Quantitative data in this report is mostly presented in charts. Percentage totals in some charts may add up to more or less than 100% due to rounding or if respondents were able to provide multiple responses. Additionally, the total number of respondents varies from chart to chart based on how many people answered each question. As part of the survey design, respondents may skip questions or see different questions based on their previous responses.

Quotes

This report includes summaries and exemplary quotes for open-ended responses. Quotes provide a mix of responses that are examples of a category and show the range of opinions shared. All quotes include demographic information provided by the respondents to better contextualize their comments.

Demographic analysis

This demographics section compares respondents to the whole City of Bellevue water service, including Clyde Hill, Hunts Point, Medina, and Yarrow Point).

PRR used analysis of variance (ANOVA) to examine relationships.

To examine relationships between survey responses and to compare differences by demographic background, PRR used analysis of variance (ANOVA), which allows for statistical comparisons across multiple groups.

This report only describes relationships that are statistically significant.

When something is statistically significant, it means it is highly unlikely to be the result of random chance. To achieve the cut-off for statistical significance, estimates must have a 0.05 significance level (a 95 percent confidence level), and a coefficient of +/- 0.15, indicating a relatively strong association.

Key Findings

Key Findings from Residential Customers

- Few people are prepared for an emergency.
  - Only 20% of Bellevue residential customers have at least one week of emergency drinking water prepared at home.
- Most respondents (77%) said it is very important that the City of Bellevue increase its ability to provide drinking water in the event of a major disaster.
- Most residents would be reliant on the City of Bellevue or other agencies for water within days of a major disaster.
- Most respondents prefer to pay just $3 or $5 per month for emergency water supply infrastructure improvements.
  - More than a third of respondents have concerns about the cost or affordability of paying more to improve the infrastructure.
  - Some residents are happy to pay more.

Key Findings from Residential and Commercial Customers

There is consensus that the priority order for emergency service restoration is:

1. First responders
2. Community recovery centers
3. Essential businesses
4. Commercial and multifamily residential neighborhoods
5. Low-density, single-family neighborhoods

Key Findings from Commercial Customers

- Most would be reliant on the City or other agencies for water soon after a major disaster.
- Most commercial customers would need to reduce services or close without water after a major disaster.

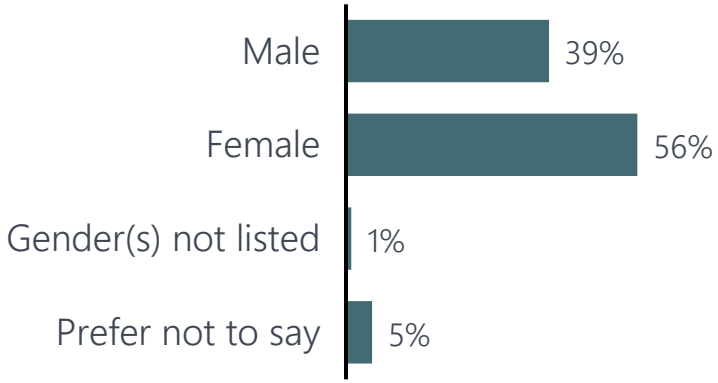
02

Residential Customer Demographic Profile

Residential Customer Demographic Profile – Part 1

Gender

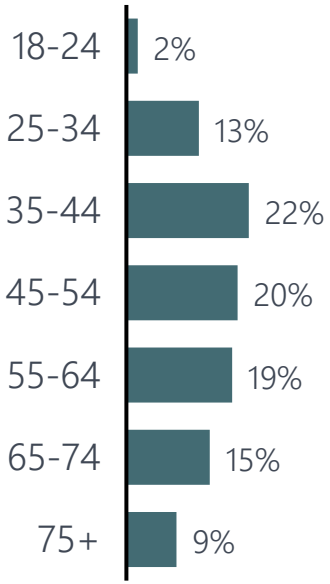
(n= 839)



Respondents skewed female compared to the population in Bellevue.

Age

(n= 826)

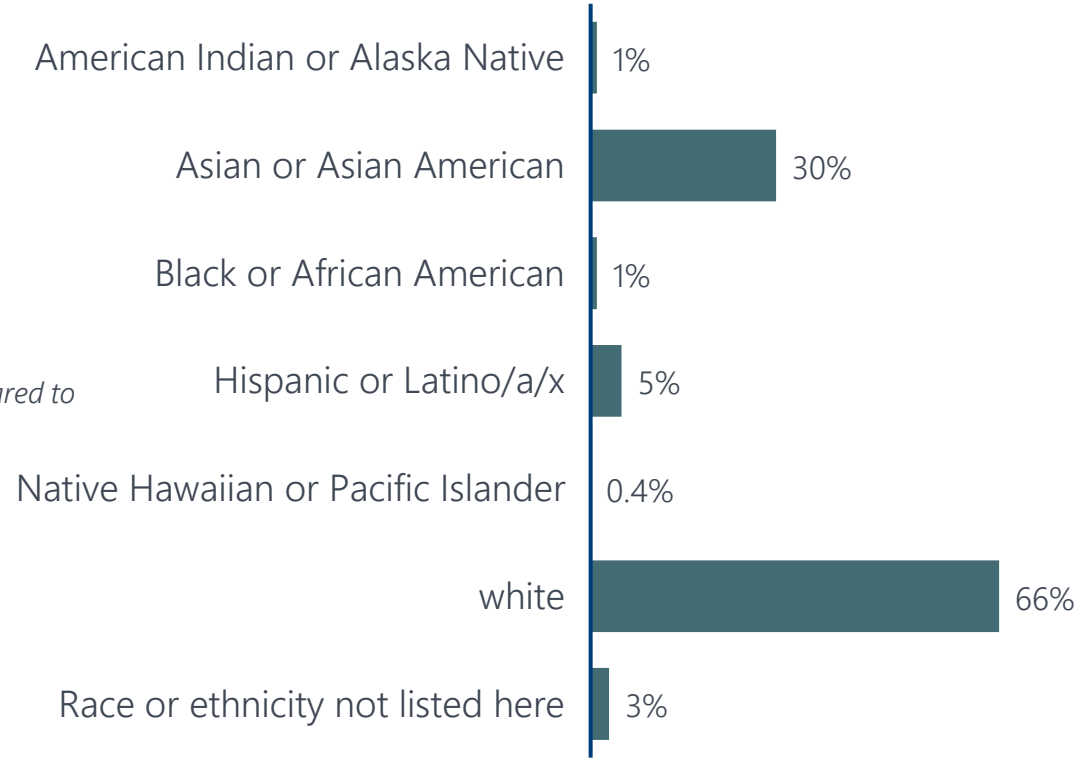


Respondents over-represented all age groups 35+ and under-represented the 18-24 and 25-34 age groups.

