Bellevue Emergency Water Supply Planning

City of Bellevue

Engineering Support

December 20, 2019

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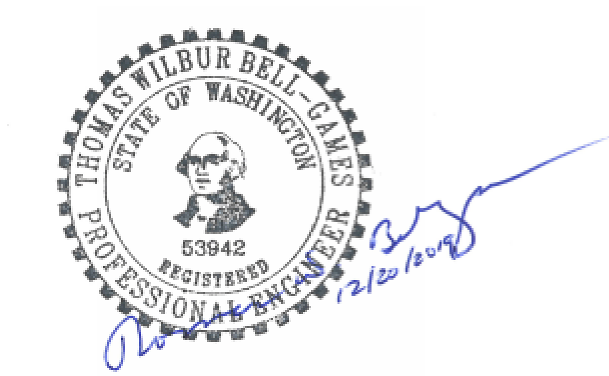
CERTIFICATION

Prepared under the Supervision of:



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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.

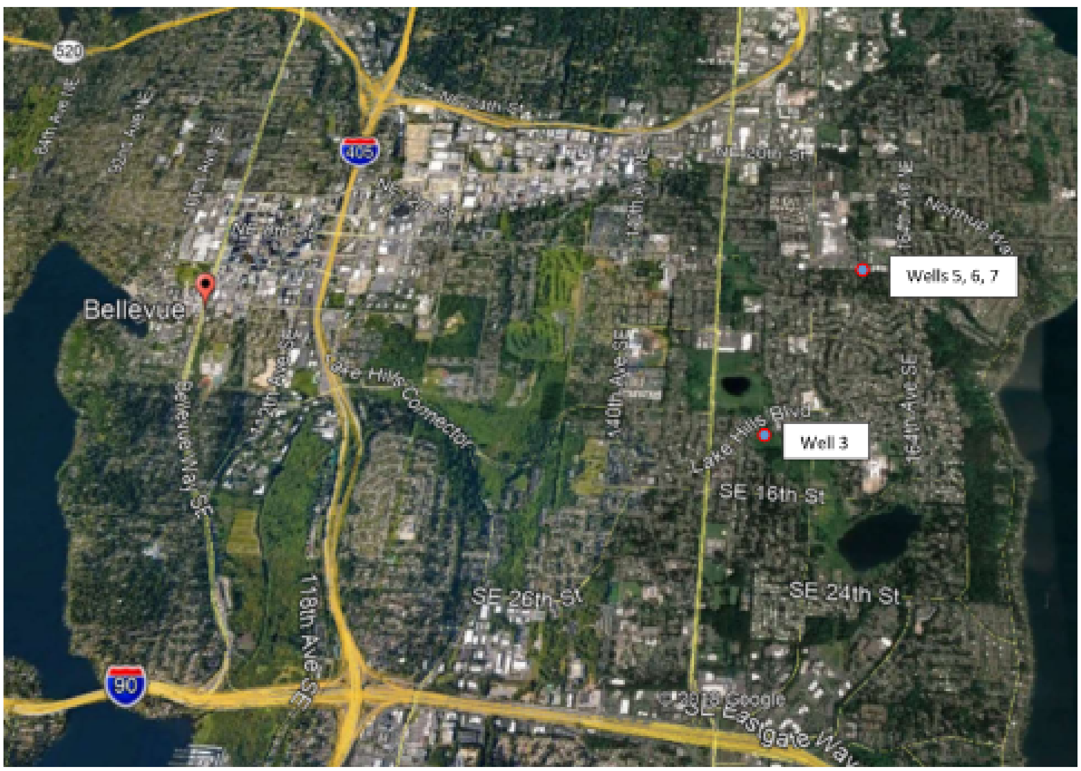

Figure EX-1. Existing Wells

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 102nd 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.

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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

Golder Associates

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

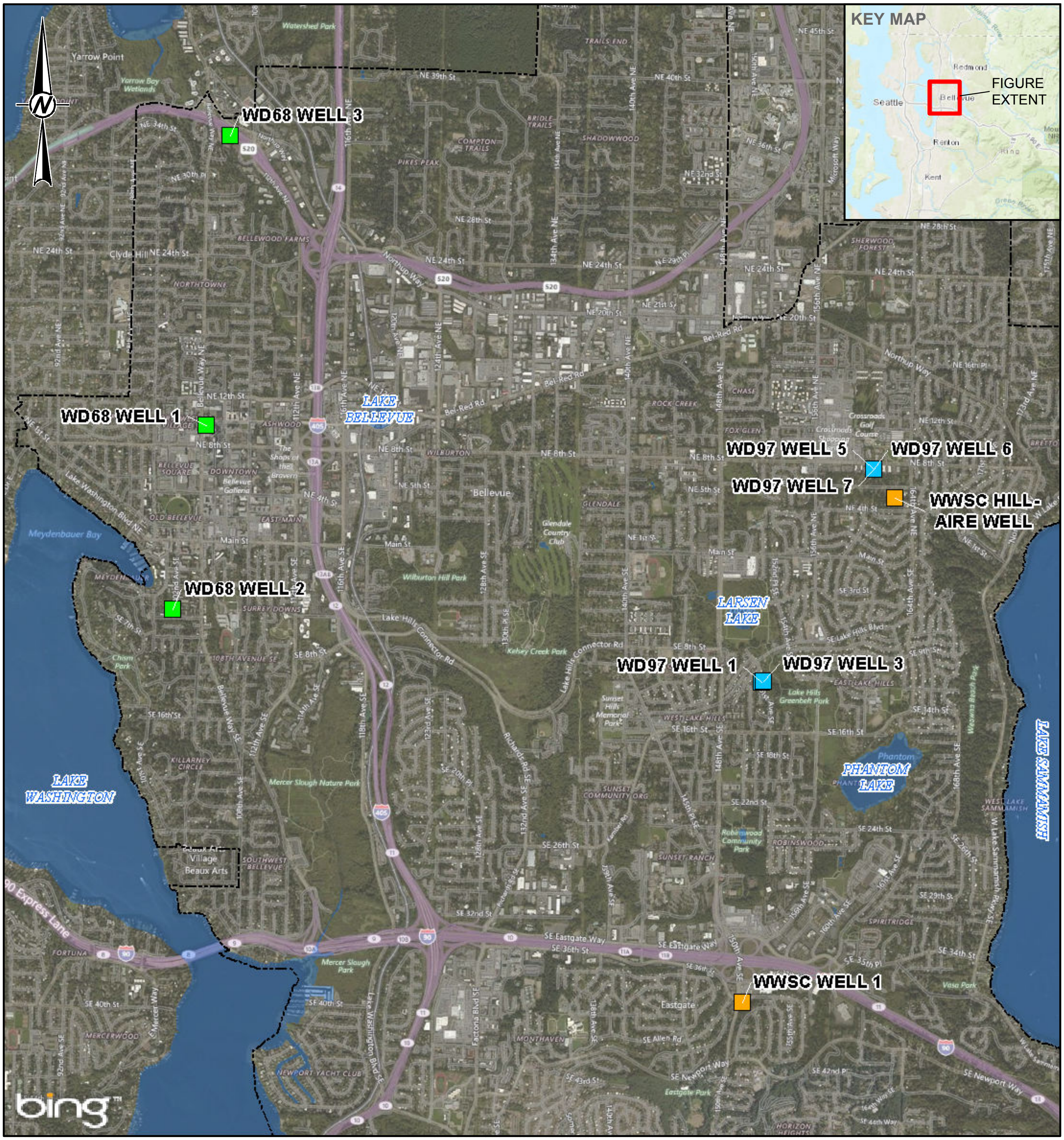
Table 6: KCWD 97 Well No. 7 Inorganic Groundwater Quality

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

Golder Associates

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

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

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

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 SE1/4-1/4 NW1/4 Sec 20 Twn 25N R 5E **EWM** ☒ **Or WWM** ☐

(s, t, r Still REQUIRED)

Lat/Long Lat Deg na Lat Min/Sec na

Long Deg na Long Min/Sec na

Tax Parcel No. (Required) 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

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

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

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

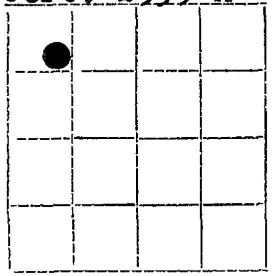


Diagram of Section

File number 24N/5E-2D

Location State of WASHINGTON

County King

Area

Map

NW ¼ NW ¼ sec 2 T 24 N, R 5 E

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.)		
	~~No well log given~~ (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

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

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 7440—12-54—3M 49108

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

Diagram of Section

24N/5E-2D
File number

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

WELL LOG—Continued No / -

KCWD 97 Well No. 3 (page 2 of 2)

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 7440—12-54—3M 40108

KCWD 97 Well No. 7
(page 1 of 2)

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

WELL LOG No A.6350

Date 8-1, 1962

Record by well driller

Source driller's record

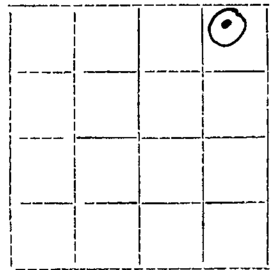


Diagram of Section

File number 25/5E-35A

Location State of WASHINGTON

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

(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)

Correlation	Material	Thickness (feet)	Depth (feet)
	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

KCWD 97 Well No. 7
(page 2 of 2)

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.		
	PERFORATIONS:		
	12" well screen 60 mesh from 275 to 284 ft.		
	12" well screen 40 mesh from 284 to 299 ft.		

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

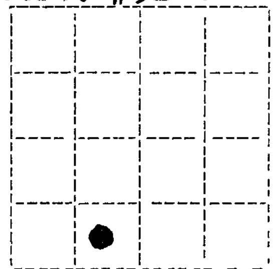


DIAGRAM OF SECTION

Location State of WASHINGTON
County King
Area
Map
SE 1/4 SW 1/4 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

File number 25N/5E-29P

(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.)

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)		

Turn up

Sheet of sheets

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

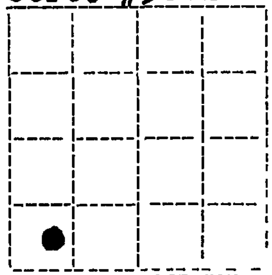


DIAGRAM OF SECTION

Location State of WASHINGTON
County King
Area
Map
SW ¼ SW ¼ sec 32 T 25 N, R 5 E

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)
	(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)		
	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)		

Turn up Sheet of sh

of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

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 1/4 NW 1/4 sec 20 T 25 N, R 5 E

DIAGRAM OF SECTION

File number 25N/5E-20F

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

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.)		
	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)		

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Sheet of sheets

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	$\frac{1}{4}$" x 3"	
	horizontal beveled 8 rows	per ft.	
	from 60' to 244'.		

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

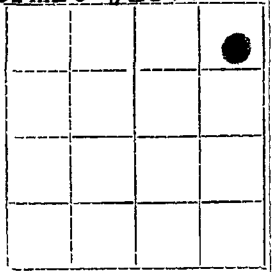


Diagram of Section

File number 25N/5E-35A

Location State of WASHINGTON

County King

Area

~~XXX~~ Lot 4 Block 2

¼ ¼ sec 35 T25 N, R 5 E ~~W~~

Drilling Co

Address

Method of Drilling drilled Date , 19

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)		
	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

WWSC Well No. 1

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

Well #2
WELL LOG

No Appl. #3251
Permit #3043

24N, 5E-11N
File number

Date February, 1954

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

Diagram of Section

Drilling Co

Address

Method of Drilling drilled Date Feb. 23, 1954

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

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

ATTACHMENT B
PHOTOGRAPHS

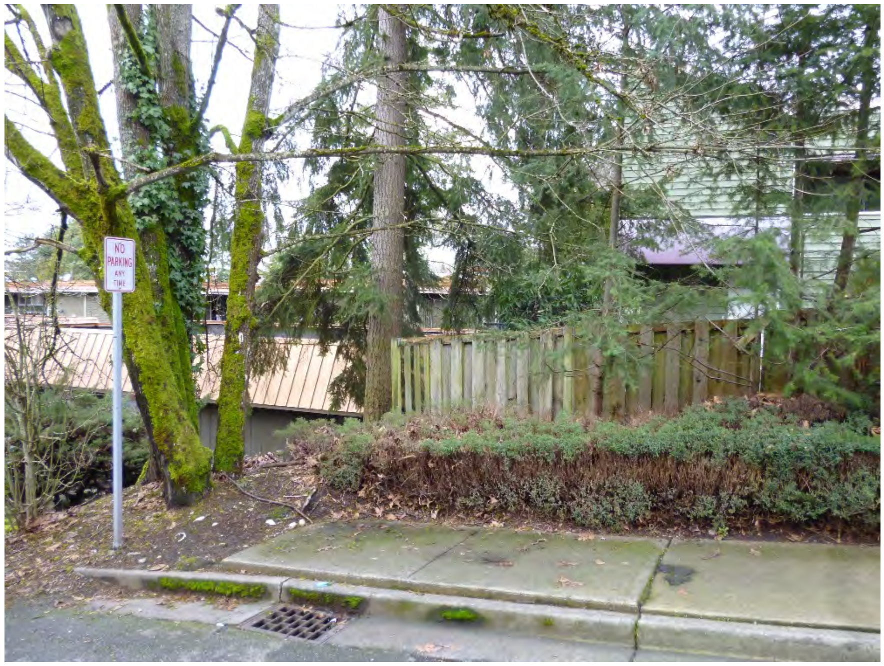
Project Title: City of Bellevue Emergency Water Supply Master Plan	
PHOTOGRAPH 1 KCWD 97 Well No. 3 (Samena) wellhead	
PHOTOGRAPH 2 KCWD 97 Well No. 3 (Samena) site	

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)	

Golder Associates

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.

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.

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TABLES

FIGURES

ATTACHMENTS

https://golderassociates.sharepoint.com/sites/11470g/shared documents/task 3.1 existing conditions/aquifer tm/final/1775477-rev0-bellevue aquifer and well yield-091819.docx

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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

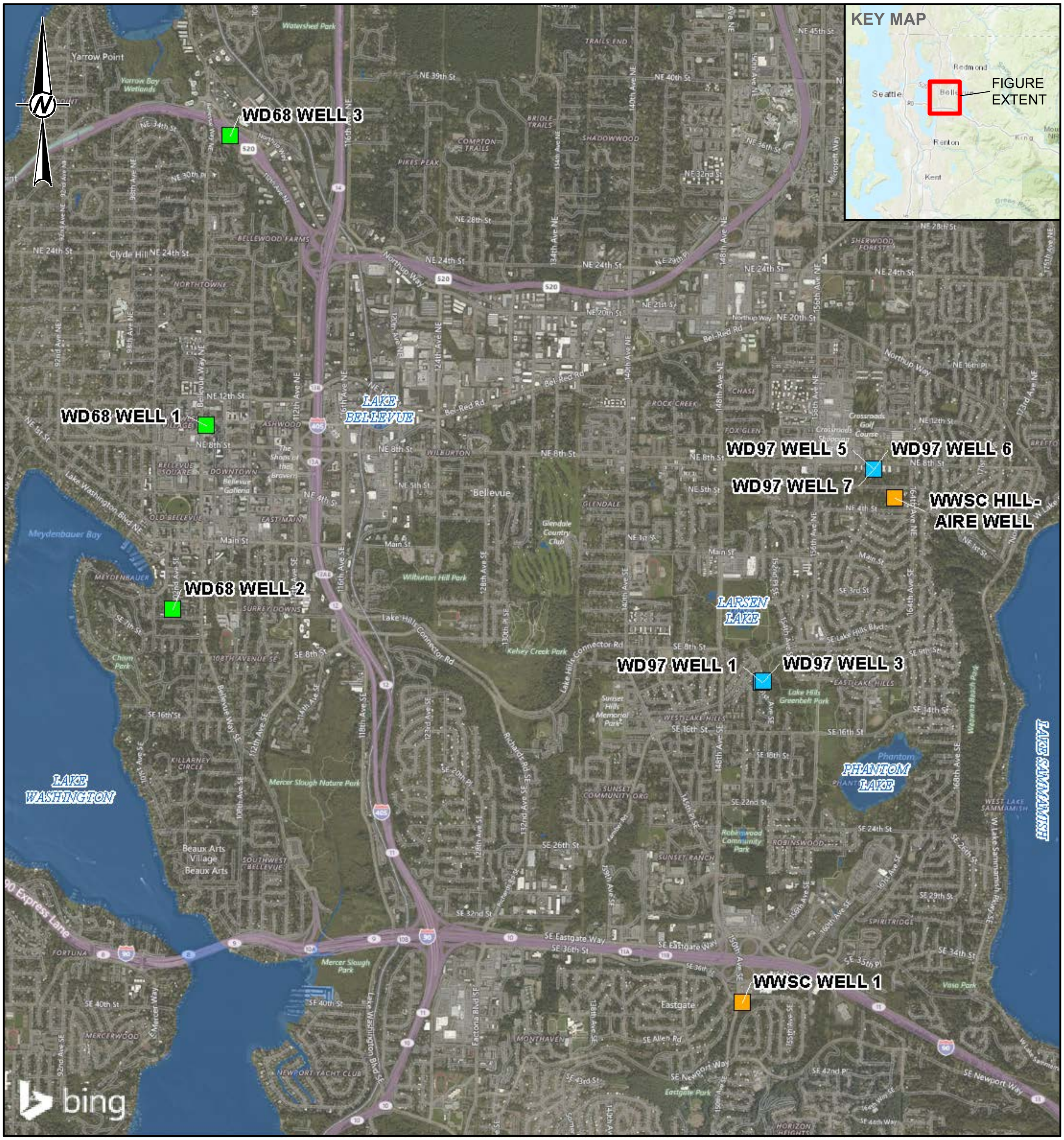
Scenario	Pumping Duration (days)	Number of Wells	Well Spacing (feet)	Individual Well Pumping Rate (gpm)	Aquifer Transmissivity (ft^2/d)	Aquifer Storativity (ft^2/d)	Drawdown in One Well (no interference drawdown) (feet)	Well Losses (feet)[1]	Interference Drawdown from Three Other Wells (feet)	Total Drawdown (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

CLIENT
STANTEC

PROJECT
CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN

TITLE
CITY OF BELLEVUE WATER SUPPLY WELL LOCATION MAP

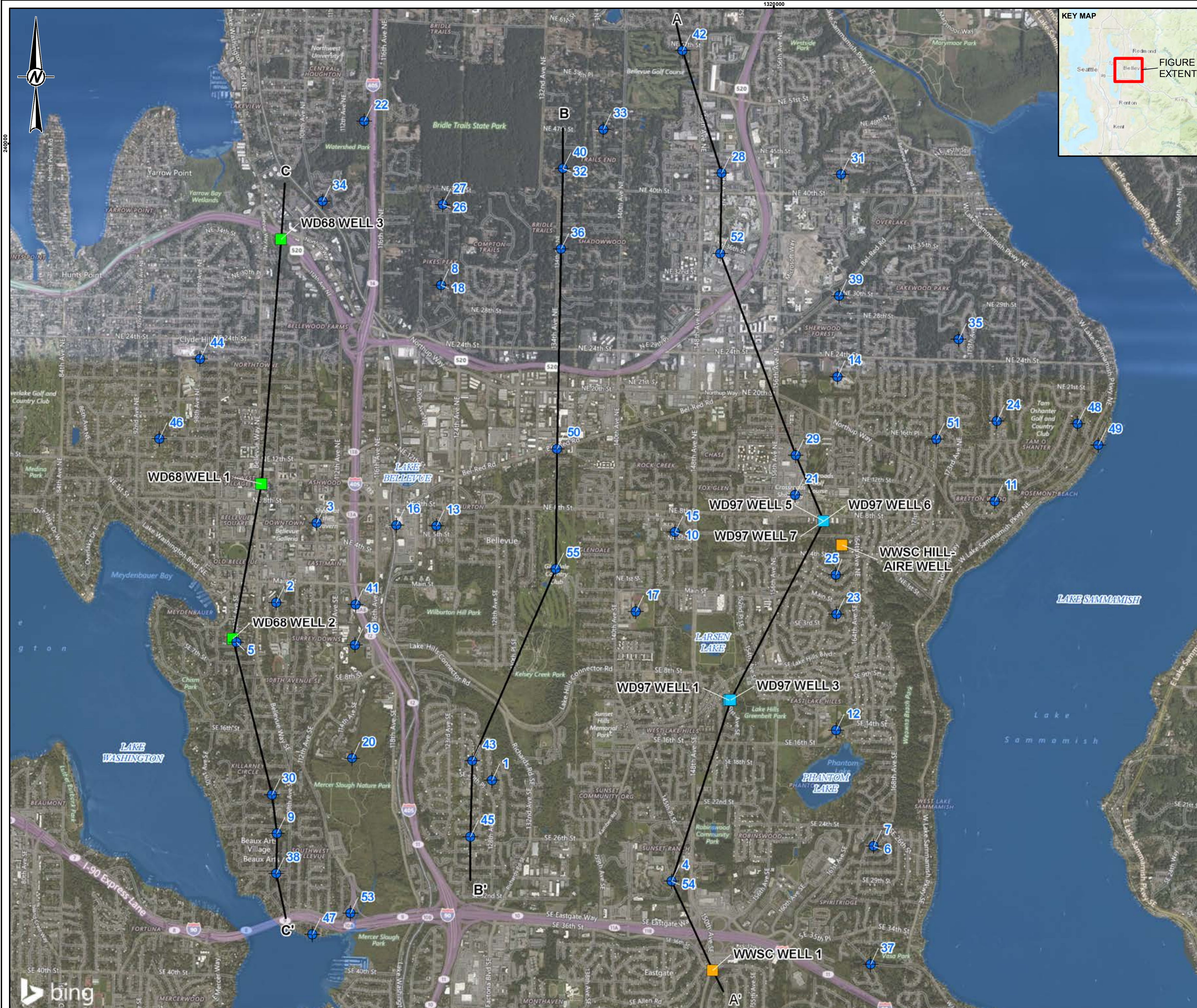
CONSULTANT
GOLDER

YYYY-MM-DD	2018-08-28
DESIGNED	BVJ
PREPARED	HJ
REVIEWED	MK
APPROVED	MK

PROJECT NO.	PHASE	REV.	FIGURE
1775477	3.1	A	1

PATH: G:\Stantec\City_of_Bellevue\99_PROJECTS\1775477_EmergencyWaterSupplyPlan\Phase_3_1\02_PRODUCTION\MXD\FIGURES\RevA\1775477_3_1_2018_001_F1_RevA_WellLocations.mxd

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
0 1 in



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
- LAKE

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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CLIENT
STANTEC

PROJECT
CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN

TITLE
CROSS-SECTION LOCATION MAP

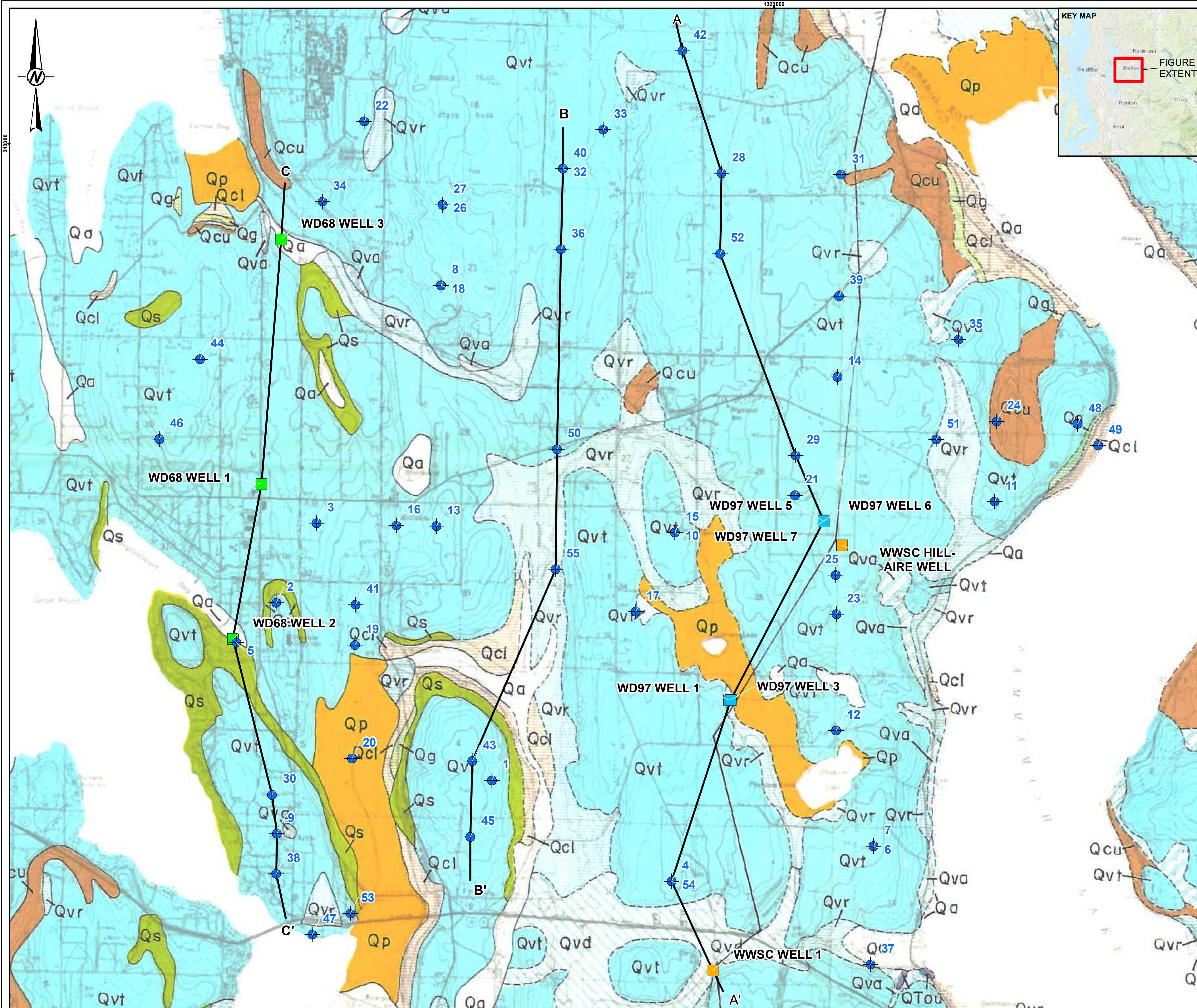
CONSULTANT
GOLDER

YYYY-MM-DD	2019-09-17
DESIGNED	BVJ
PREPARED	HJ
REVIEWED	MK
APPROVED	MK

PROJECT NO.	PHASE	REV.	FIGURE
1775477	3.1	1	2

PATH: G:\Stantec\City_of_Bellevue\99_PROJECTS\1775477_EmergencyWaterSupplyPlan\Phase_3_1\02_PRODUCTION\MXD\FIGURES\Rev1\1775477_3.1_003_F2_Rev1_CrossSections.mxd PRINTED ON: 2019-09-17 AT: 10:20:11 AM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B



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

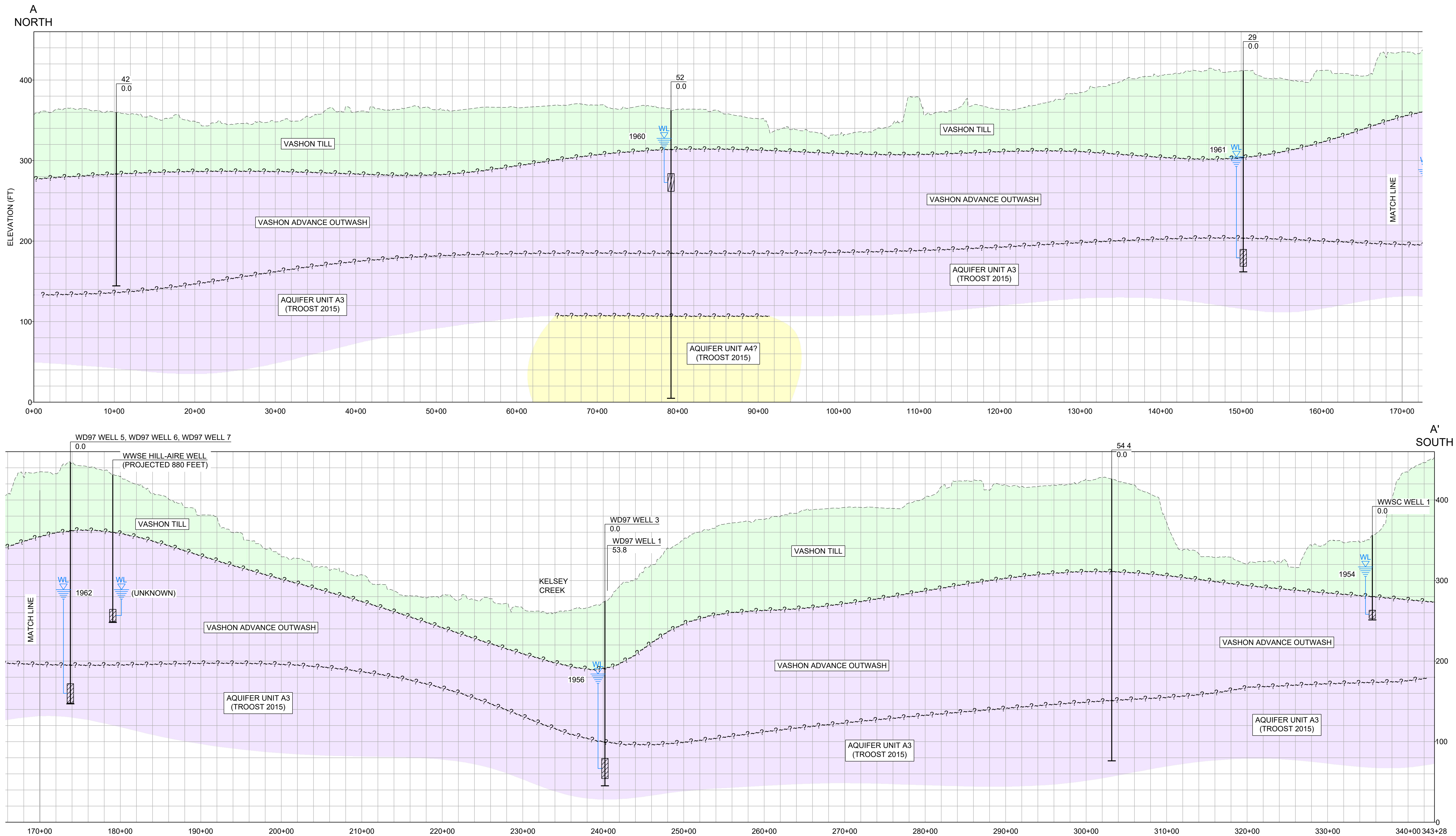
PROJECT
CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN

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



NOTE(S)

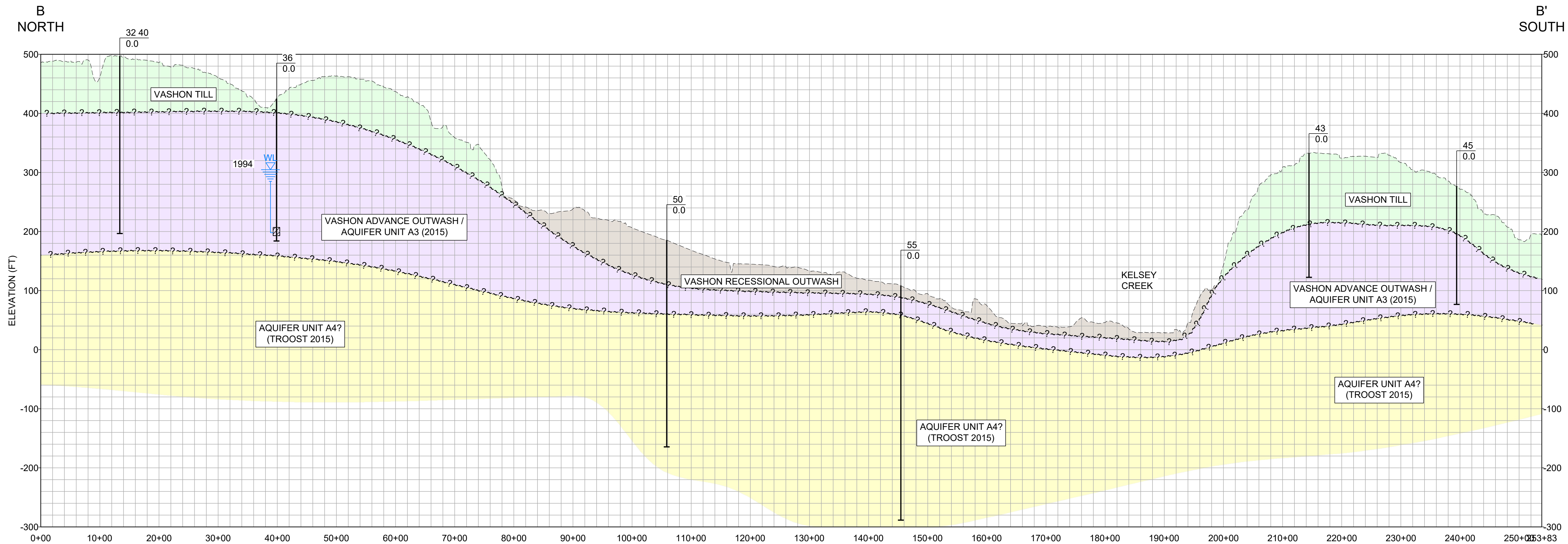
1. SEE FIGURE 5 FOR LEGEND.

0 600 1200
1" = 600' VERT. FEET

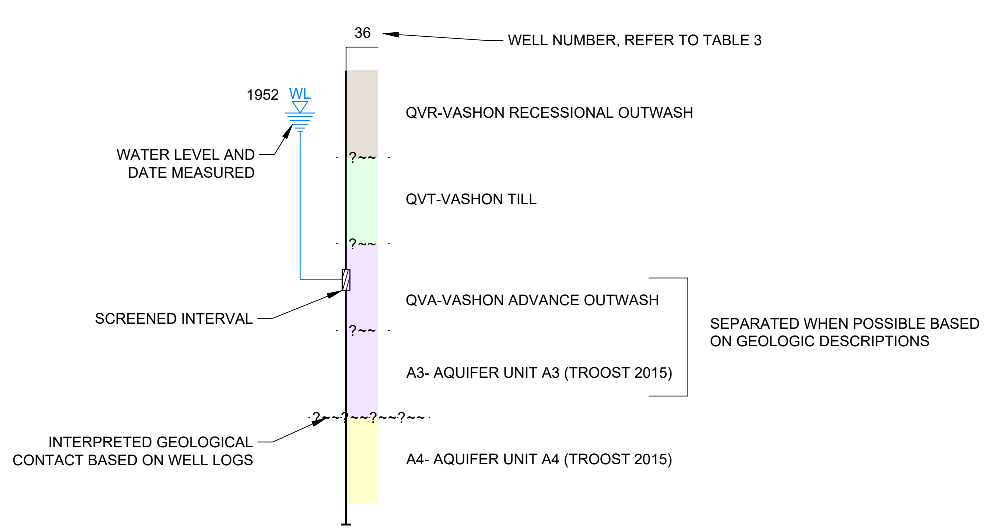
0 600 1200
1" = 600' HORIZ. FEET

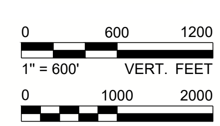
CLIENT	STANTEC
CONSULTANT	GOLDER
YYYY-MM-DD	2019-06-16
DESIGNED	-
PREPARED	REDMOND
REVIEWED	MK
APPROVED	MK
PROJECT	CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN
TITLE	**GEOLOGIC CROSS-SECTION A-A'**

PROJECT NO.	PHASE	REV.	FIGURE
1775477	3.1	A	4



LEGEND

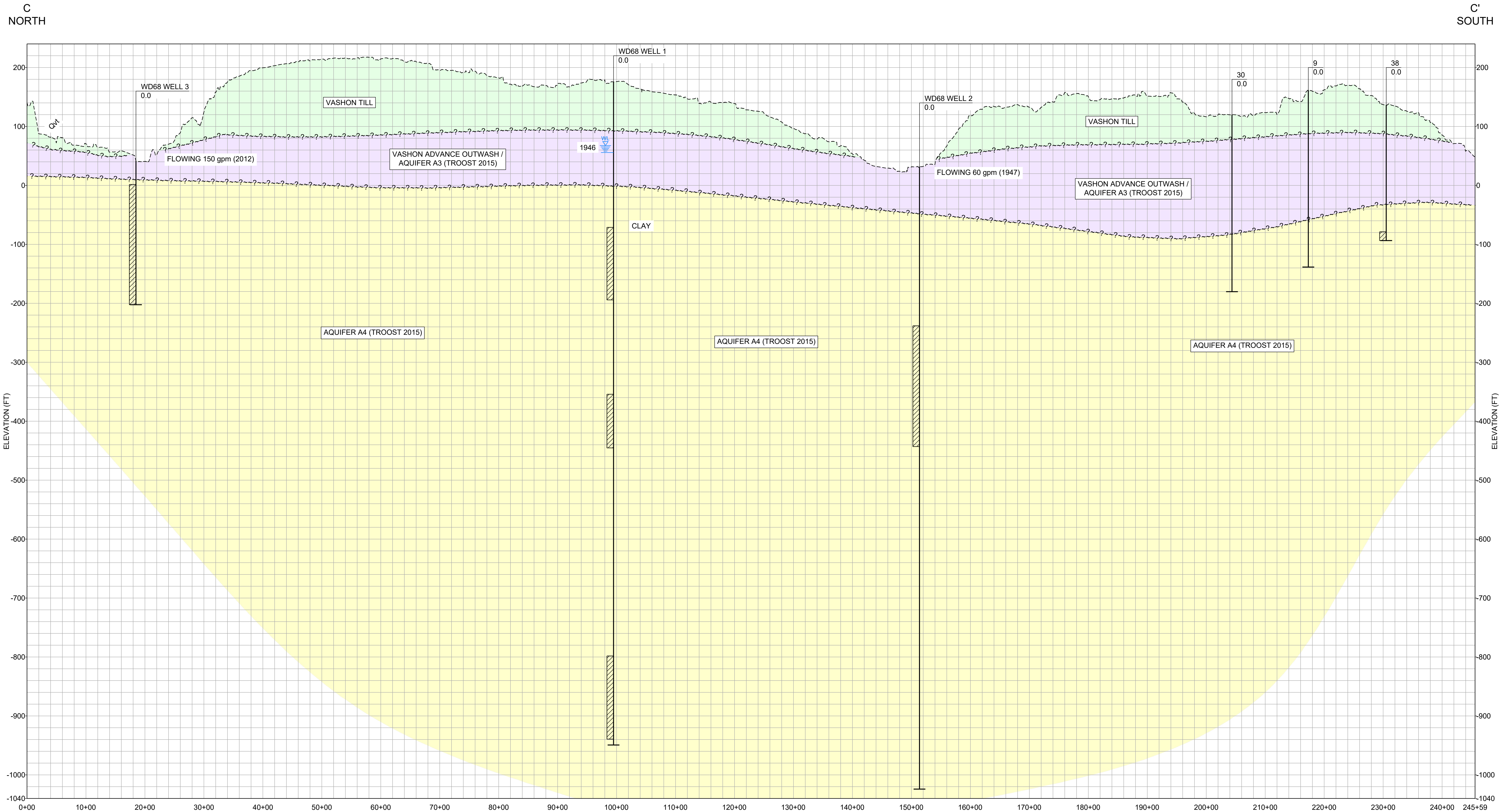




CLIENT	STANTEC
PROJECT	CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN
CONSULTANT	GOLDER
YYYY-MM-DD	2019-06-16
DESIGNED	-
PREPARED	REDMOND
REVIEWED	MK
APPROVED	MK
TITLE	GEOLOGIC CROSS-SECTION B-B'
PROJECT NO.	1775477
PHASE	3.1
REV.	A
FIGURE	5