Race and Ethnicity

select all that apply

(n= 792)



Respondents skewed white compared to the population in the service area.

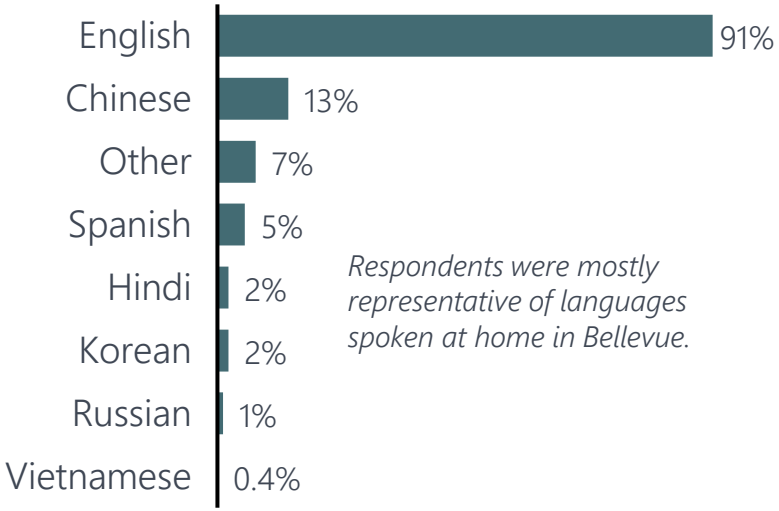
Due to rounding, or options where participants could select multiple answers, percentages may not sum to 100%. Rounding occurs on all demographic slides.

Residential Customer Demographic Profile – Part 2

Languages Spoken at Home

select all that apply

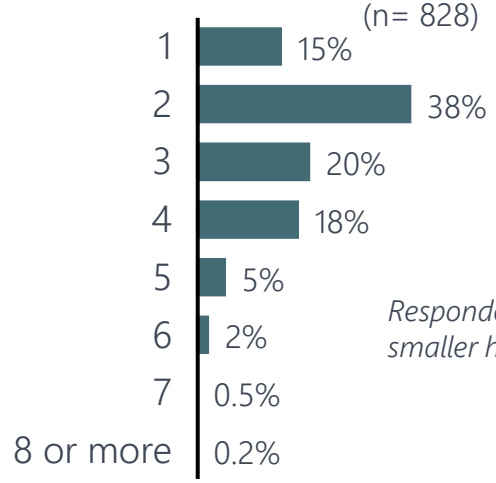
(n= 798)



Respondents were mostly representative of languages spoken at home in Bellevue.

Persons per Household

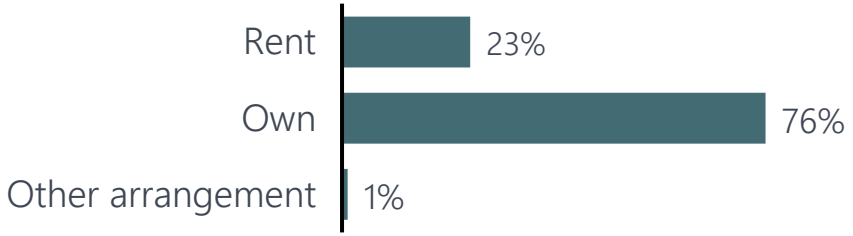
(n= 828)



Respondents over-represented smaller household sizes.

Rent or Own Home

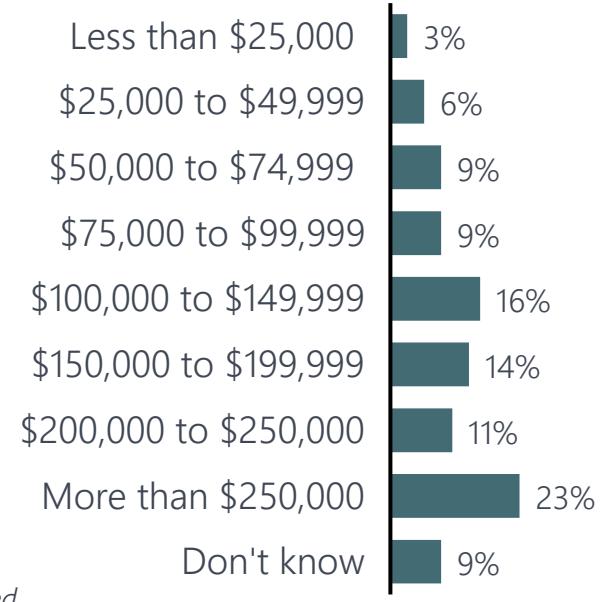
(n= 826)



Respondents over-represented homeowners.

Household Income

(n= 786)



Respondents over-represented households with a higher income.

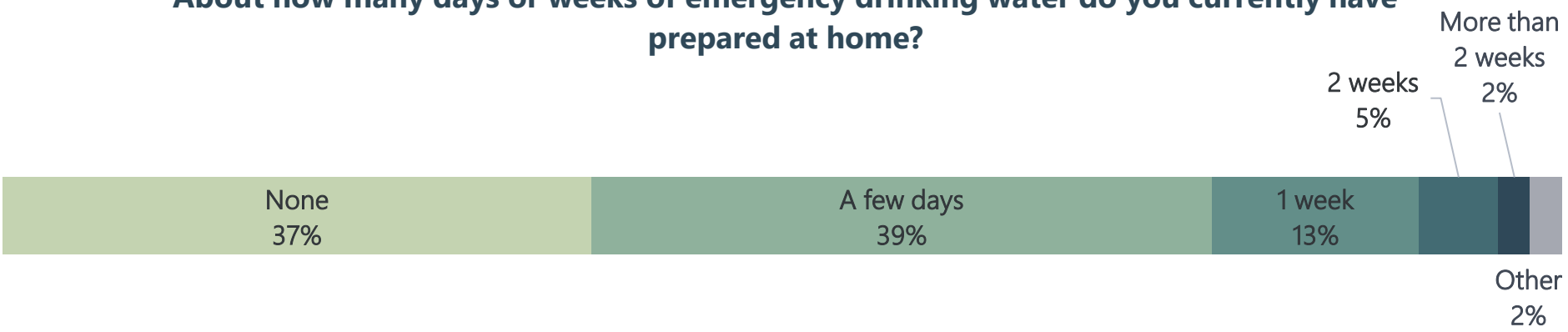
Due to rounding, or options where participants could select multiple answers, percentages may not sum to 100%. Rounding occurs on all demographic slides.

02

Residential Customer Findings

Only 20% of Bellevue residential customers have at least one week of emergency drinking water prepared at home.

About how many days or weeks of emergency drinking water do you currently have prepared at home?



Overall, **the level of preparedness among residential customers is low**. While many respondents said they have at least a few days of emergency drinking water at home, few were prepared for a longer emergency.

- 37% said they have no emergency drinking water
- Only 20% of residential customers said their supplies would last at least one week.
- Only 5% were prepared for 2 weeks and only 2% were prepared for more than 2 weeks.

Additionally, **6% of respondents said they have a special need for water or know someone else who does**. These needs included CPAP machines, dialysis, medical devices, infant formula, and caring for children or elderly persons.

Respondents who selected "other" said they hoped to get drinking water from other sources.

"We have a fishpond that could supply us with water to boil."

"Two days and 580 gallons in storage on external tanks with life straws for each household member"

"Unless we have water in our hot water tank available"

"We have a day or two of bottled water. We also have a 'waterBOB' to store water in our bathtub if we have advanced warning."

"We have a small seasonal stream nearby that we could filter water from"

"We have a portable filtration system for each family member. As long as we have access to water, we can filter it for weeks for each person."

Some mentioned having very limited supplies.

"One or two days only"

"Only have a bit of sparkling water and soda to drink"

Most respondents expect the City of Bellevue to provide drinking water throughout a major disaster.

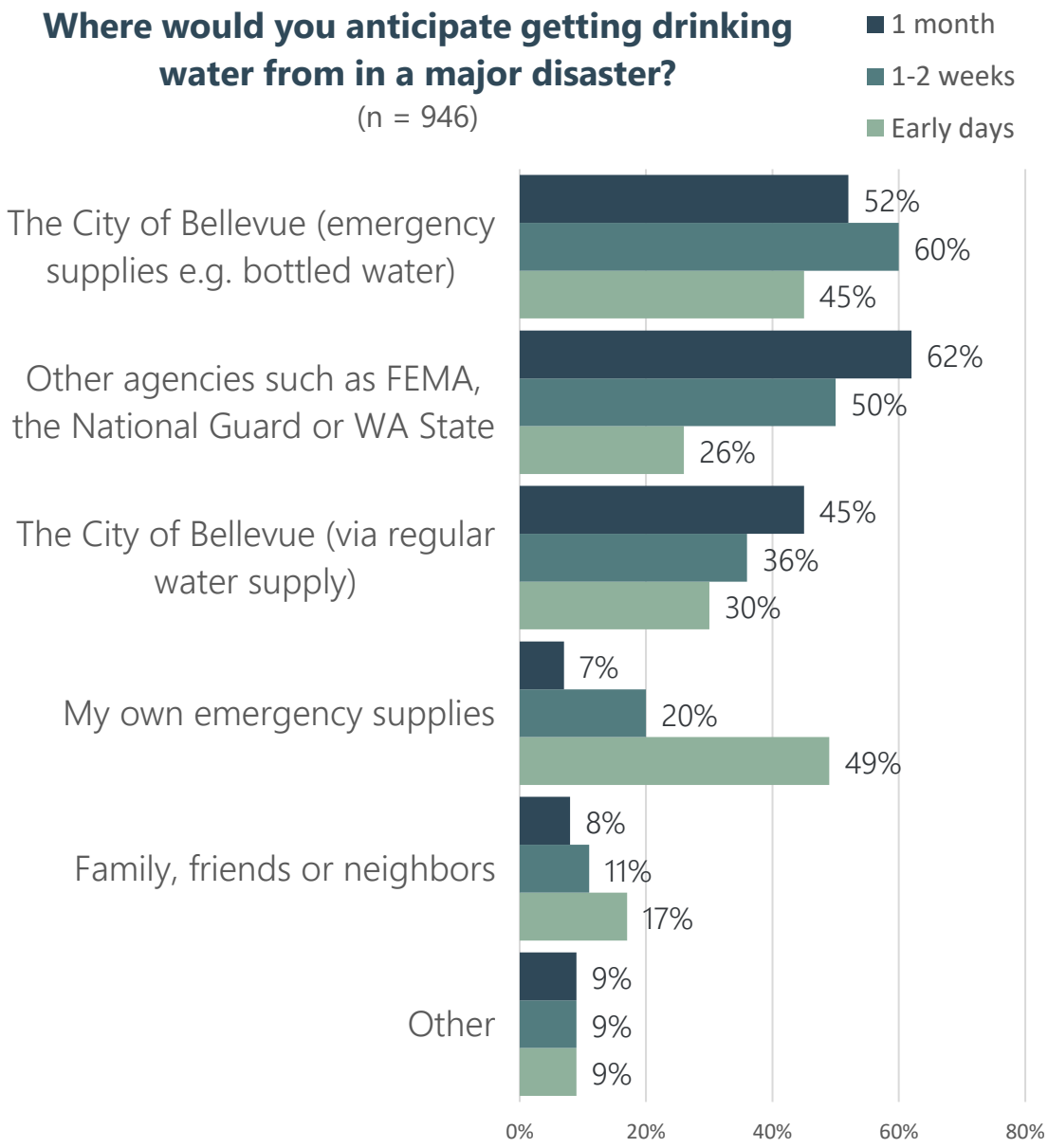
While almost half of respondents anticipate using their own emergency drinking water supply in the early days of a major disaster, by 1-2 weeks in, 60% of respondents expect the City of Bellevue to provide emergency supplies.

Half of the respondents expect other agencies to provide water by 1-2 weeks into a major disaster, and 62% expect that support from other agencies by a month into a major disaster.