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: 1775477-3.1-001.dwg | Last Edited By: trybar Date: 2019-09-17 Time:9:33:15 AM | Printed By: TRybar Date: 2019-09-17 Time:9:37:08 AM



NOTE(S)

1. SEE FIGURE 5 FOR LEGEND.

0 80 160
1" = 80' VERT. FEET

0 800 1600
1" = 800' HORIZ. FEET

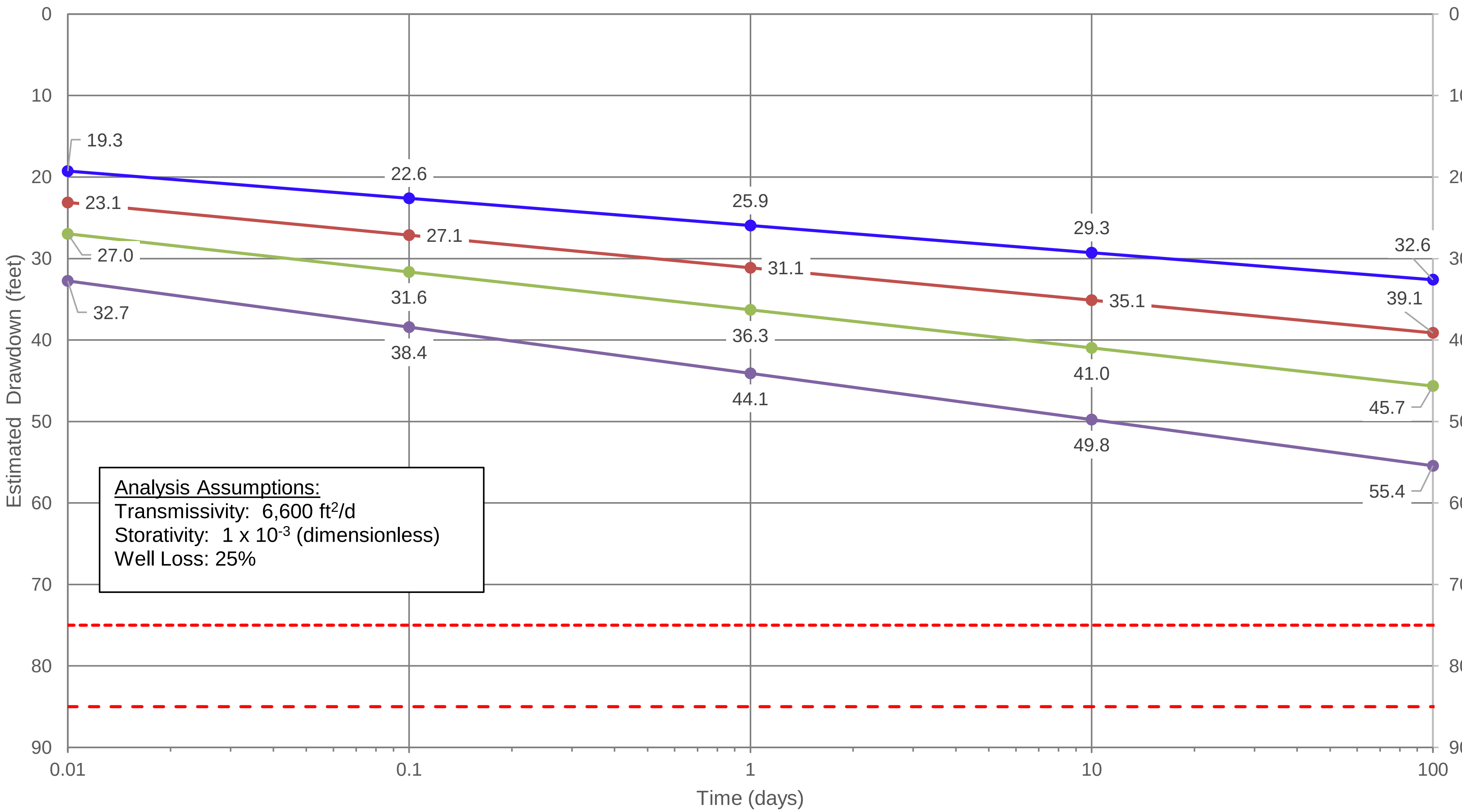
CLIENT	STANTEC
CONSULTANT	GOLDER
YYYY-MM-DD	2019-06-16
DESIGNED	-
PREPARED	REDMOND
REVIEWED	MK
APPROVED	MK

PROJECT
CITY OF BELLEVUE EMERGENCY WATER SUPPLY PLAN

TITLE
GEOLOGIC CROSS-SECTION C-C'

PROJECT NO.	PHASE	REV.	FIGURE
1775477	3.1	A	6

PATH: https://golderassociates.sharepoint.com/sites/11470g/Shared Documents/Task 3.1 Existing Conditions/Aquifer TM/Final | FILE NAME: Calculations-Excel Figures.xlsx



LEGEND
- 500 gpm
- 600 gpm
- 700 gpm
- 850 gpm
- Available Drawdown - High Groundwater Level
- Available Drawdown - Low Groundwater Level

CLIENT
STANTEC

CONSULTANT
GOLDER

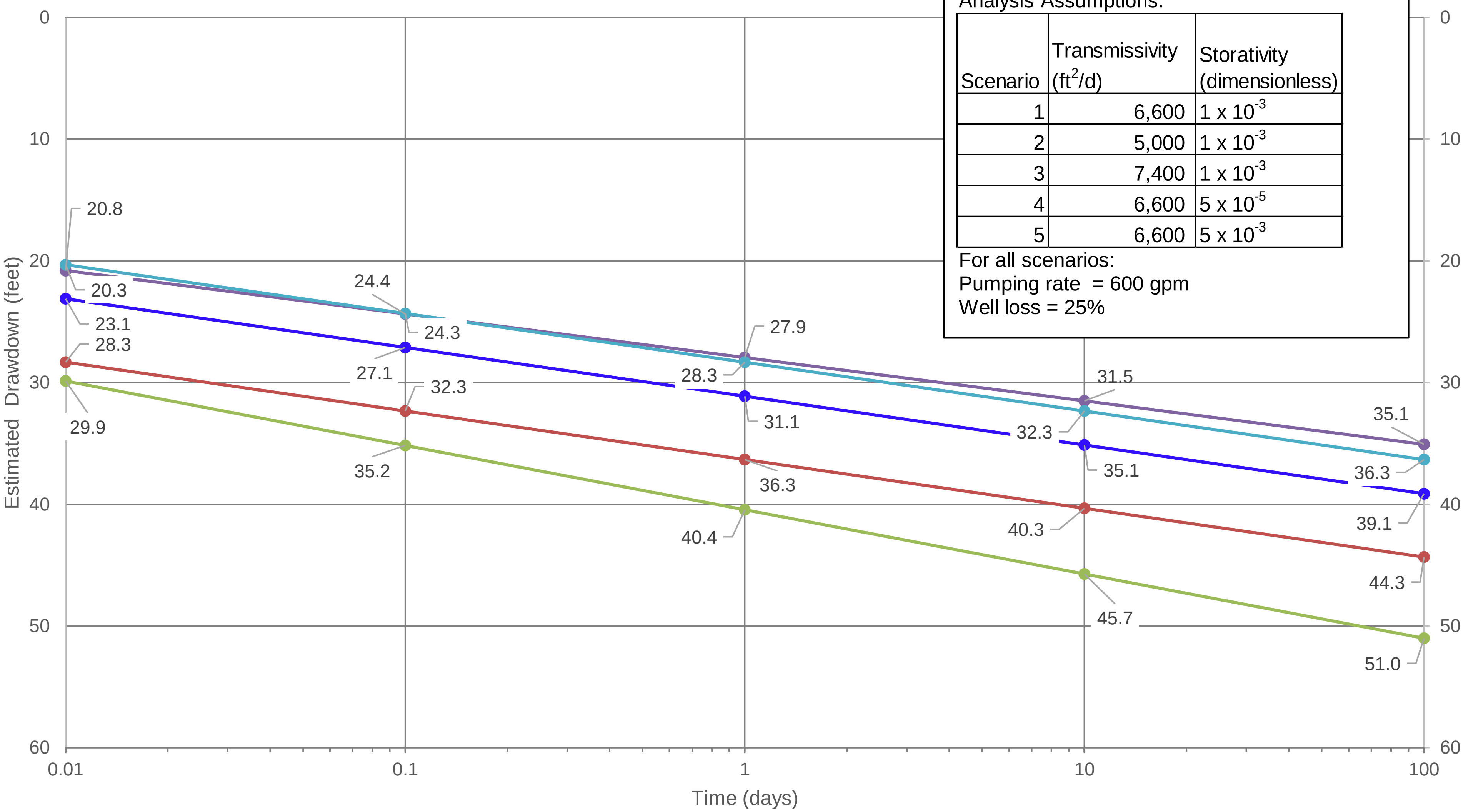
YYYY-MM-DD	2019-09-16
DESIGNED	---
PREPARED	MPK
REVIEWED	EA
APPROVED	DB

PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
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)

CLIENT
STANTEC

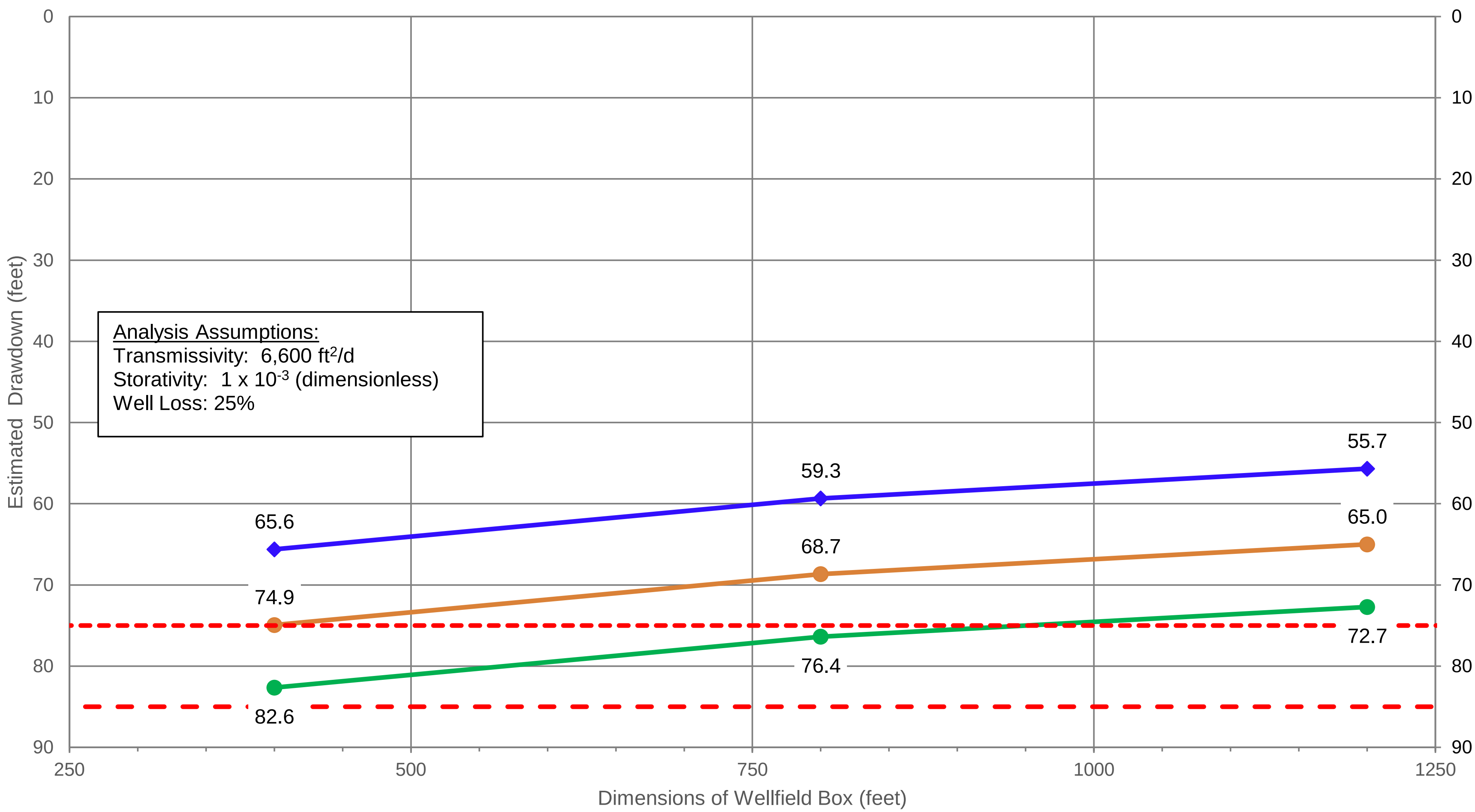
CONSULTANT
GOLDER

YYYY-MM-DD	2019-09-16
DESIGNED	---
PREPARED	MPK
REVIEWED	EA
APPROVED	DB

PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
ESTMATED DRAWDOWN SENSITIVITY
SINGLE WELL
100 DAYS PUMPING

PROJECT NO.	CONTROL	REV.	FIGURE
1775477.3.1		A	8



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

CLIENT
STANTEC

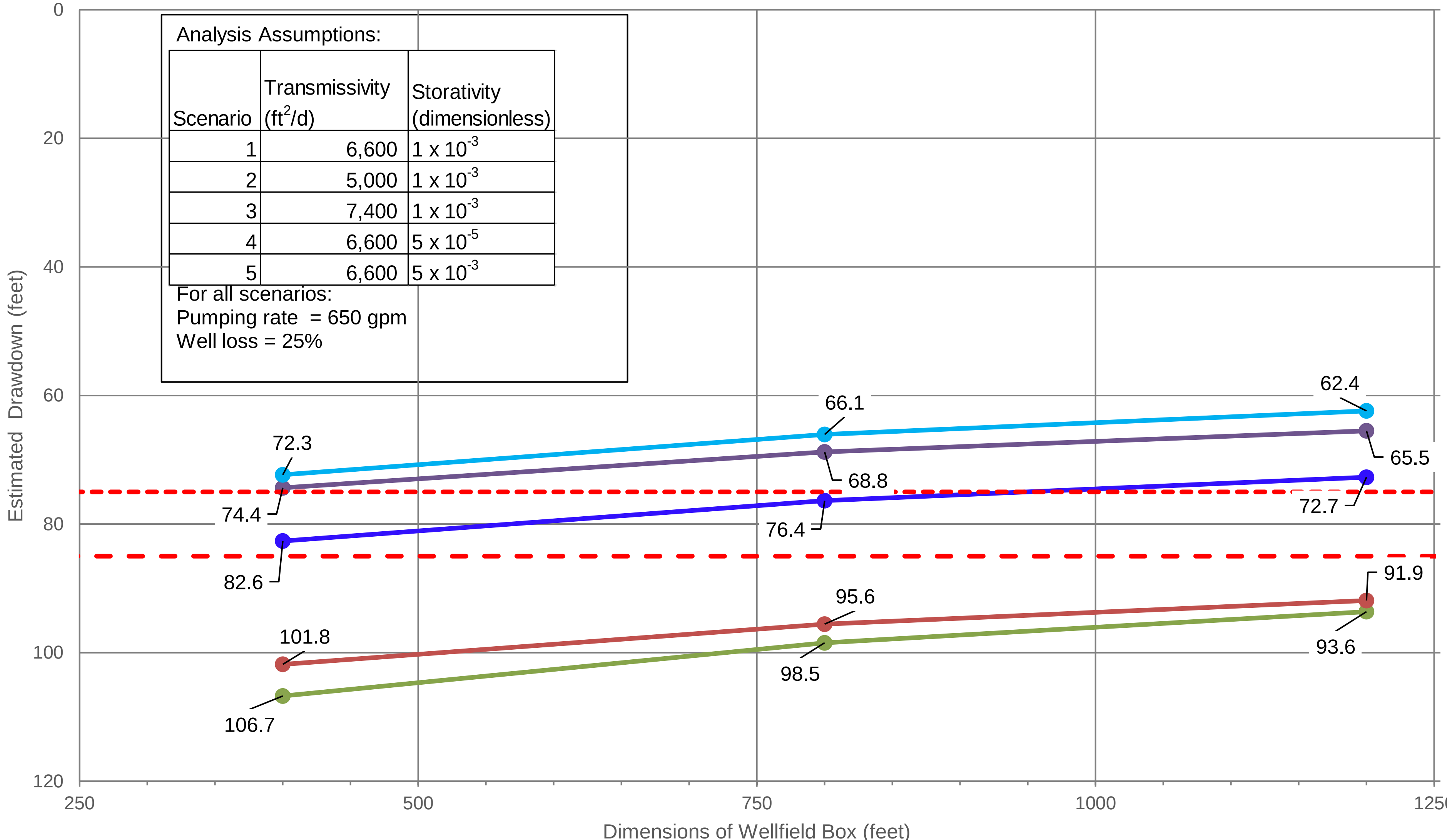
CONSULTANT
GOLDER

YYYY-MM-DD	2019-09-16
DESIGNED	---
PREPARED	MPK
REVIEWED	EA
APPROVED	DB

PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
WELLFIELD EVALUATION
ESTIMATED DRAWDOWN
4 WELLS PUMPING 7 TO 100 DAYS

PROJECT NO.	CONTROL	REV.	FIGURE
1775477.3.1		A	9



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}

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)
- Scenario 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

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)*

[X] Construction

[ ] Decommission *ORIGINAL INSTALLATION Notice of Intent Number* ______

Type of Well *(select one)*

[X] Resource Protection

[ ] Geotech Soil Boring

Consulting Firm: Geo Loop Tec

Unique Ecology Well ID Tag No.: BIT 153

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 [X] 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.