Respondents who selected "other" listed these examples for where they would get drinking water after a major disaster:

- Boiling water from Coal Creek or Lake Sammamish
- Bottled water from the grocery store
- Use their own camping water filters (e.g., LifeStraw)
- Use water from household hot water tank, toilet, swimming pool, etc.
- Collect rainwater on their property

Where would you anticipate getting drinking water from in a major disaster?
(n = 946)



Most would be willing to pay an extra $3 or $5 per month to make emergency water preparedness improvements.

There was no consensus on how much residents were willing to pay for these improvements.

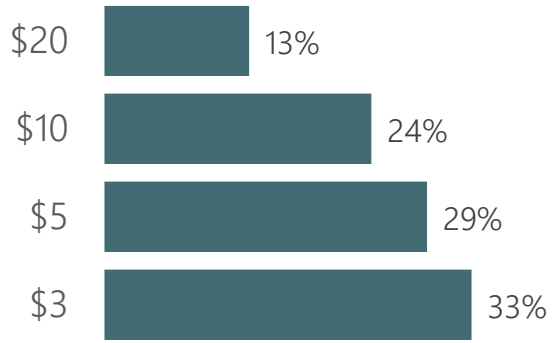
- The most popular option was a third of respondents would be willing to pay $3 per month. However, when asked for more information about why they chose that option, 31 of the 288 respondents who chose the $3 option said they would prefer to not pay for improvements.
- The $5 option was a close second place and followed by the $10 option in third place, selected by about a quarter of the respondents..

Responses to a question about why they chose each option revealed:

- Some said that knowing more about how the additional funding would be spent and how fast these improvements could happen would impact how much they are willing to pay.
- Respondents who have high utility bills, especially those who identified themselves as low-income or retired, were concerned about the additional costs.
- Some respondents wanted more information about the city's current water budget.
- A few respondents suggested the additional fees be proportionate to household incomes.

How much are you willing to pay (monthly) to make these improvements?

(n = 829)



What people were willing to pay varied somewhat based on household income. For example, respondents with households below $50k per year were willing to pay about $5 per month on average. However, respondents in households with incomes greater than $50k per year were willing to pay about $8 per month on average.

Of the 456 people who responded to an open-ended question about why they would pay that much, most selected an amount they said was affordable or reasonable (44%) or not a concern (13%). They tended to choose $5 or more.

Common themes included:

- Willing to pay an amount that felt reasonable
- Can afford to pay more
- Interested in making the investment because this is so important

$20 "I can afford it and believe in proactive emergency planning." *– female, 45-54, $100k to $149k*

$10 "Hard to say without timeline vs cost, but with water being essential, I think we need to be prepared." *– female, white, 65-74, $75k to $99k*

$5 "All I can afford" *– did not answer demographic questions*

$10 "Our infrastructure needs as much help as it can get." *– gender(s) not listed, Asian or Asian American, 25-34, $100k to $149k*

$20 "Advance planning for critical infrastructure is a necessity"- *male, white, 65-74, $75k to $199k*

$5 "We could afford more but I'm basing it on a more affordable number for all." *– female, 45-54*

$10 "I'm seriously concerned about the threat of a major earthquake." *– male, white, 35-44,. $250k+*

$20 "I want faster recovery for all of us.." *– female, Asian or Asian American, 45-54, $100k to $149k*

$20 "If 100% will go to the improvements we are willing to pay more." *– female, Asian or Asian American, 35-44, $250k+*

More than a third (37%) who responded to the open-ended question had concerns about cost or affordability. Most of these respondents chose the $3 option.

Common themes included:

- Already paying a lot for water
- Wondering why there aren't existing funds sufficient to cover the cost
- The cost of living in Bellevue is high, so any additional costs are a financial burden
- Concerns about the impact on low-income residents

Many of these themes were echoed in the social media post responses in the Appendix.

$3 "$0/month. Those costs should already be taken into account." – *male, white, 35-44, $50k to $74k*

$3 "too old to be around much longer." – *male, white, 75+, $150k to $199k*

$3 "Any additional amount will be financially difficult at this time, but this is critical." – *female, white, 55-64, $100k to $149k*

$3 "I pay a lot as it is being on limited income." – *female, white, 65-74, $25k to $50k*

$3 "Minimal as I think current funds could be better utilized and allocated." – *male, white, 65-74, $75k to $99k*

$3 "We are a low-income family so it's hard to add extra costs in the budget." – *female, Hispanic or Latino/a/x, 25-34, <$25k*

$3 "Water bill is extraordinarily high already in Bellevue." – *male, race(s) not listed, 65-74, $100k to $149k*

$3 "The question assumes we must increase rates. And if it must be so, I'd start low, but I would hope that other sources (grants, federal funds earmarked for infrastructure, reallocation of existing city funds) have been explored first." – *male, white, 45-54, $150k to $199k*

Some (12%) who responded to the open-ended question requested more details before committing to spending more. Most of these respondents mostly were willing to pay $3 or $5, but some would pay more.

Respondents' opinions highlight the importance of transparency and communication when planning improvements to the water system.

Most respondents are willing to pay extra for emergency preparedness if they know how the money will be spent, and how quickly they can expect the infrastructure improvements to be made.

$3 "Our bills are already astronomical. What improvements are you planning? People need to know before answering this question." – *female, 65-74*

$3 "I already pay a ridiculously high bill for water/sewer/runoff, and the nation just passed a major infrastructure bill. The choices above are useless without knowing context: what would each level of additional charges buy us?" – *male, Asian or Asian American and white, 65-74, $100k to $149k*

$5 "Since I don't know your current budget and how you spend our current tax dollars, it's hard to answer. Also worry about low- and fixed-income residents. ." – *female, white, 65-74*

$3 "I would prefer a complete plan outlook and detail funding report to support fully with the amount requested." – *female, Asian or Asian American, 45-54, $50k to $74k*

$3 "I would like to see a plan if I have to pay more. What kind of improvements can we expect and how quickly?" – *female, Asian or Asian American, 65-74, >$250k*