[X] Driller [ ] Engineer [ ] Trainee Name (Print) Kris Pancheri

Driller/Engineer /Trainee Signature [signature]

Driller or Trainee License No. 3028

If trainee, licensed driller's Signature and License No. ______

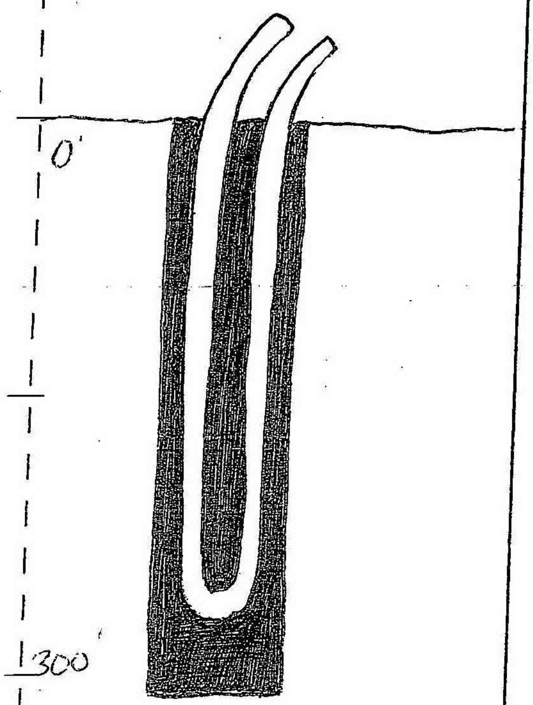
Lat/Long (s, t, r still REQUIRED) Lat Deg ______ Lat Min/Sec ______ Long Deg ______ Long Min/Sec ______

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	Formation Description
	Install 1" closed ground loop. Place thermally enhanced grout from 300' to 0' Bore #- 53	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

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

#54

401578

24-5E-10 H

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 [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 ______

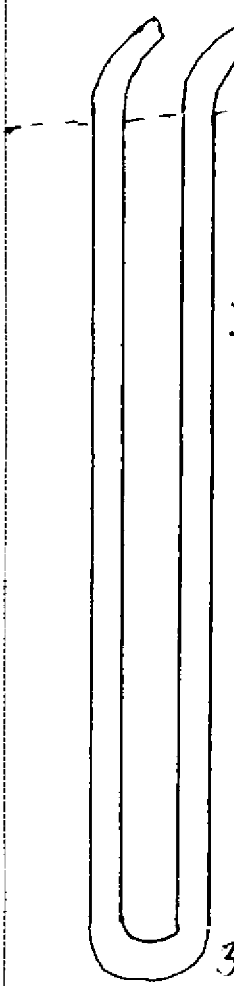
Tax Parcel No. N/A

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	Formation Description
 0 — 1" HDPE Loop Pipe Installed 0-350' — 350'	0-5' BENTONITE chips - 3 sacks 5'-350' Thermal Grout 15 - Barotherm 60 - Sand	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

#29

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

WELL LOG No A.5961,P.5605

Date 8-11, 1961

Record by well driller

Source driller's record

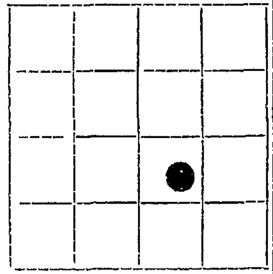


Diagram of Section

25/5-26K
File number

Location State of WASHINGTON

County King

Area

Map

SE¼NW ¼ SE ¼ sec 26 T 25 N, R 5 E

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

(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.)

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

Turn up (over) Sheet of sheets

WELL LOG —Continued No / -

Corre lation	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 74-9—12 54—3M 40108

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

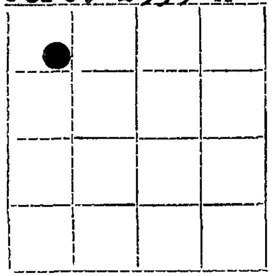


Diagram of Section

File number 24N/5E-2D

Location State of WASHINGTON
County King
Area
Map
NW ¼ NW ¼ sec 2 T 24 N, R 5 E
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.)		
	~~No well log given~~ (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

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 7440—12-54—3M 40108

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

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

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

Diagram of Section

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

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.		

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

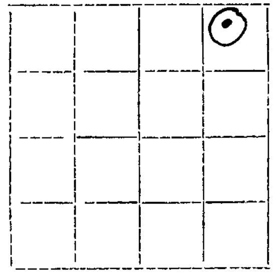


Diagram of Section

25 15E 35A
File number

Location State of WASHINGTON

County King

Area

Map

¼ ¼ sec ~~2~~ 35 T ~~24~~ 25 N, R 5 E

Drilling Co Harstad Associates

Address Seattle, Wash.

Method of Drilling Date June 14, 19 62

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

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.

PERFORATIONS:
12" well screen 60 mesh from 275 to 284 ft.
12" well screen 40 mesh from 284 to 299 ft.

#28

File Original and First Copy with Department of Ecology
Second Copy — Owner's Copy
Third Copy — Driller's Copy

ENTERED

WATER WELL REPORT

STATE OF WASHINGTON

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: ☒ Domestic ☐ Irrigation ☐ DeWater ☐ Industrial ☐ Test Well ☐ Municipal ☐ Other

(4) TYPE OF WORK: Owner's number of well (If more than one) ______
Abandoned ☐ New well ☒ Deepened ☐ Reconditioned ☐
Method: Dug ☐ Cable ☒ Rotary ☐ Bored ☐ Driven ☐ 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 ☒ " Diam. from ______ ft. to ______ ft.
Liner installed ☐ " Diam. from ______ ft. to ______ ft.
Threaded ☐

Perforations: Yes ☐ No ☒
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 ☒ 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 ☒ Size of gravel ______
Gravel placed from ______ ft. to ______ ft.

Surface seal: Yes ☒ No ☐ To what depth? 18' ft.
Material used in seal Bentonite
Did any strata contain unusable water? Yes ☐ No ☒
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 ☒ 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 ☒ 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, 1999 Completed 5-26, 1999

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) [signature] (WELL DRILLER) License No. 2481
Contractor's Registration No. AQUAFI*099QG Date 6-3, 1999

(USE ADDITIONAL SHEETS IF NECESSARY)

ECL 050-1-20 (2/93)

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 ____

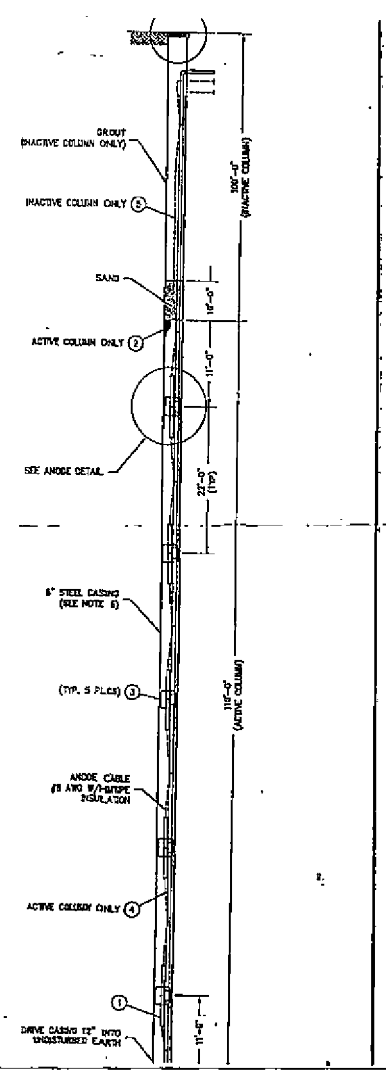
Long Deg ____ Min ____ Sec ____

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 ____

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION AND DEVELOPMENT

WELL LOG Well #1 No Appl.#5591

Date 5-27, 1960

Record by well driller

Source well driller's record

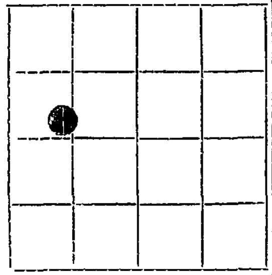


Diagram of Section

Location State of WASHINGTON

County King

Area Tract 3, Overlake

Map Industrial Park

¼ ¼ sec 23 T25 N, R 5 E

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

File number 25/5-23E

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	8	200
	(over)		

Turn up Sheet of sheets

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

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

Diagram of Section

File number 25N/5E-35A

Drilling Co

Address

Method of Drilling drilled Date , 19

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)		
	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

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

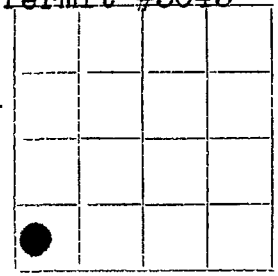


Diagram of Section

Location State of WASHINGTON

County King

Area

Map

SW ¼ SW ¼ sec 11 T 24 N, R 5 E

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

File number 24N/5E-11N

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

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		

#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

Diagram of Section

File number 25 / 5E 34E

Location State of WASHINGTON

County King

Area

Map

¼ ¼ sec 34 T 25 N, R 5 E

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, blue clay w/gravel	53	248
	Blue clay	10	258
	Blue clay w/gravel	6	264

Turn up (over) Sheet of sheets

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 7440—12 54—3M 40108

Please print, sign and return by mail to Department of Ecology

RE[#40] PROTECTION WELL REPORT

(SU[...] ELL REPORT PER WELL INSTALLED)

CURRENT Notice of Intent No. G016213

265705

Construction/Decommission *(select one)*
- [x] Construction
- [ ] Decommission *ORIGINAL INSTALLATION Notice of Intent Number* ________

Type of Well *(select one)*
- [ ] Resource Protection
- [x] ~~[illegible]~~ GEO-THERMAL

Consulting Firm ________

Unique Ecology Well ID

Tag No. ________

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) CURTIS GOSLING

Driller/Engineer /Trainee Signature [signature]

Driller or Trainee License No. 2659

If trainee, licensed driller's Signature and License No. ________

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 [x] EWM [ ] WWM

Lat/Long (s, t, r still REQUIRED) Lat Deg ____ Lat Min/Sec ____ Long Deg ____ Long Min/Sec ____

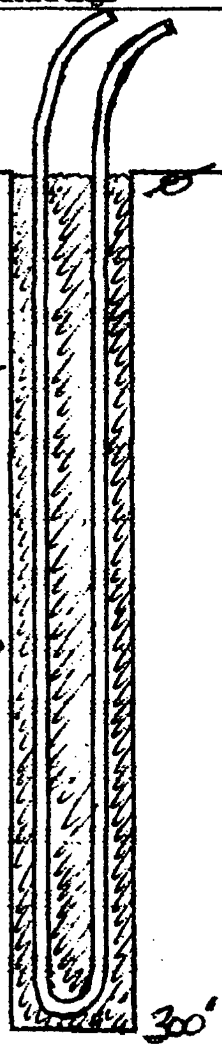
Tax Parcel No. ________

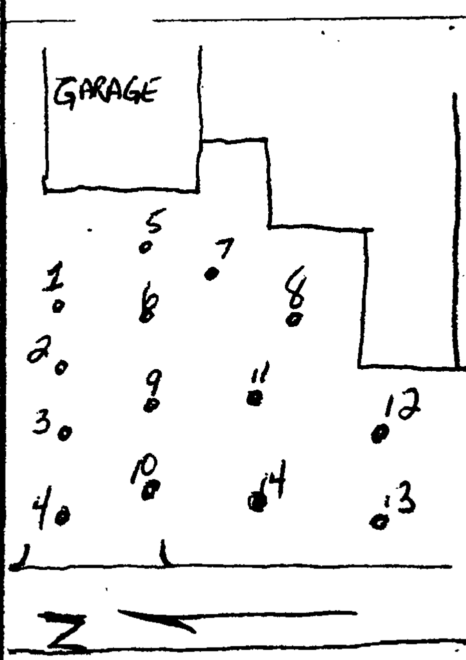
Cased or Uncased Diameter 6" Static Level ________

Work/Decommission Start Date March 9/07

Work/Decommission Completed Date March 9/07

Construction/Design	Well Data	Formation Description
FILL BORE FROM BOTTOM TO TOP WITH THERMAL EN-HANCED GROUT 1" PLACE POLY-ETHELYNE GROUND LOOP TO 300'	GEO-BORE #5	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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JUN 1 1 2007
DEPT. OF ECOLOGY

272495 24.5E.4K

#43

[RESO]URCE PROTECTION WELL REPORT

Notice of Intent No. G007711

([O]NE WELL REPORT PER WELL INSTALLED)

Construction/Decommission *("x" in circle)*

- ☒ 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*

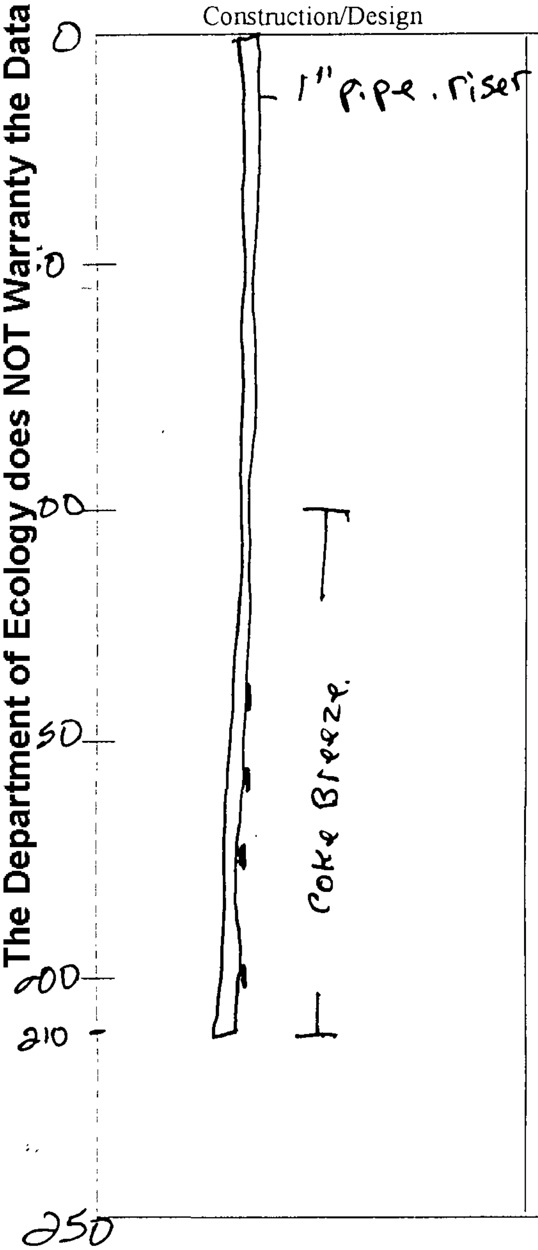
Lat/Long (s, t, r still REQUIRED) Lat Deg ______ Lat Min/Sec ______ Long Deg ______ Long Min/Sec ______

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
	0-100 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"= ______

ECY 050-12 (Rev 2/01)

File Original and First Copy with Department of Ecology
Second Copy — Owner's Copy
Third Copy — Driller's Copy

#36

ENTERED

25/5/22F

WATER WELL REPORT

STATE OF WASHINGTON

Start Card No. W18040
UNIQUE WELL I.D. # ABM 016
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) 3400 - 134th Ave NE, Bellevue WA

(3) PROPOSED USE: [X] Domestic [ ] Irrigation [ ] DeWater [ ] Industrial [ ] Test Well [ ] Municipal [ ] Other

(4) TYPE OF WORK: Owner's number of well (If more than one) ______
[ ] Abandoned [X] New well [ ] Deepened [ ] Reconditioned
Method: [ ] Dug [ ] Cable [X] Rotary [ ] Bored [ ] Driven [ ] 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 ______ " Diam. from ______ ft. to ______ ft.
[ ] Liner installed ______ " Diam. from ______ ft. to ______ ft.
[ ] Threaded

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) [signature] (WELL DRILLER) License No. 1904
Contractor's Registration No. STEYERI172PF 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)*

- [x] Construction
- [ ] Decommission *ORIGINAL INSTALLATION Notice of Intent Number* ______

Type of Well *(select one)*

- [x] Resource Protection
- [ ] Geotech Soil Boring

Consulting Firm: Geo Loop Tec

Unique Ecology Well ID Tag No.: BIT 205

Property Owner: Smith

Site Address: 13250 NE 40th SE

City: Bellevue County: King

Location: SW 1/4-1/4 SW 1/4 Sec 15 Twn 25N R 05E Select One [x] EWM [ ] WWM

Lat/Long (s, t, r still REQUIRED) Lat Deg ______ Lat Min/Sec ______ Long Deg ______ Long Min/Sec ______

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

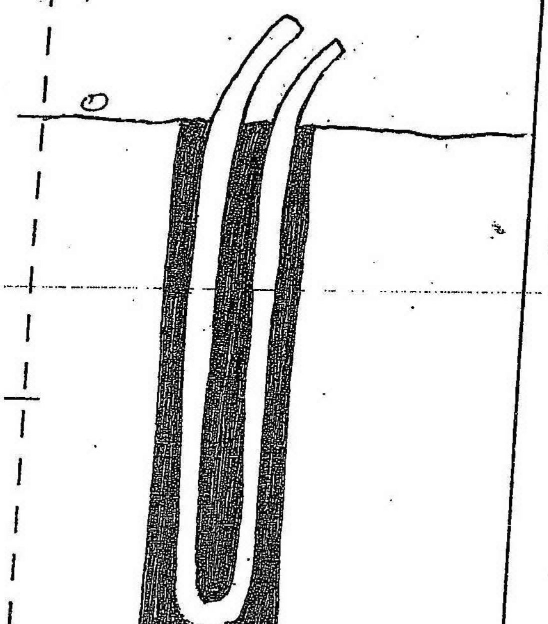
WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

[x] Driller [ ] Engineer [ ] Trainee Name (Print): Kris Panchen

Driller/Engineer /Trainee Signature: KP

Driller or Trainee License No.: 3028

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

#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 Installed: ☐ Welded ____" Diam. from ____ ft. to ____ ft.
☐ 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. N/A

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 EWM ☒ Or WWM ☐

(s, t, r Still REQUIRED)

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
	RECEIVED	
	MAR 21 2013	
	NWRO WR	

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

Driller/Engineer/Trainee Signature

Driller or trainee License No. 2534

IF TRAINEE: Driller's License No:

Driller's Signature: [signature]

Drilling Company Gregory Drilling Inc.

Address 17609 NE 70th St.

City, State, Zip Redmond, WA, 98052

Contractor's Registration No. GREGODI110JP Date 3/12/13

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.*

#45

GROUND SOURCE HEAT PUMP BORING 24-SE-9B

375390

START CARD NO. GE00136

PROJECT NAME:

WELL IDENTIFICATION NO.

DRILLING METHOD: Mud Rotary

DRILLER: Chris Stratton

FIRM: Gregory Drilling

SIGNATURE: Chris Stratton

CONSULTING FIRM: NA

REPRESENTATIVE: NA

COUNTY: King

LOCATION: NW¼ NE ¼ 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 med brn sand	
80-95 med gravels	
95 - 135 silt	
135 - 180 fill w/ gravel	
180 - 190 gravels	
190-200	

Surface Seal/#Sacks NA

Bentonite Seal/#Sacks 7 grout 2 sand

Diameter of Borehole 5½"

Remarks: Well tag# BBT-849

#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*)

☑ 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.

☑ Driller ☐ Engineer ☐ Trainee

Name (Print Last, First Name) GOSLING CURTIS

Driller/Engineer /Trainee Signature [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 ____

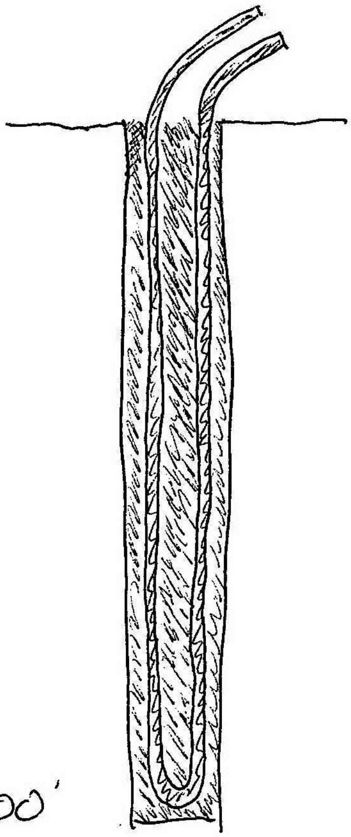
Long Deg ____ Min ____ Sec ____

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	Formation Description
0'  300'	INSTALL 1" HDPE POLYETHELYNE GROUND LOOP TO 300' PUMP THERMAL GROUT FROM 300' TO 0' BY TREMMIE TC TEST BORE	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 ____

ECY 050-12 (Rev 02-2011) To request ADA accommodation including materials in a format for the visually impaired, call Ecology Water Resources Program at 360-407-6872. Persons with impaired hearing may call Washington Relay Service at 711. Persons with speech disability may call TTY at 877-833-6341.

#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* ______

Type of Well *(select one)*

☒ Resource Protection

☐ Geotech Soil Boring

Consulting Firm: Shannon & Wilson

Unique Ecology Well ID Tag No.: BIK 214

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: ☒ EWM ☐ 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

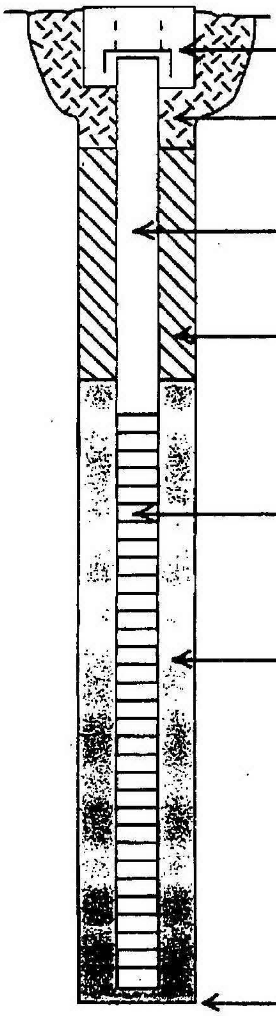
WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee Name (Print): Brian Owens

Driller/Engineer/Trainee Signature: [signature]

Driller or Trainee License No.: 2997

If trainee, licensed driller's Signature and License No. ______

Construction/Design	Well Data	Formation Description
	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 cilica WELL DEPTH 230'	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. REMARKS VWP Installed @ 148' and 130'

RECEIVED

MAY 04 2015

DEPT OF ECOLOGY NWRO - WR

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

File number 25N/5E-29P

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

(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)

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)		

Turn up

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

/ASHINGTON
F CONSERVATION
ELOPMENT

No Appli. #490
Cert. #360A

Date July 1, 1947

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

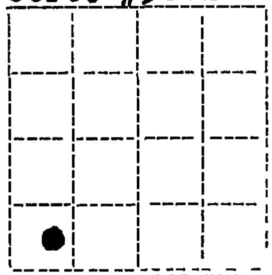


DIAGRAM OF SECTION

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)
	(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)		
	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)		

Turn up

Sheet ___ of ___ sh

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.		

S F 7449 46 REMINGTON INC 20 20 743-24

KCWD 68 Well No. 3 (decommissioning)

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

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

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 SE1/4-1/4 NW1/4 Sec 20 Twn 25N R 5E EWM ☒ Or WWM ☐

(s, t, r Still REQUIRED)

Lat/Long Lat Deg na Lat Min/Sec na

Long Deg na Long Min/Sec na

Tax Parcel No. (Required) 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

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

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

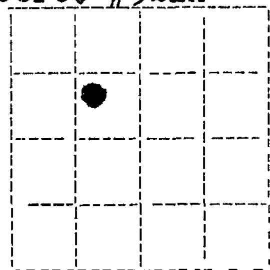


DIAGRAM OF SECTION

Location State of WASHINGTON
County King
Area
Map
SE 1/4 NW 1/4 sec 20 T 25 N, R 5 E
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

File number 25N/5E-20F

(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)

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)		

Turn up

Sheet ____ of ____ sh

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'.		

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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.

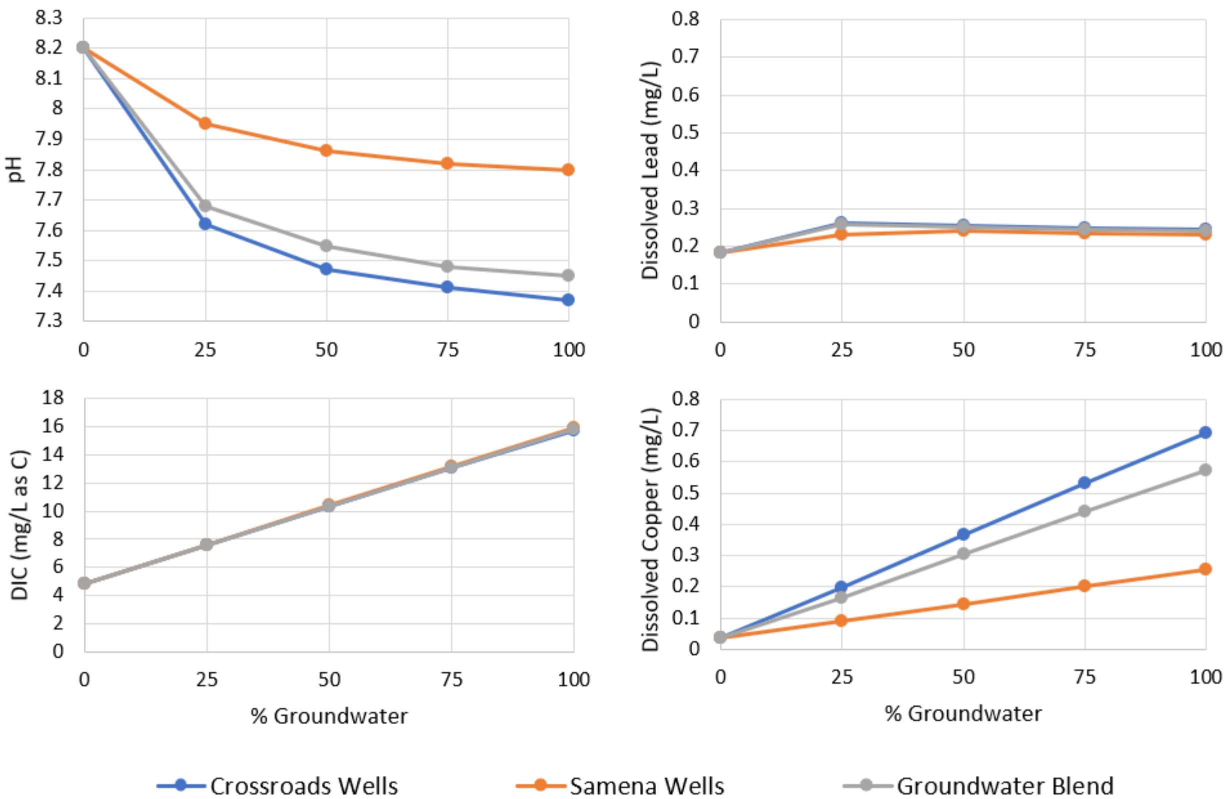

Figure 1. Predicted water quality characteristics for different levels of blending.

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

<table>
<tr><th rowspan="2">Treatment Objective</th><th colspan="3">Treatment Recommendation</th></tr>
<tr><th>Option #1</th><th>Option #2</th><th>Option #3</th></tr>
<tr><td>Disinfection (with chlorine)</td><td colspan="2">Chlorine residual required but 4-log virus inactivation not necessary</td><td>4-log virus inactivation recommended</td></tr>
<tr><td>Ammonia removal</td><td colspan="3">Breakpoint chlorination required to achieve stable free chlorine residual</td></tr>
<tr><td>Fe/Mn removal</td><td>Not required</td><td colspan="2">Recommended to avoid loading Fe/Mn to distribution system</td></tr>
<tr><td>pH Adjustment</td><td>Not required</td><td>Likely not justified based on cost/complexity</td><td>Consider based on results of corrosion control study</td></tr>
</table>

6.0 REFERENCES

City of Bellevue Water System Plan, 2015.

AWWA, Internal Corrosion Control in Water Distribution Systems, Manual of Water Supply Practices, M58, 2nd ed., 2017.

Robinson Noble, Emergency Well Evaluation, Technical Memoranda 3 and 4, 2015.

GeoEngineers, Progress Report No. 18, Groundwater and Vapor Monitoring and Sampling - Gasoline UST Release, City of Bellevue Parks Maintenance Facility, 2016

Murray, Smith & Associates, Inc. and Confluence Engineering Group, LLC, Chlorine Residual Evaluation – Initial Services through Alternatives Identification, Technical Memorandum, 2016.

Leslie, J., Deem, S. and Salo-Zieman, V. Disinfection By-Product Formation Study in Coastal Groundwater Supplies, WQTC, Portland, OR, November 12-16, 2017.

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

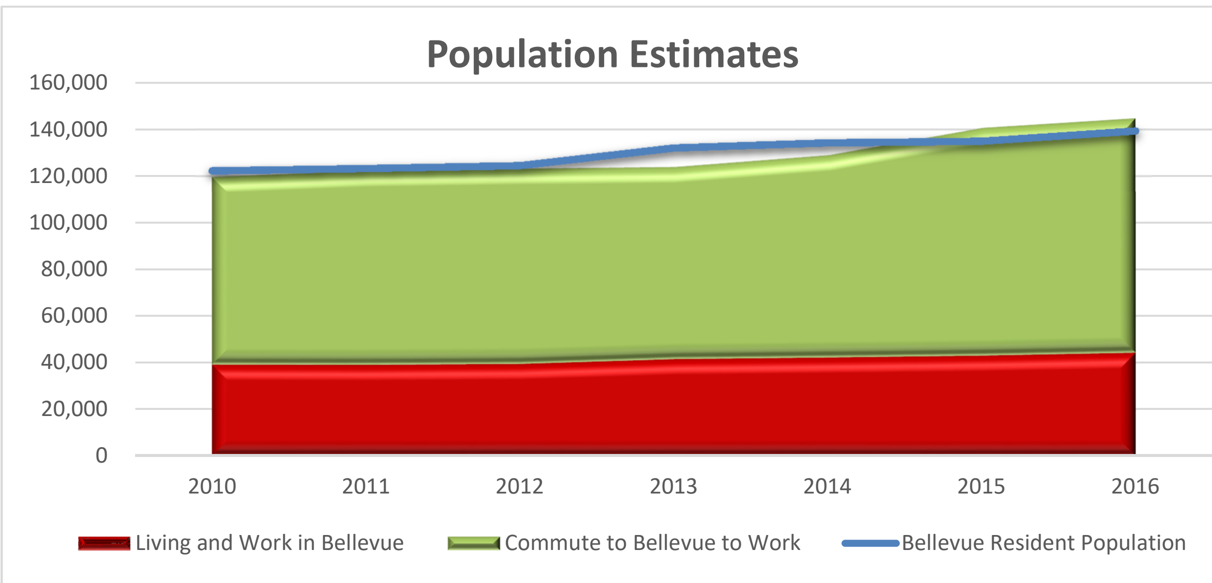
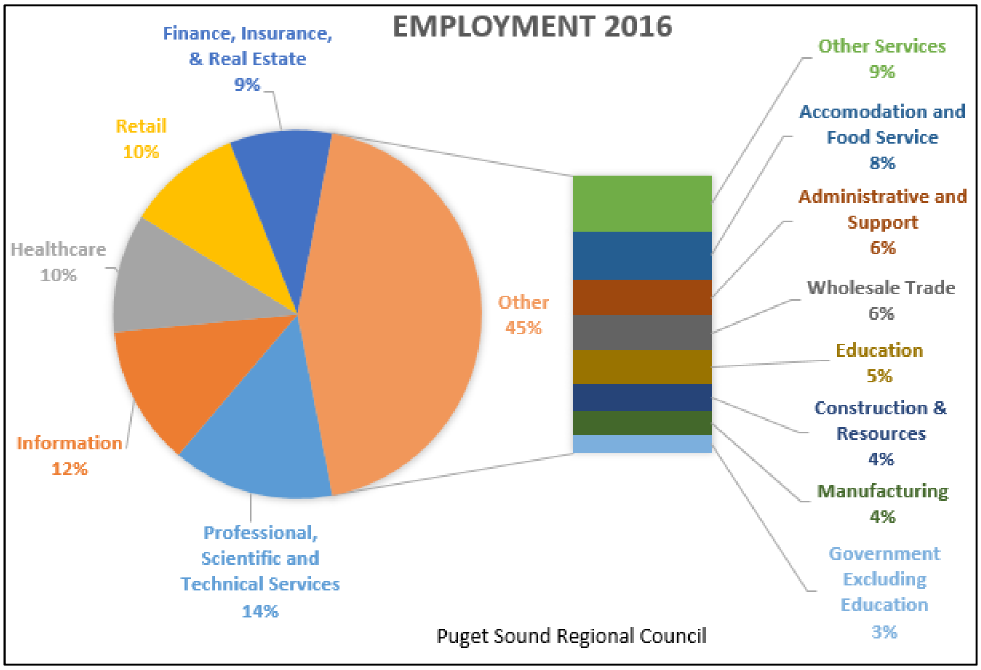


*Chart 1 data was taken from Puget Sound Regional Council (PSRC) and Bureau of Labor Statistics (BLS).

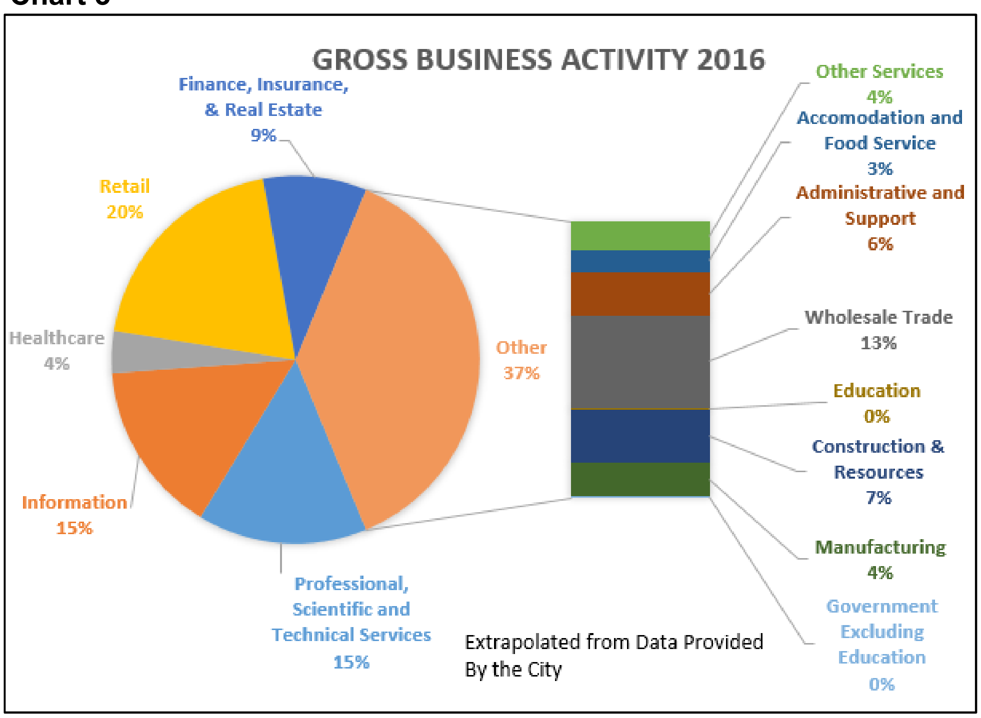
Bellevue's largest employment sector is services, wholesale trade, transportation, and utilities. Within this category the majority of these jobs are office-type jobs including professional, scientific and technical services. When finance, insurance and real estate jobs are included, nearly three quarters 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.

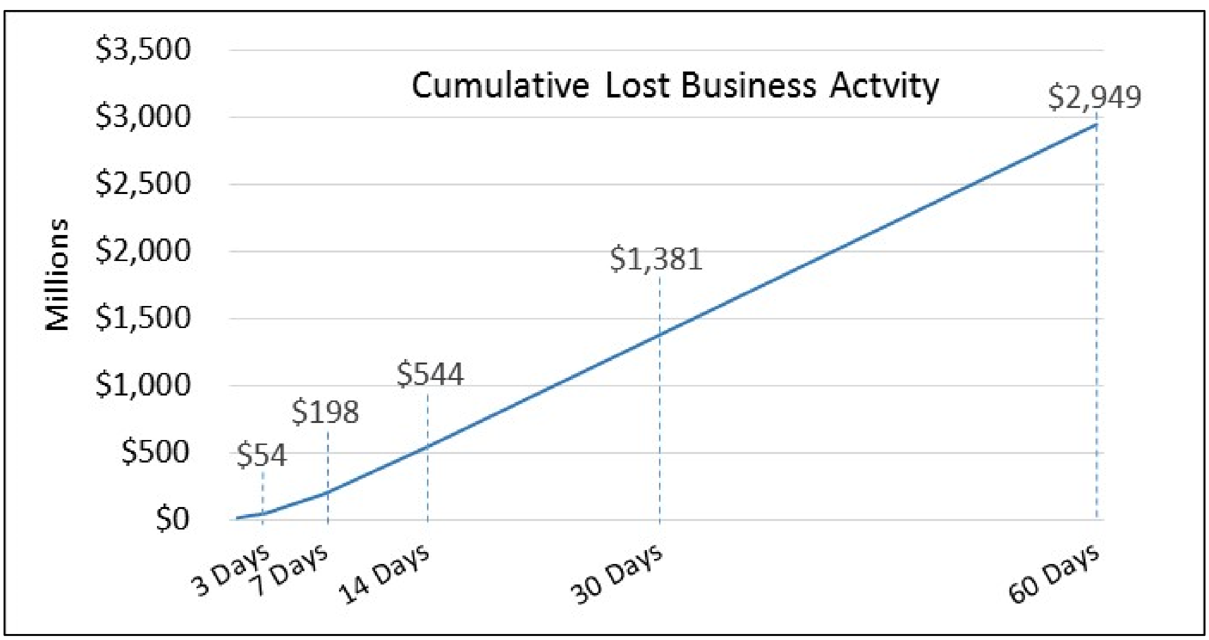
Business Activity

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.