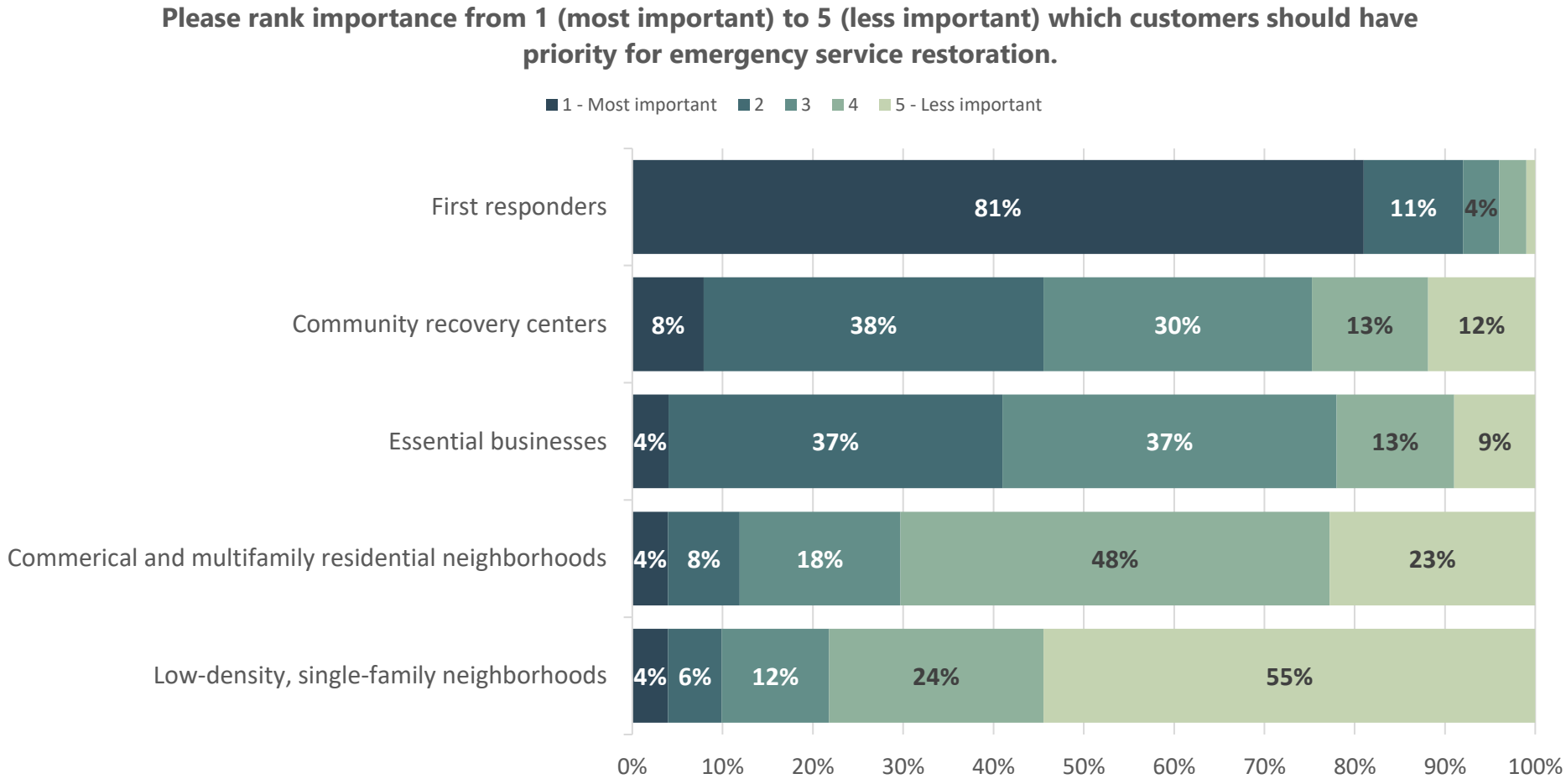
$20 "It's important - but I also wonder how the money would be spent." – *female, white, 65-74, $150k to $199k*

$5 "I need to see the plan and what the additional funds would buy before committing more." – *female, white, 65-74, $200k to $250k*

02

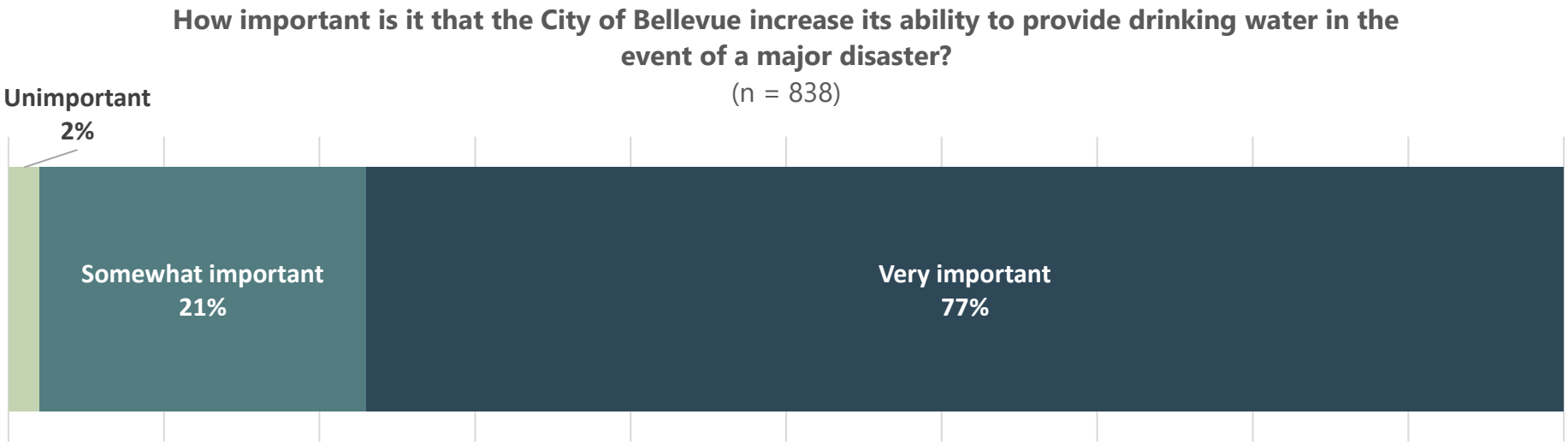
Residential and Commercial Customer Findings

There is general agreement among both residential and commercial customers that first responders should have the highest priority for emergency service restoration in the event of a major disaster.



We asked this questions of both residential and commercial customers. Since there was consensus across both customer communities, we reported the responses together.