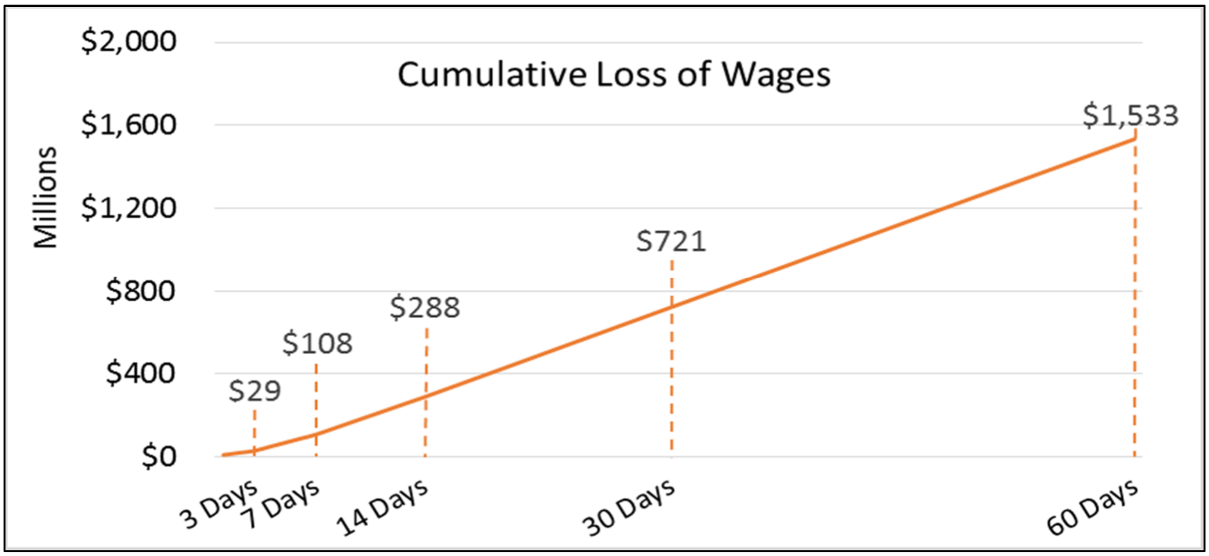
Chart 4



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



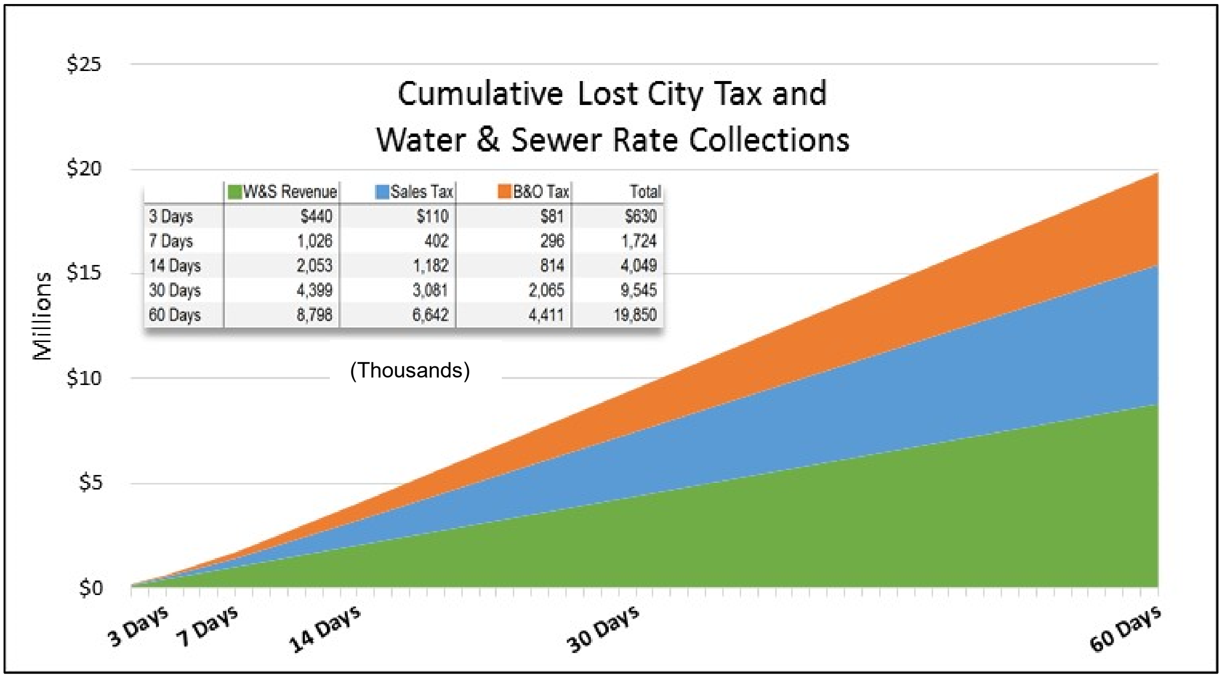
Lost Local Tax and Water and Sewer Rate Collections

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



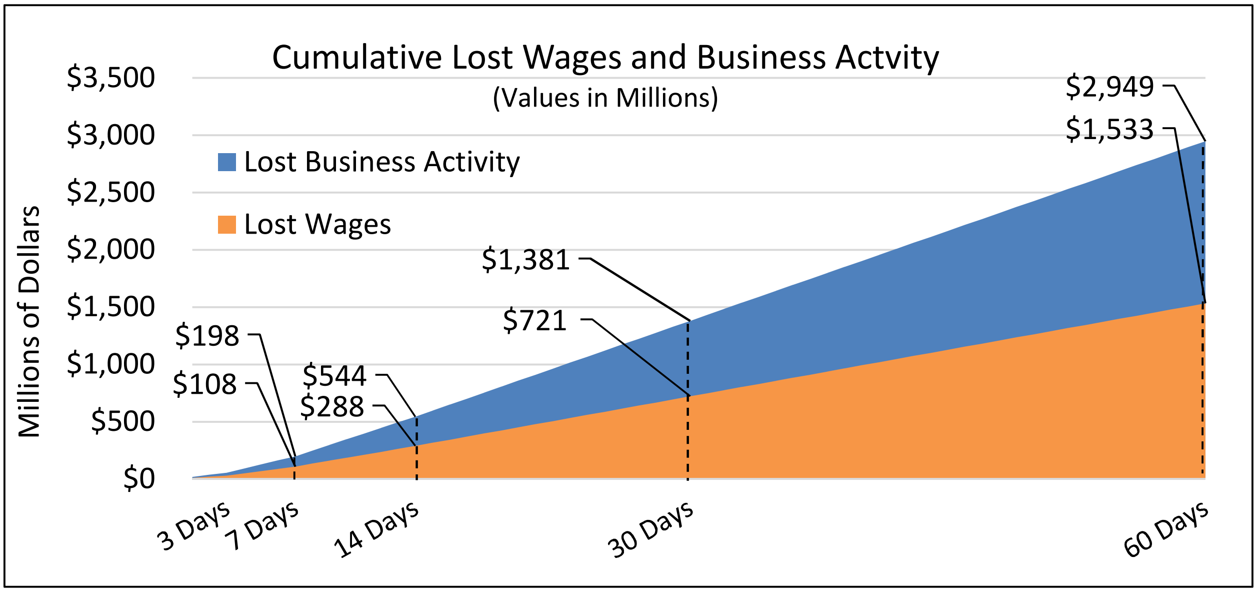
	W&S Revenue	Sales Tax	B&O Tax	Total
3 Days	$440	$110	$81	$630
7 Days	1,026	402	296	1,724
14 Days	2,053	1,182	814	4,049
30 Days	4,399	3,081	2,065	9,545
60 Days	8,798	6,642	4,411	19,850

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.

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 5×10^{-5} (scenario 4) and high storativity of 5×10^{-3} (scenario 5).
- Till Hydraulic Conductivity: high hydraulic conductivity of 2.83 ft/d (scenario 6) and low hydraulic conductivity of 2.83×10^{-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 5×10^{-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 5×10^{-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 1×10^{-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 2.83×10^{-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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7/12/19

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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

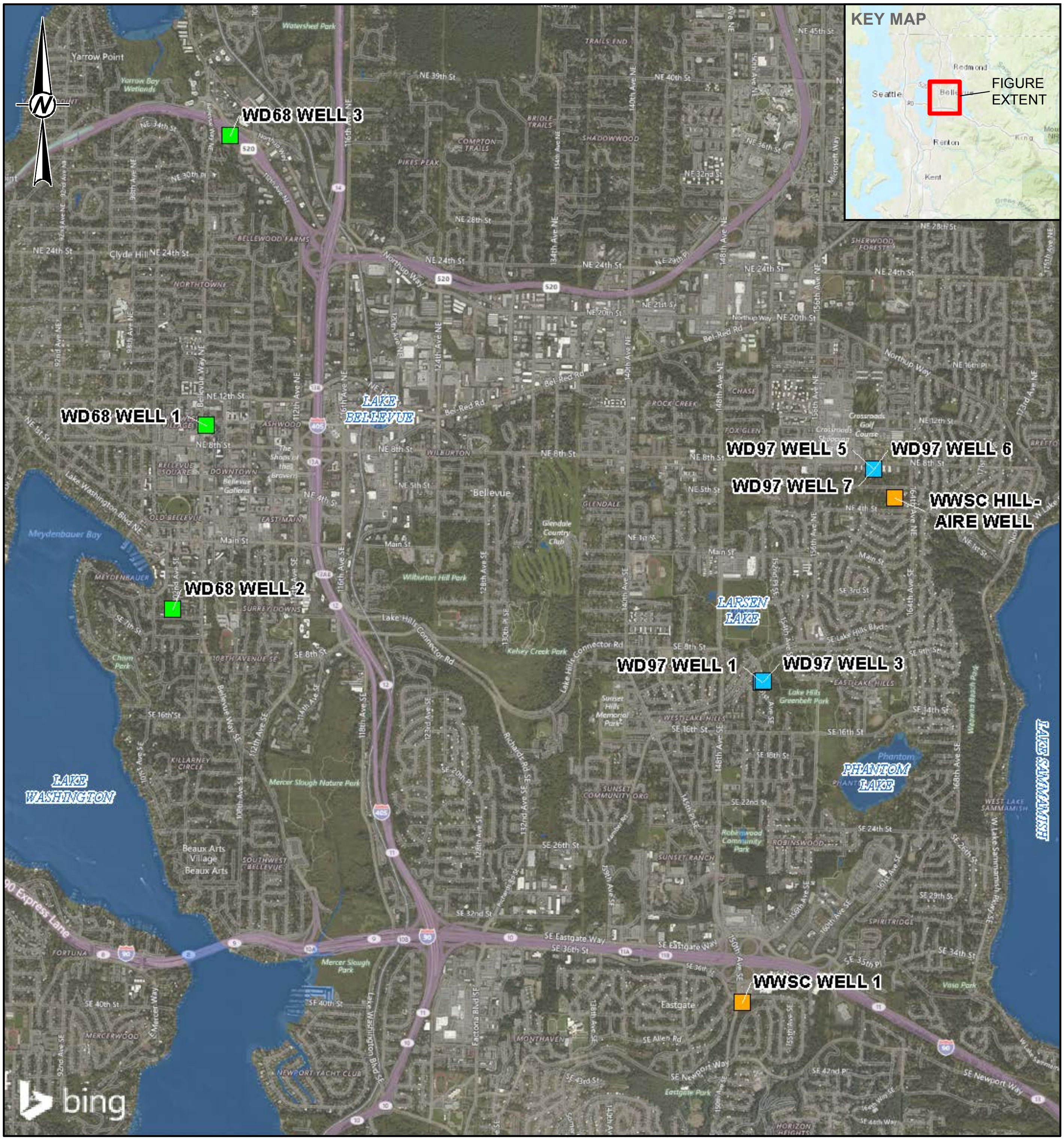
Table 6: Wellfield Analysis Scenarios and Results - Lake Sammamish Tributaries

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

Scenario	Analysis	Pumping Rate (gpm)	Kelsey Creek				Lake Sammamish Tributary				Total			
			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
1775477	3.1	A	1

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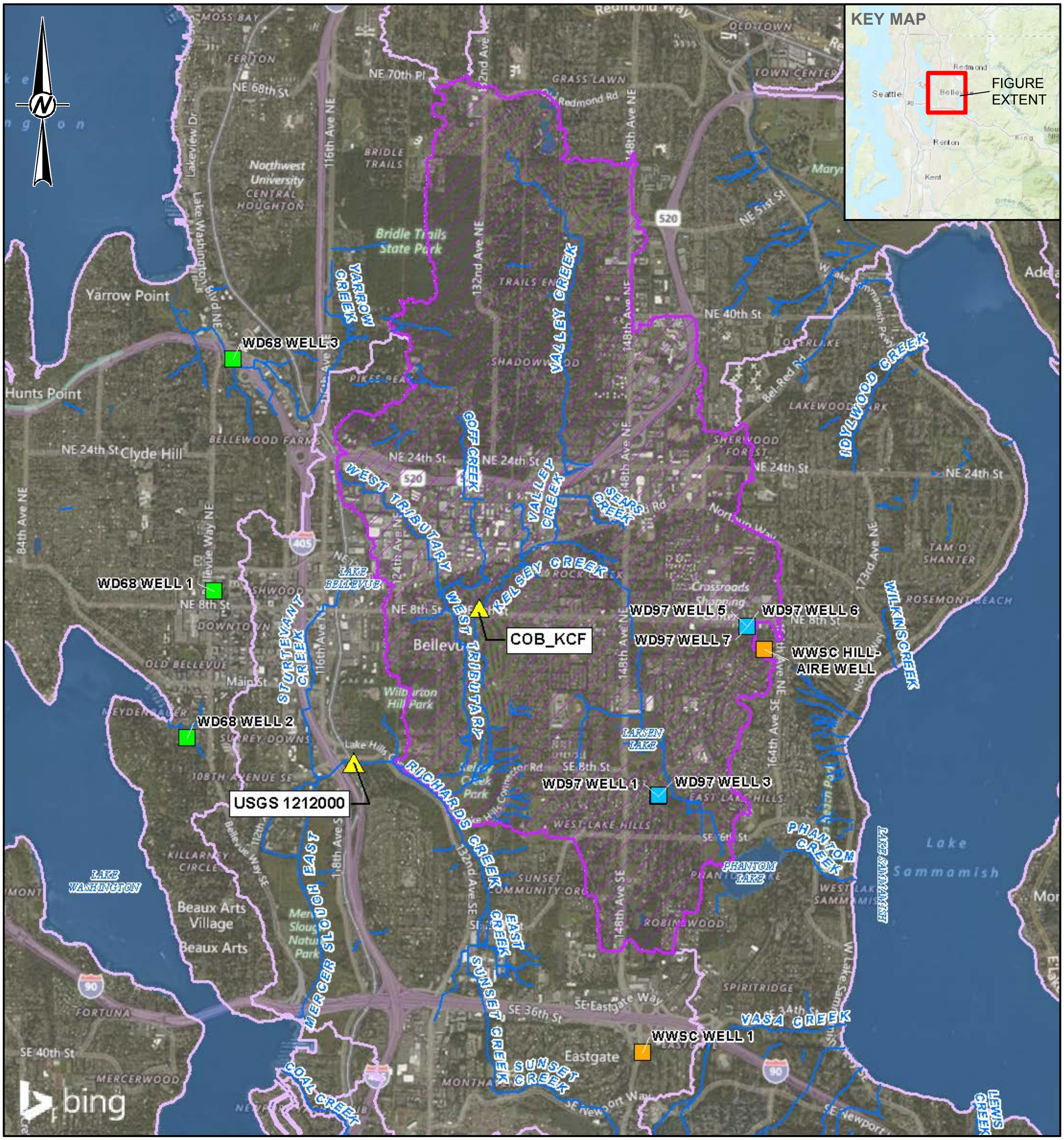
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A



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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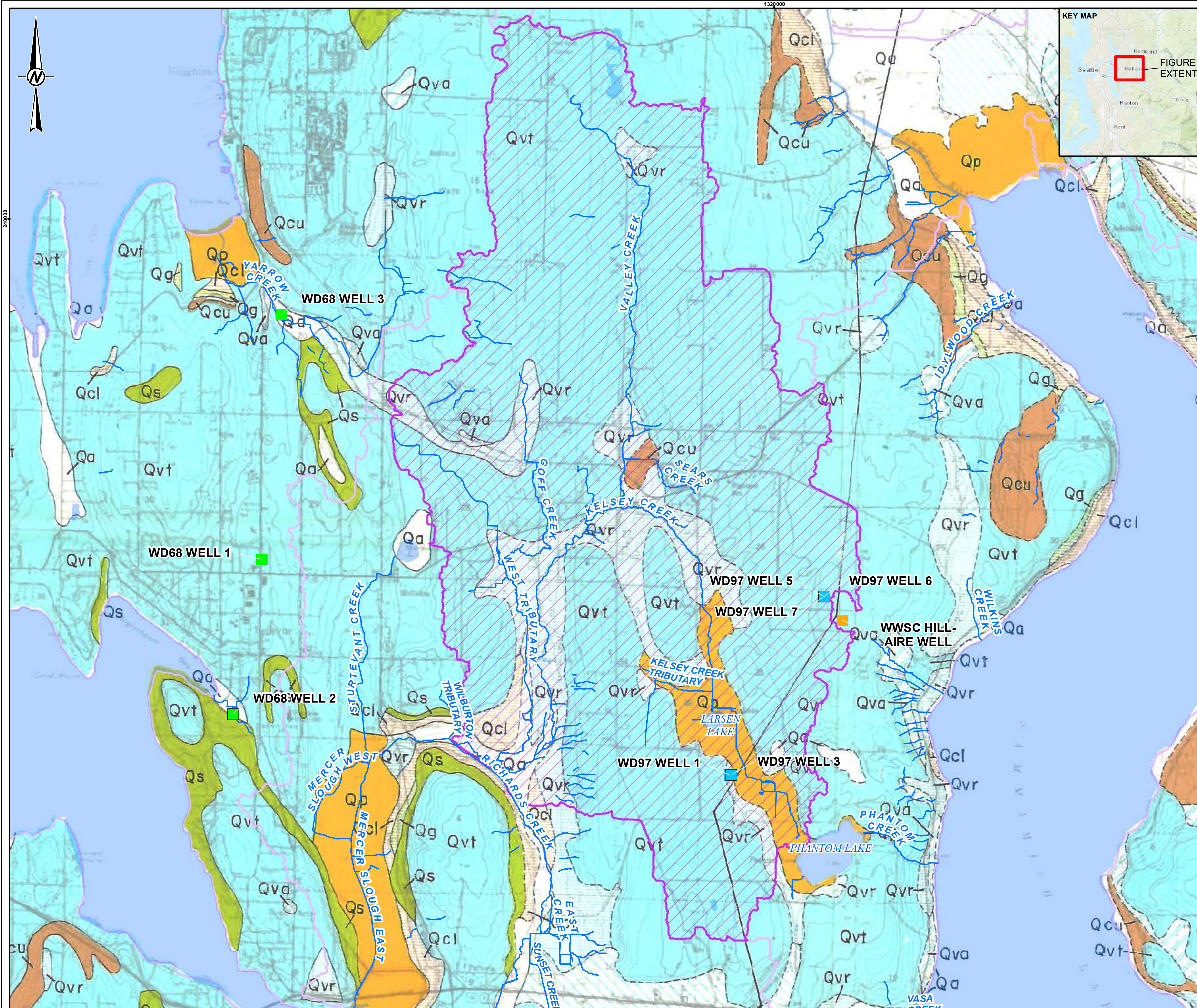

LEGEND

- 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
1775477	3.1	A	3

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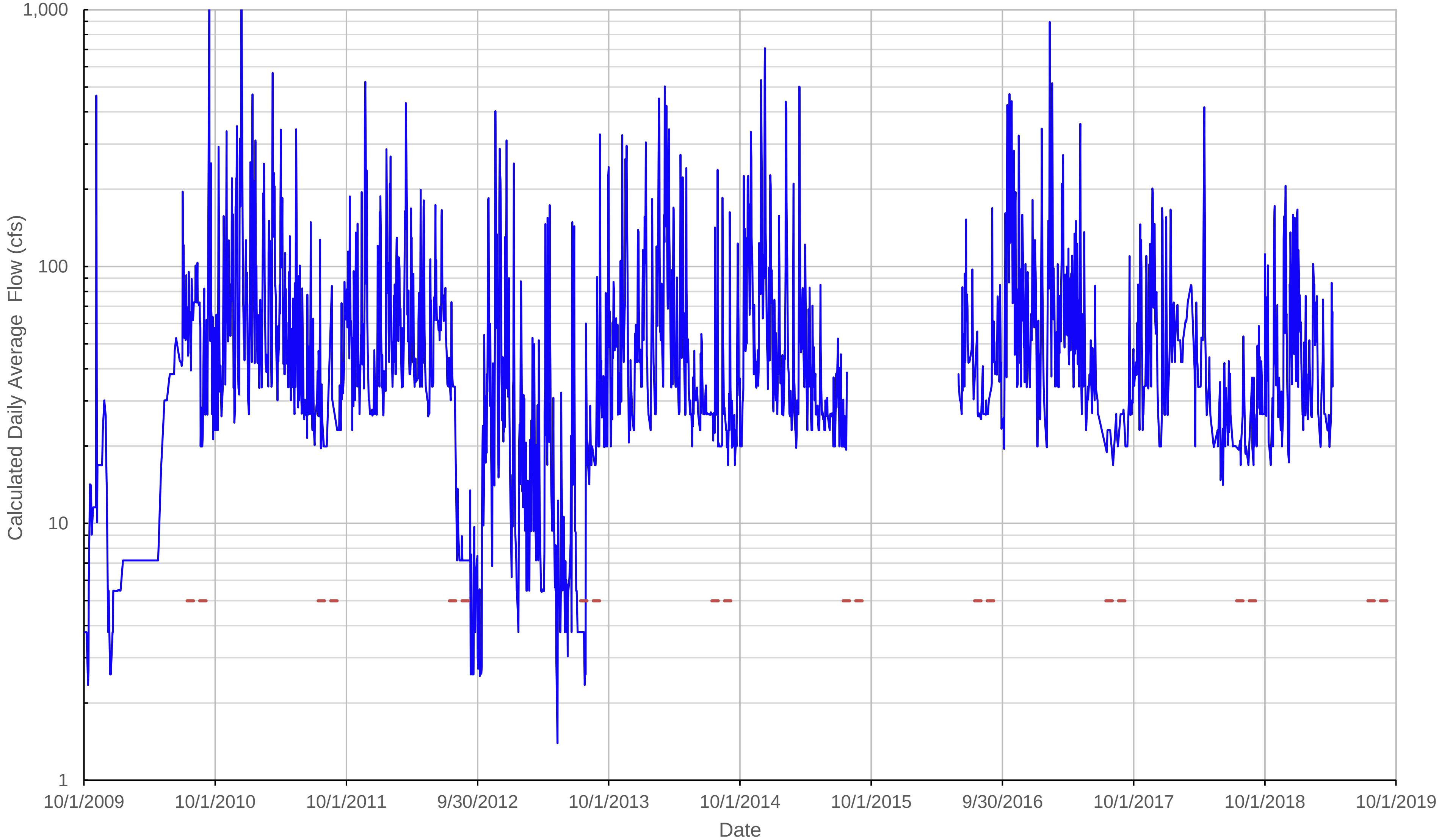

LEGEND

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
177-5477.3.1	009.9A	A	4

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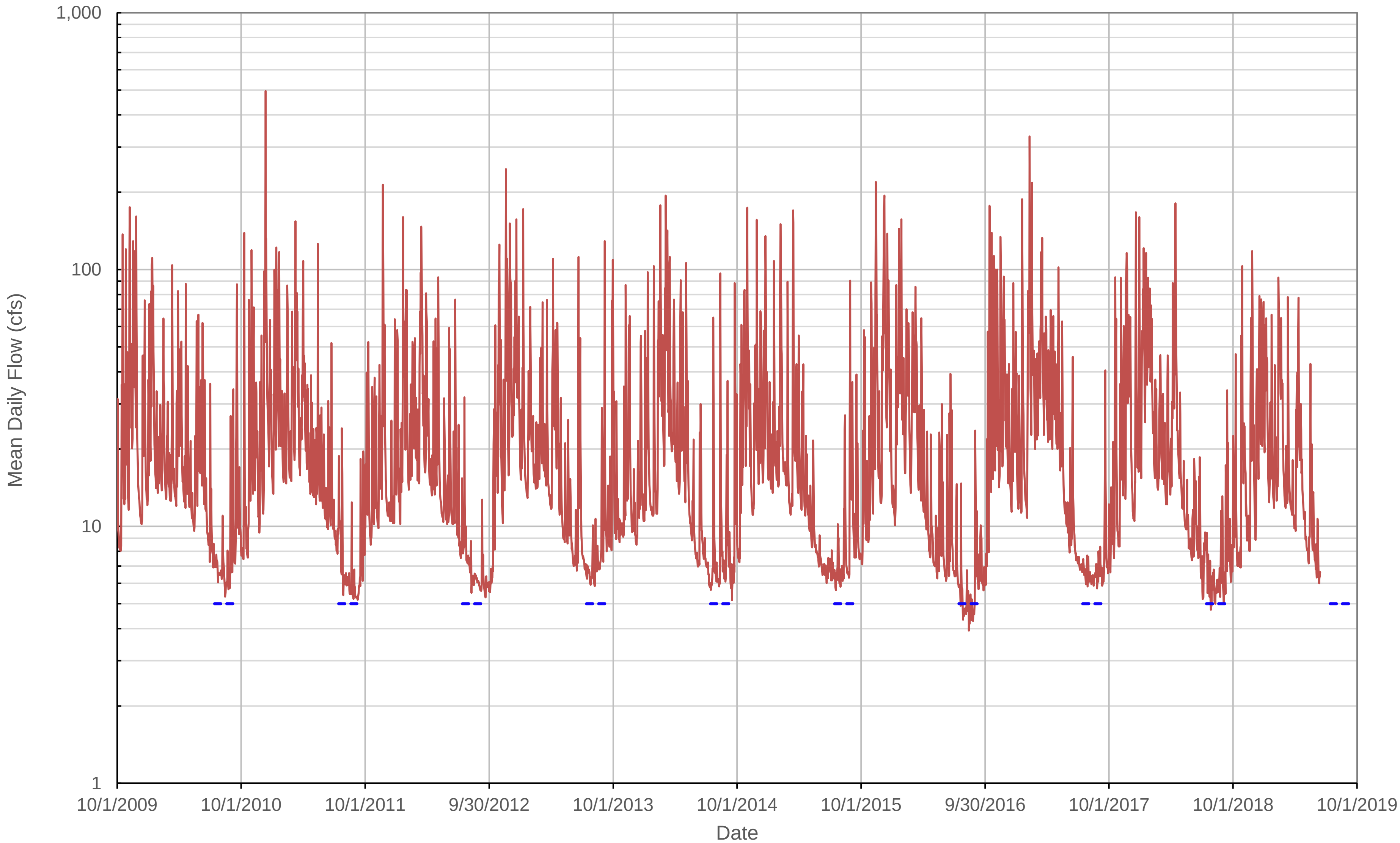

LEGEND

Measured Mean Daily Flow

Baseflow Period (approximate)

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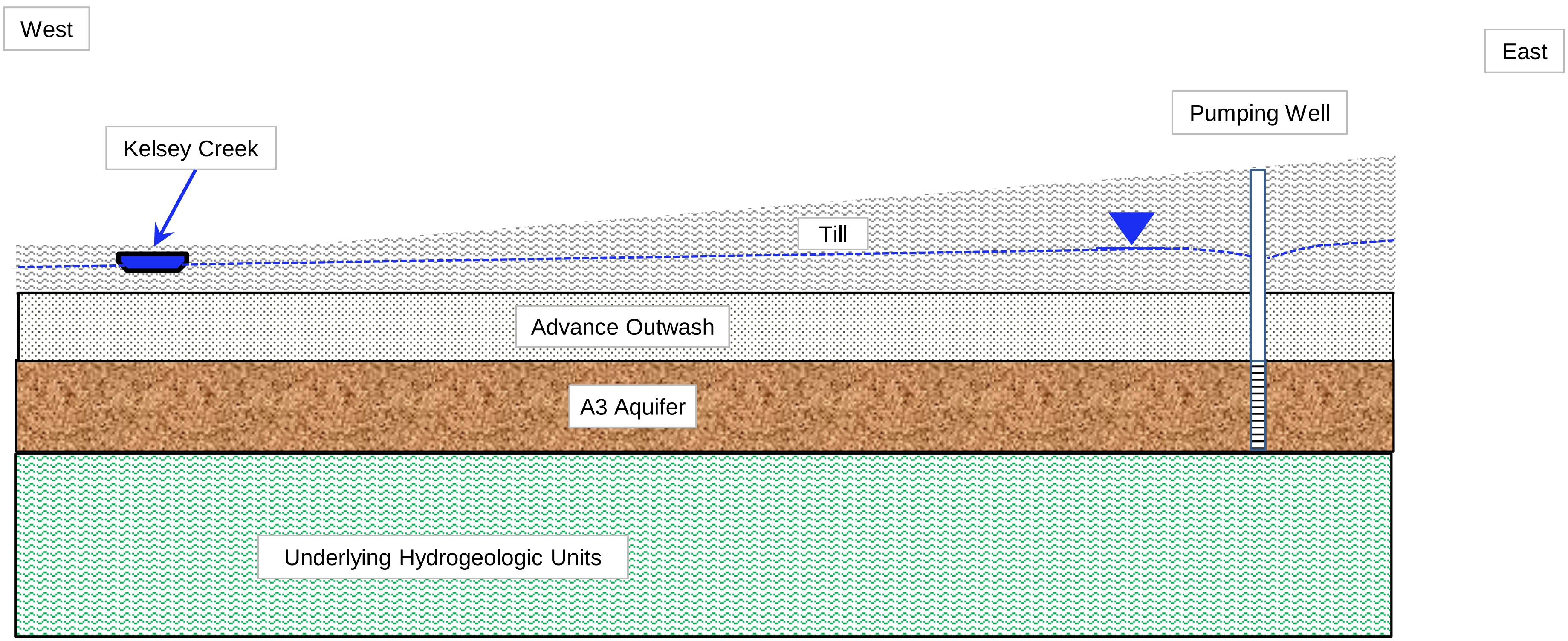
PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
MERCER CREEK NEAR BELLEVUE GAGE
USGS 12120000
STREAMFLOW HYDROGRAPH

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1	009.9A	A	5



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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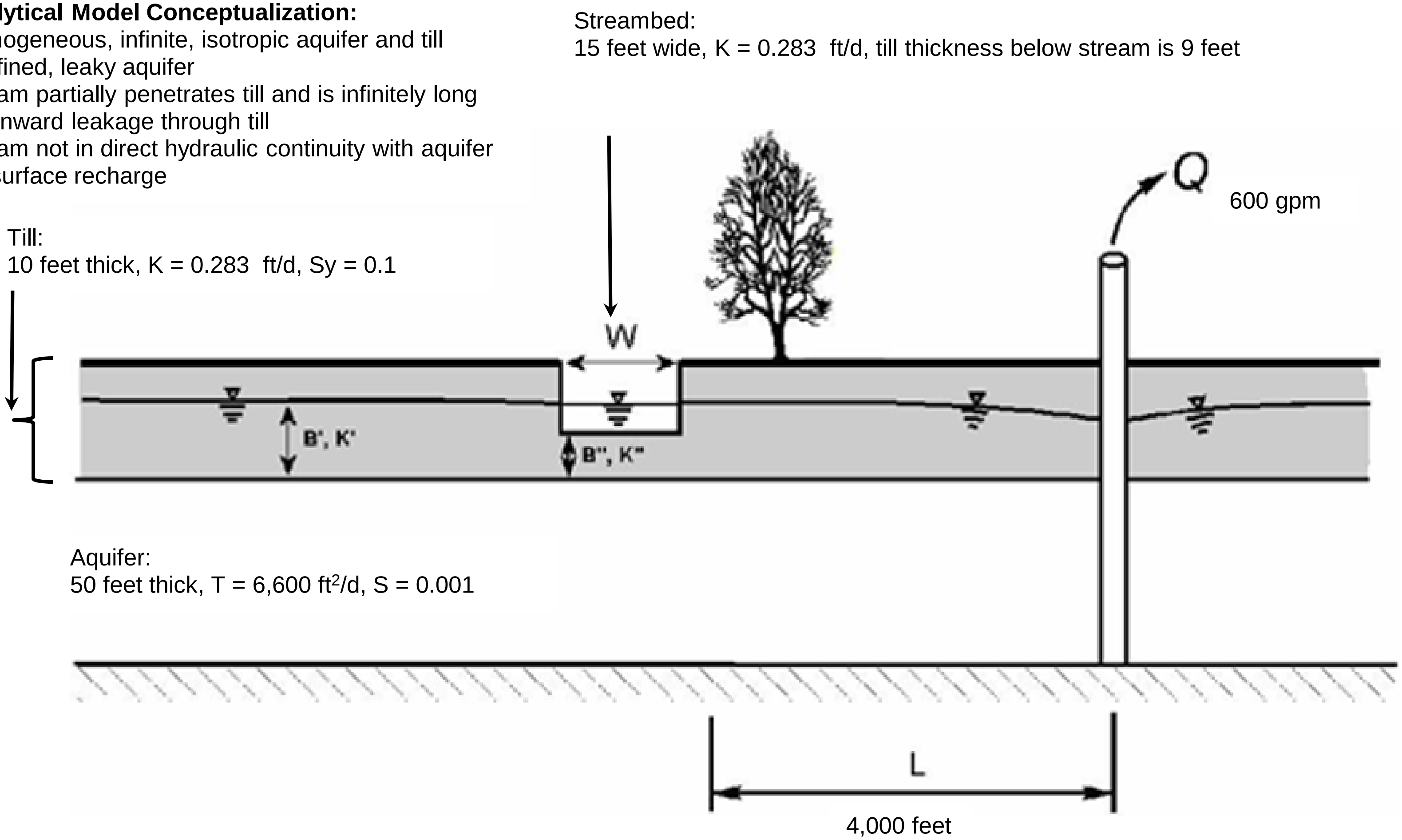
PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
CONCEPTUAL MODEL
FOR KELSEY CREEK

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	6

PATH: \\golderassociates.sharepoint.com@SSL\DavWWWRoot\sites\11470g\Shared Documents\Task 3.1 Existing Conditions\Aquifer-Stream TM\Final July 2019\Final | FILE NAME: Figures Rev July 2019.xlsx

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



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

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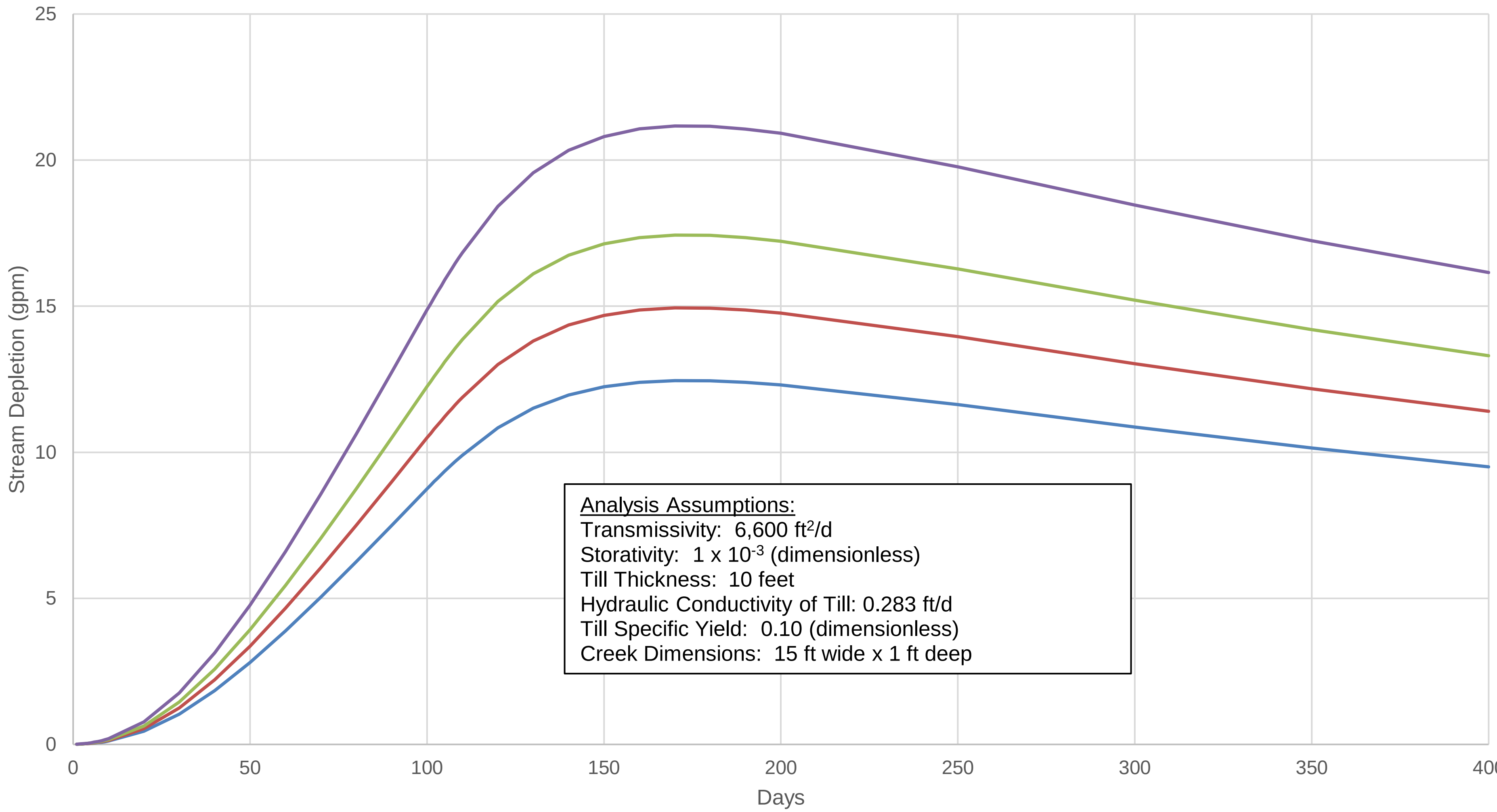

LEGEND

- Scenario 1a (500 gpm)
- Scenario 1b (600 gpm)
- Scenario 1c (700 gpm)
- Scenario 1d (850 gpm)

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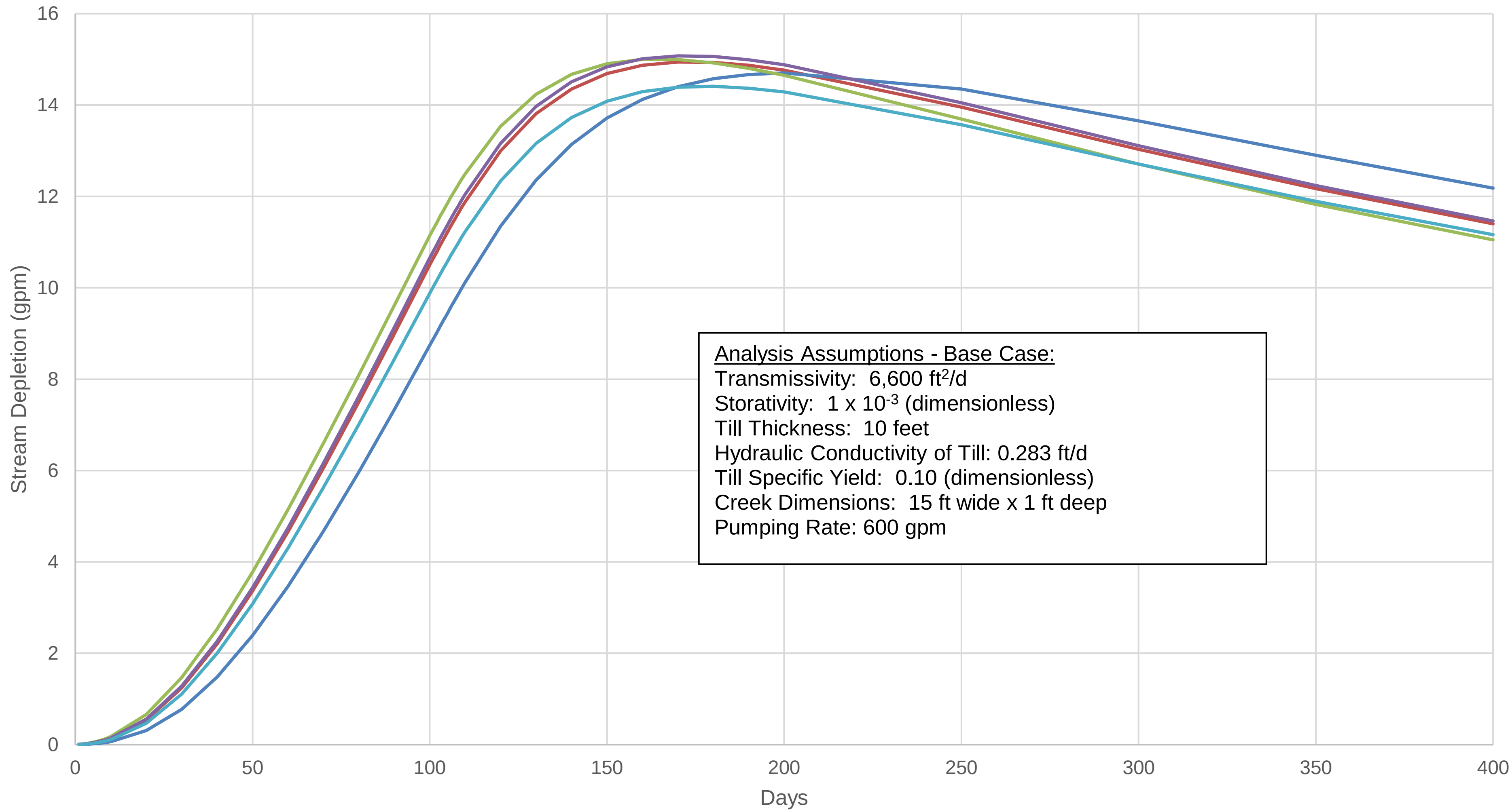
PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
STREAM DEPELETION ANALYSIS - KELSEY CREEK
SINGLE WELL 100 DAYS PUMPING