The overwhelming majority (77%) of respondents believe it is very important the City increase its ability to provide drinking water in the event of a major disaster



We asked this questions of both residential and commercial customers. Since there was consensus across both customer communities, we reported the responses together.

02

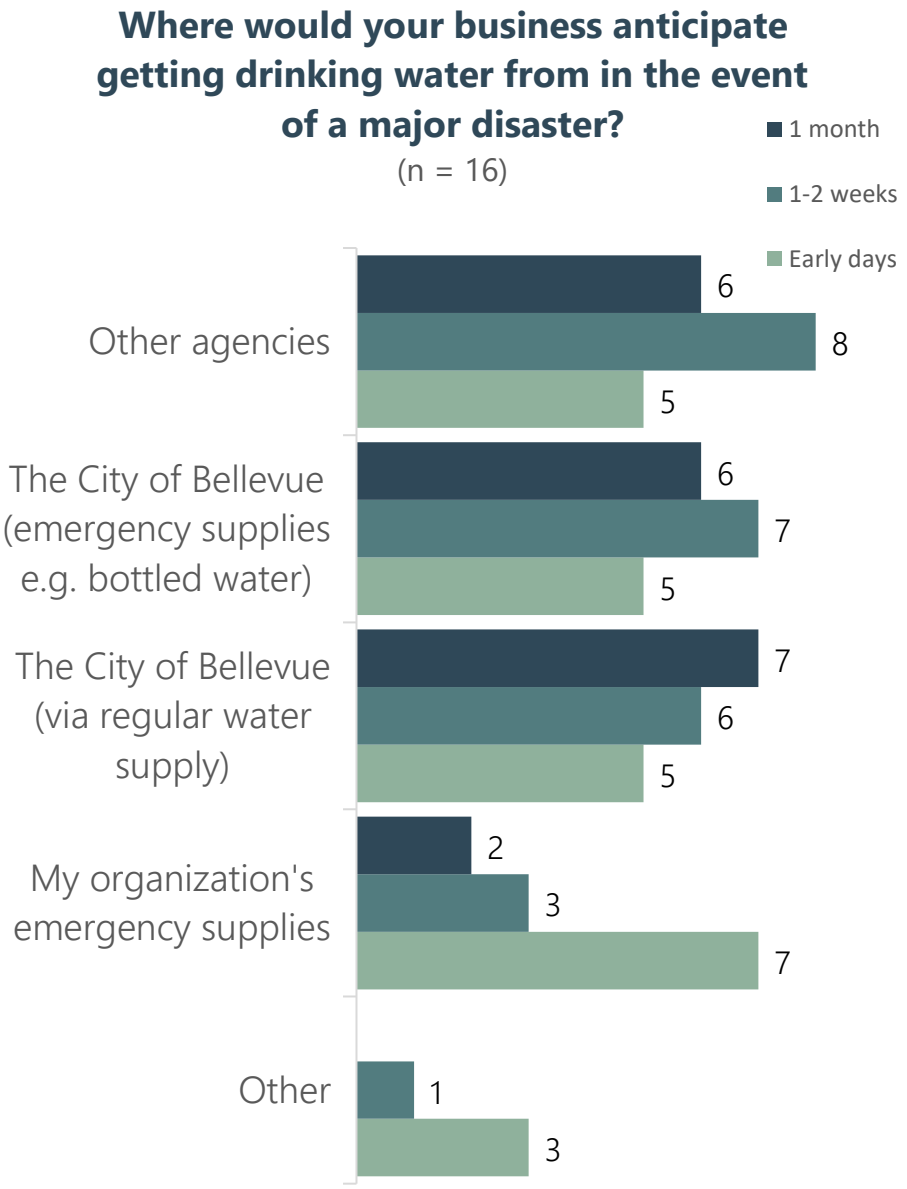
Commercial Customer Findings

Many commercial customers would anticipate receiving water from the City of Bellevue throughout a major disaster.

Most commercial respondents did not have emergency supplies that they expected to rely on for drinking water.

Of commercial customers with some emergency water supply, most only expect that that their own supply will cover them through the early days of a major disaster.

Expectations for support for the duration of a major disaster were fairly evenly divided among the City of Bellevue's emergency supplies, the City's regular water supply, and other agencies like the State and FEMA.



All the commercial customers who responded shared that they would need to close or reduce services during the water shortage. Many were unsure if they would be able to operate with reduced services or need to close entirely.

Close

Pk-8th grade school
Use: Drinking, restrooms

Close or Reduce Services

Technology company
Use: Cooking, cleaning, restrooms, potable water fountains, landscaping
Sensitivity: Restroom availability and sanitization would be key factor in level of closure

Restaurant
Use: Cooking, dishwashing, restrooms

Dr office
Use: Safety equipment, needed for routine medical procedures, cleaning, maintenance

Anonymous

Reduce Services

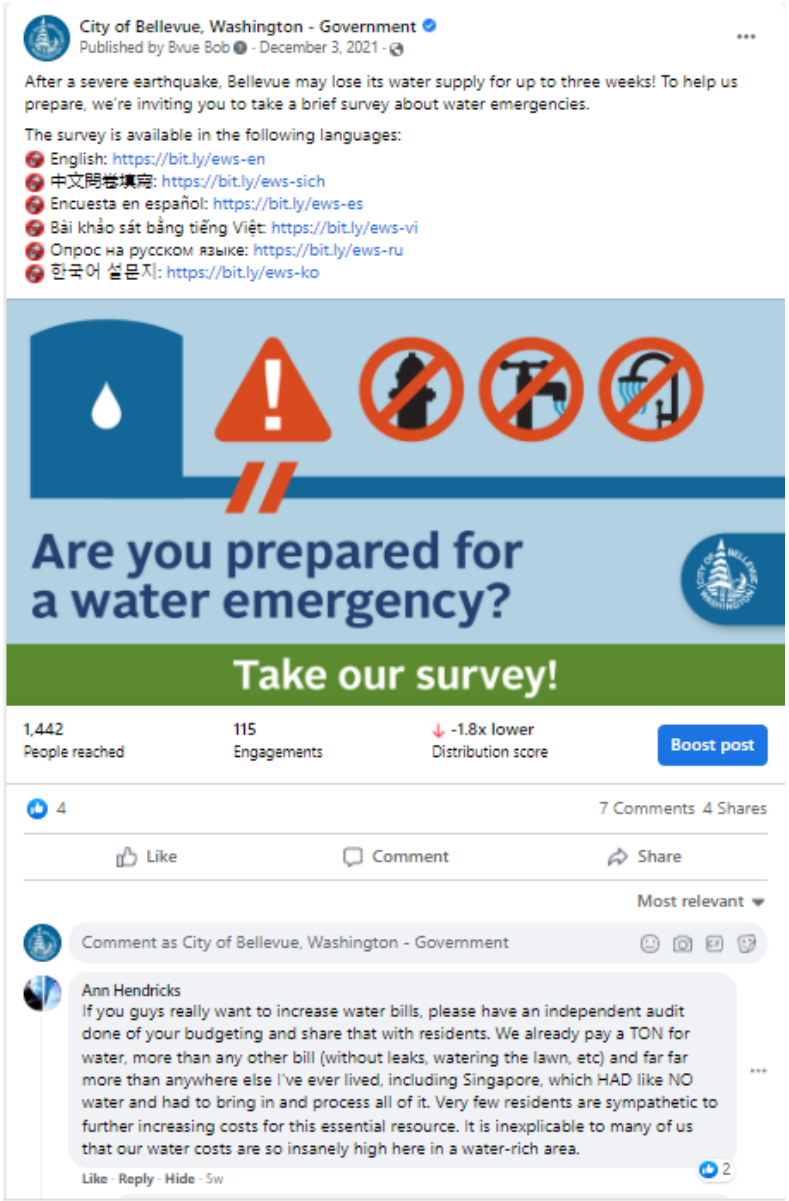
Independent Senior Living and Skilled Nursing Community
Use: Cooking, drinking, bathing, hygiene
Sensitivity: Water is essential for operation

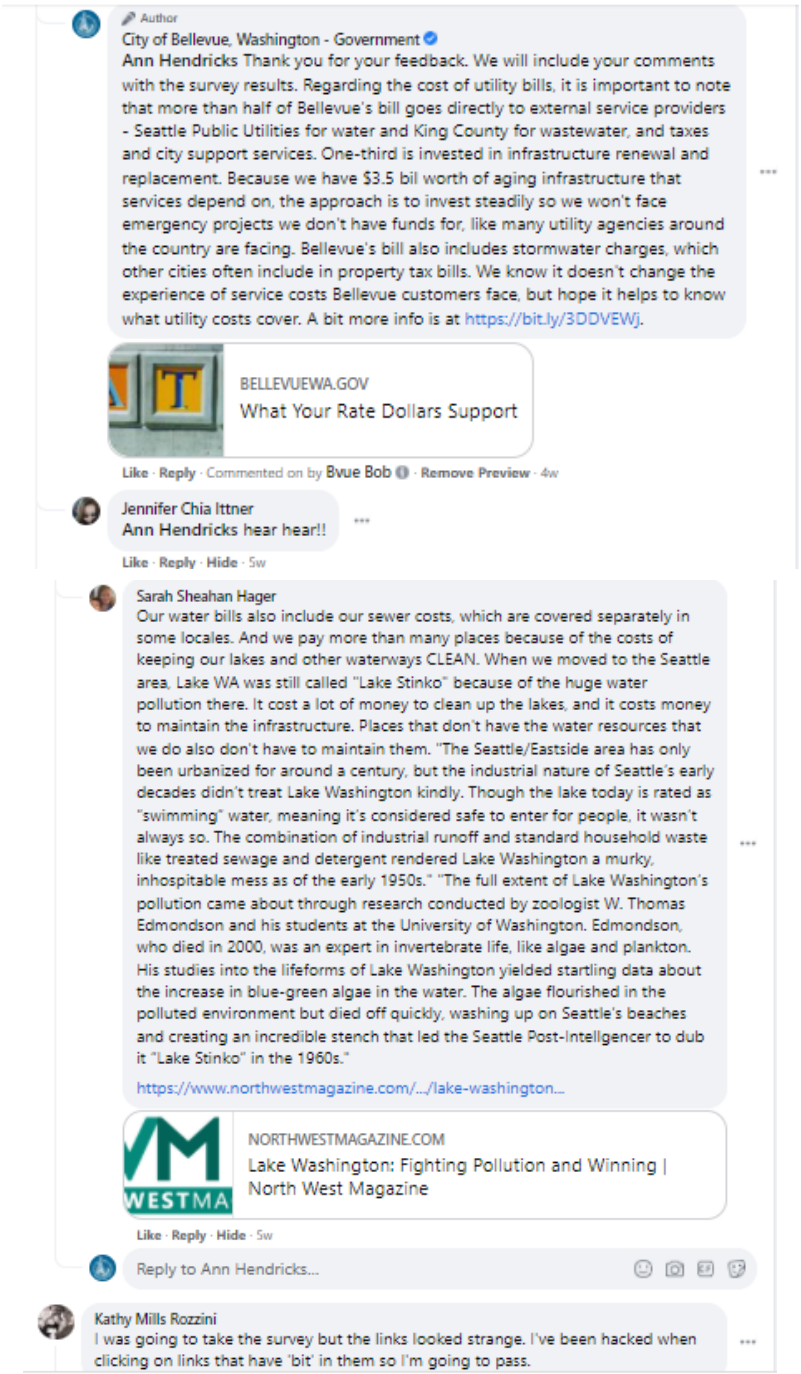
Health Care
Use: Drinking
Sensitivity: Only in residential facility

Anonymous

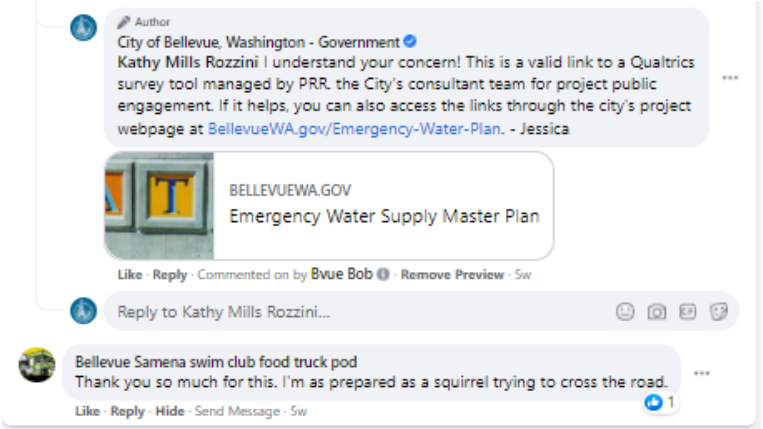
Appendix: Social Media Comments

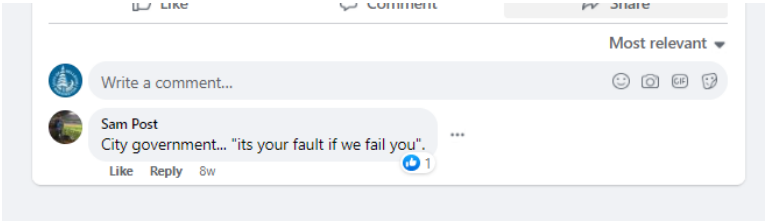
Facebook Ad – Residential Audience



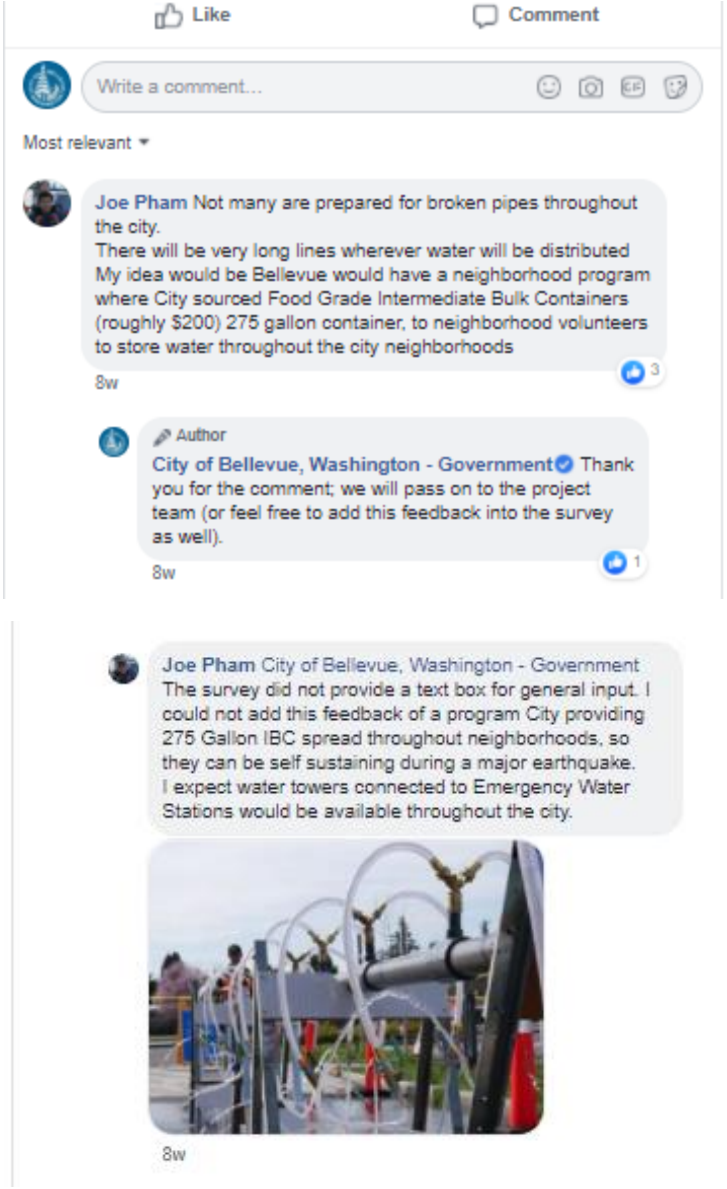


Facebook Ad – Residential Audience (continued)





Facebook Ad – Business Audience



Facebook Ad – Business Audience (continued)

Jennifer Davis Denise Vukov Harris I live here for 1 day and this appeared on my feed. They're listening
8w

Denise Vukov Harris Jennifer Davis they always are.
8w

Joe Pham Jennifer Davis We're all listening to you, what do you have to say?
8w

Gregory Summers Why not residents too!!! Shouldnt this meeting be for all the general public to decide together and not just business folks, corporations and or the rich?
8w

Author
City of Bellevue, Washington - Government Hi Gregory, you're absolutely right. We did send the survey link to our Bellevue resident audience as well. You're seeing the post targeted toward businesses. We appreciate your feedback!
8w

Kymmiekim Brown Where? I live on Bellevue no earthquake and no news in the area of any survey
7w

Tere Galligan Rain water collection barrels hooked up to homeowners gutters, with overflow valves. Of course you'd still need to boil it but you'd have a supply of it in Seattle.
7w

Daniel Sheldon But there was no earthquake.
8w

Joe Pham Daniel Sheldon There never will be any earthquakes here
8w

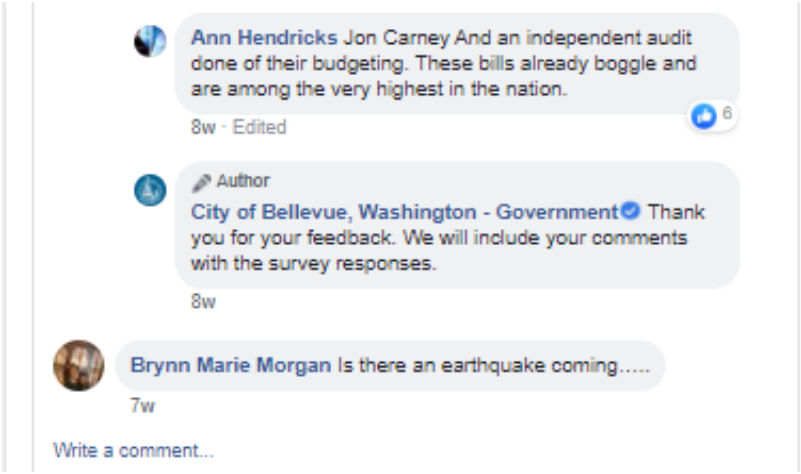
Nadia Tiffany Ahmadian Daniel Sheldon
https://amp.cnn.com/.../earthquake-swarm-oregon/index.html

8w

Write a comment...

Facebook Ad – Residential Audience, English

Facebook Ad – Residential Audience, English (continued)



Facebook Ad – Residential Audience, Chinese