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	8

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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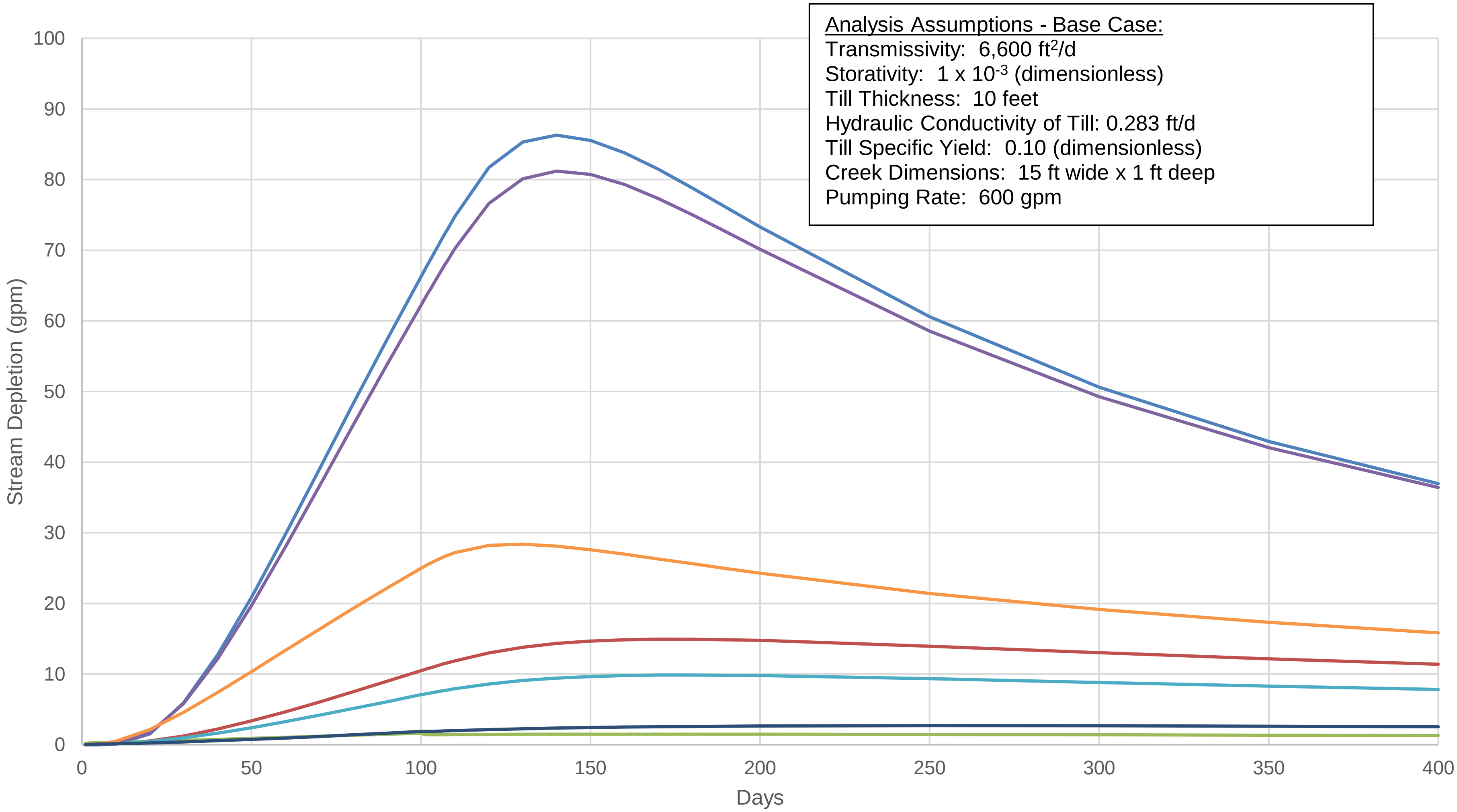
PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
STREAM DEPELETION ANALYSIS - 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)

CLIENT
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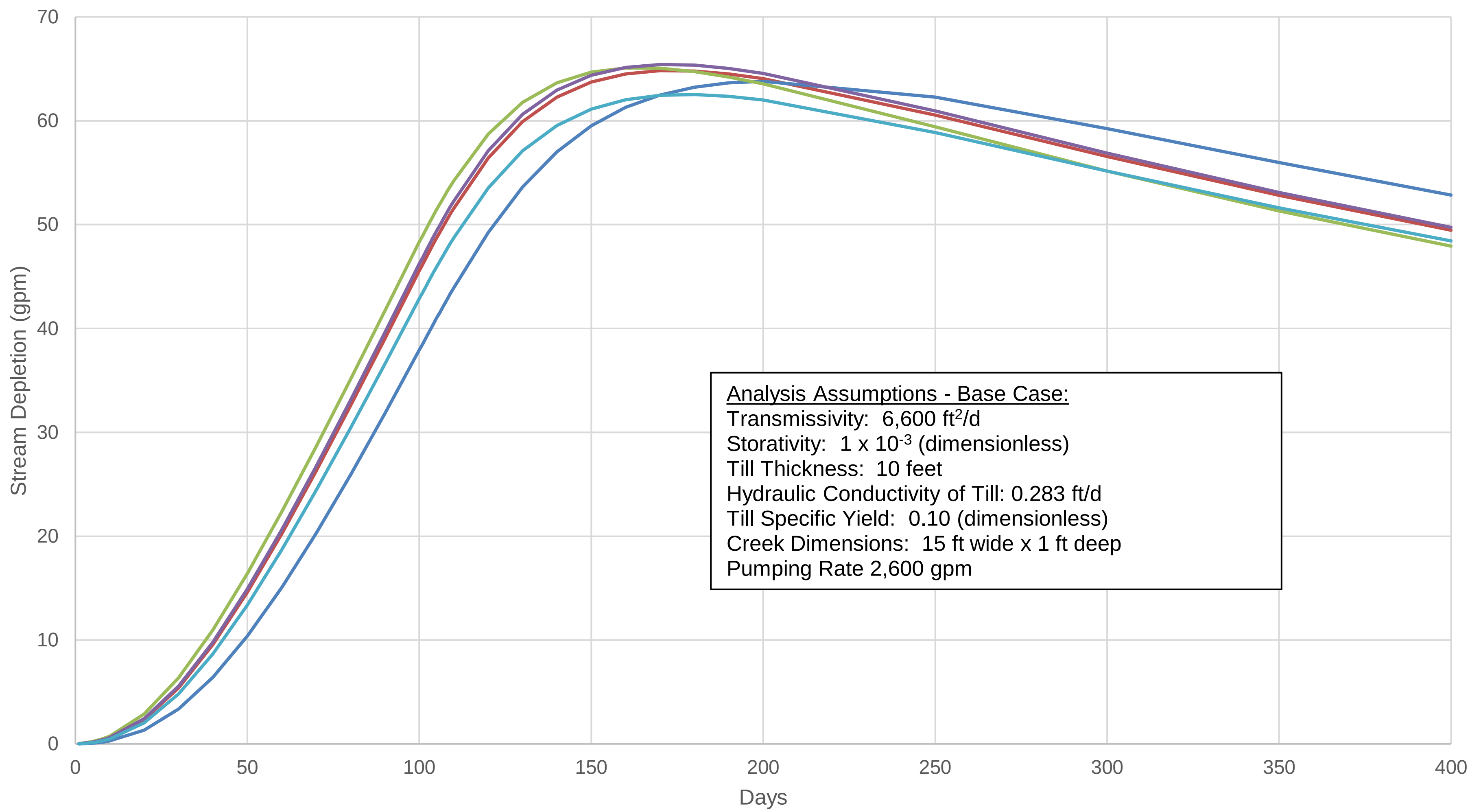
GOLDER

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
177-5477.3.1		A	10

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 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)

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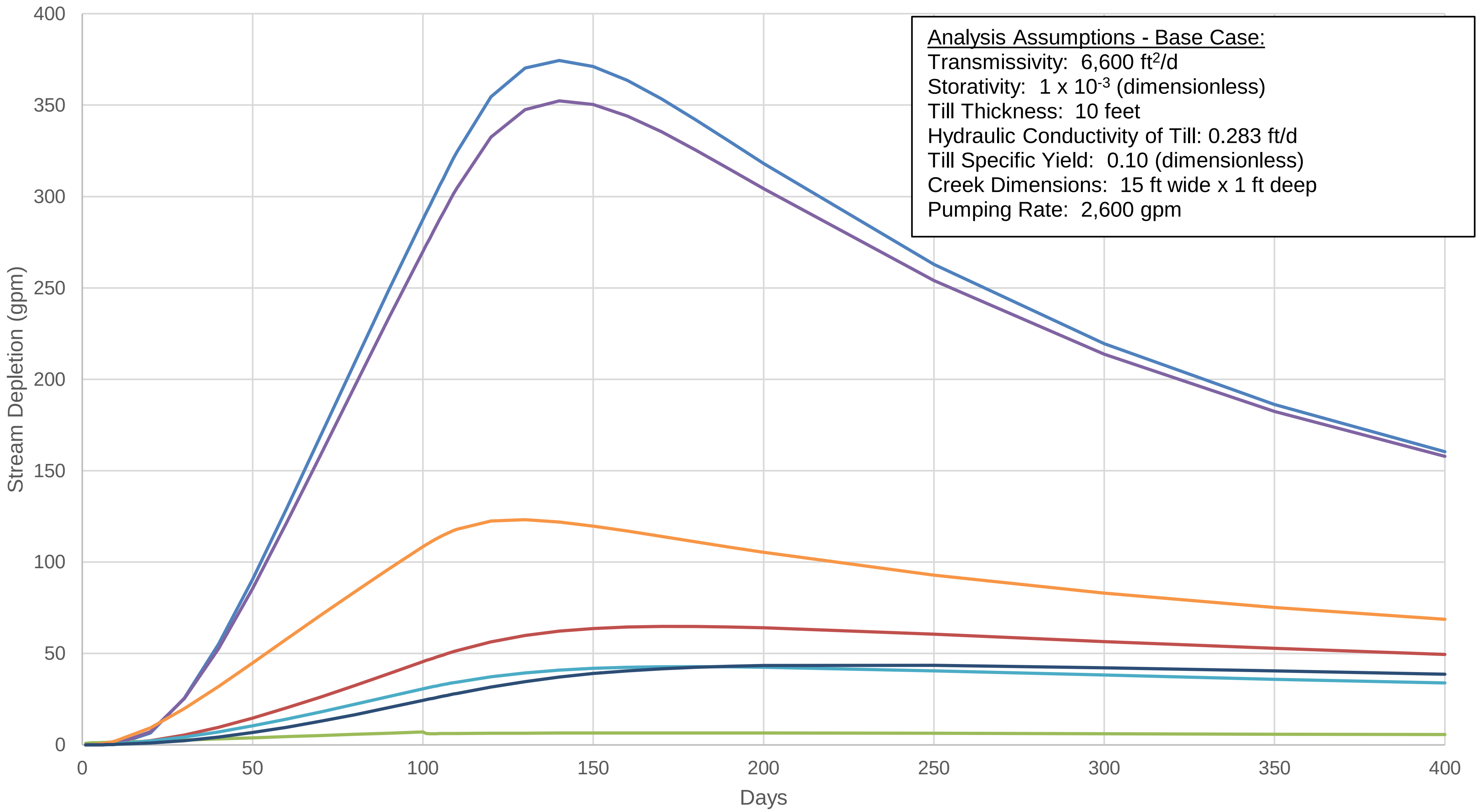
PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
STREAM DEPELETION ANALYSIS - KELSEY CREEK
WELLFIELD PUMPING AND AQUIFER PROPERTIES SENSITVITY

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	11

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 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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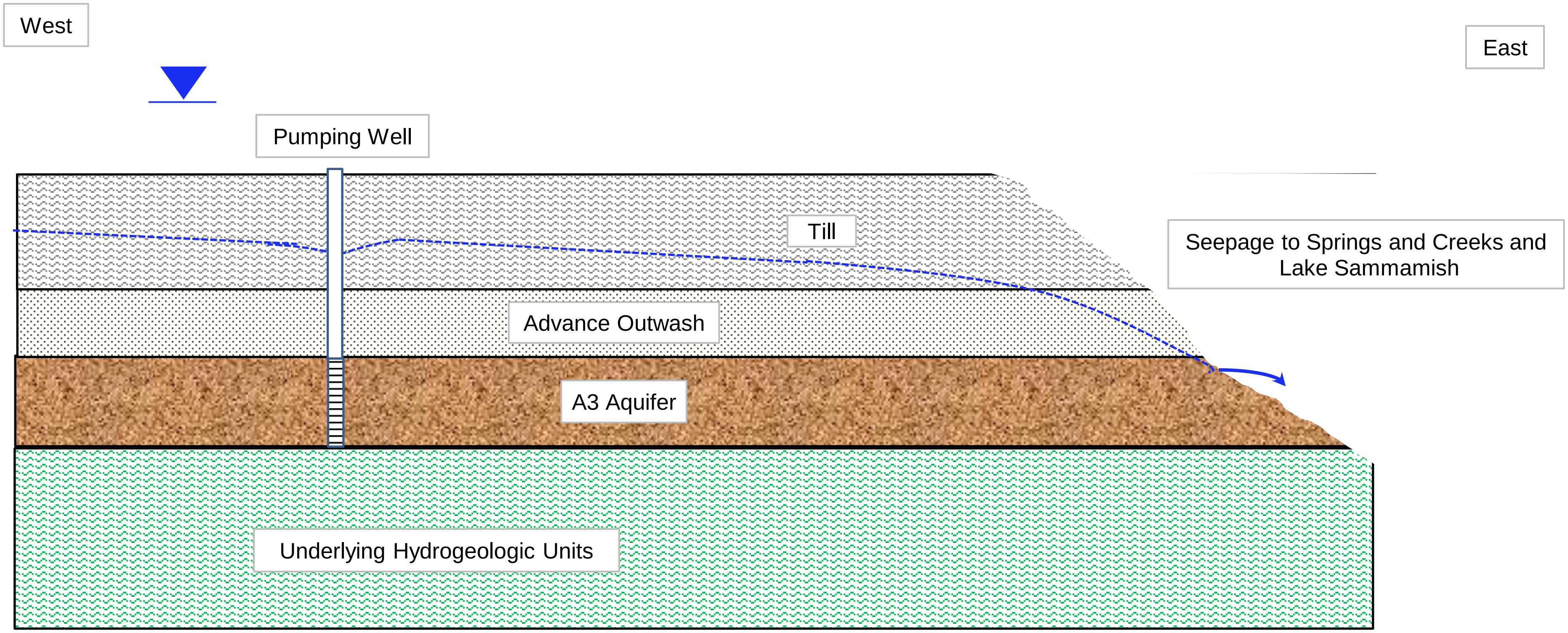
PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

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

CLIENT
STANTEC

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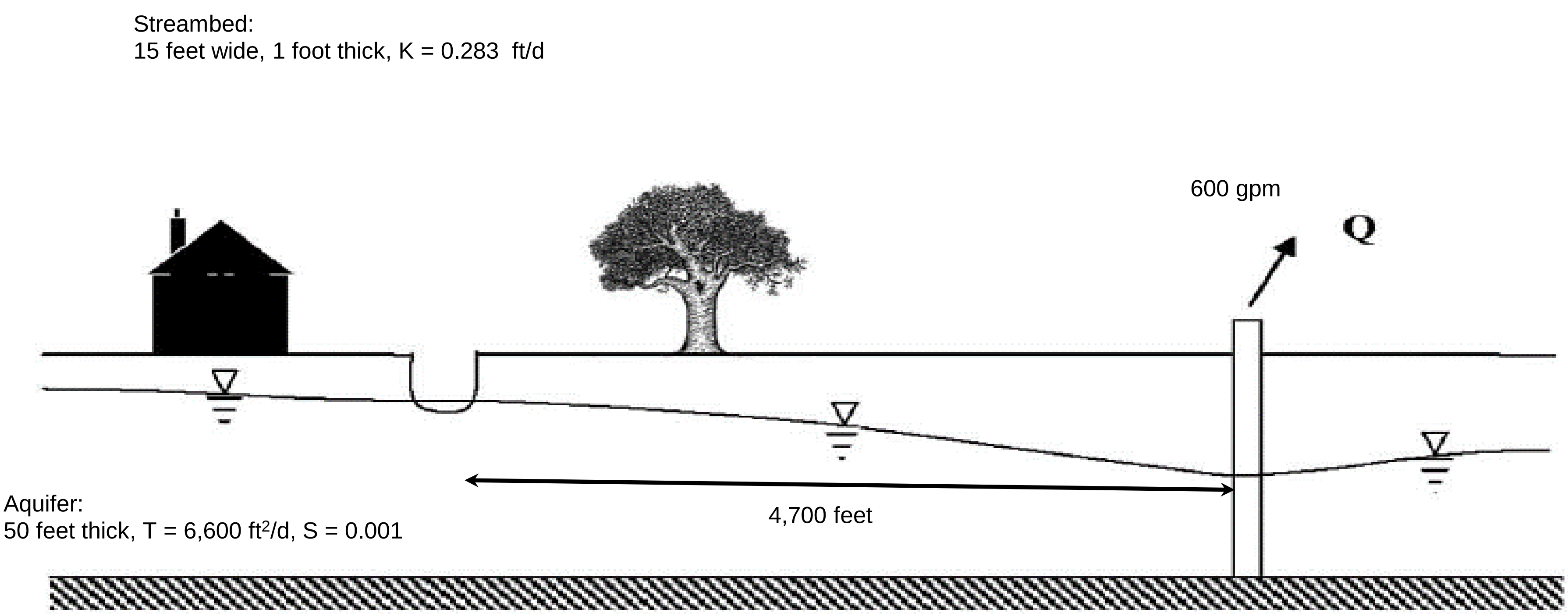
PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
CONCEPTUAL MODEL
FOR LAKE SAMMAMISH TRIBUTARIES DEPLETION

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	13



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

CLIENT
STANTEC

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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

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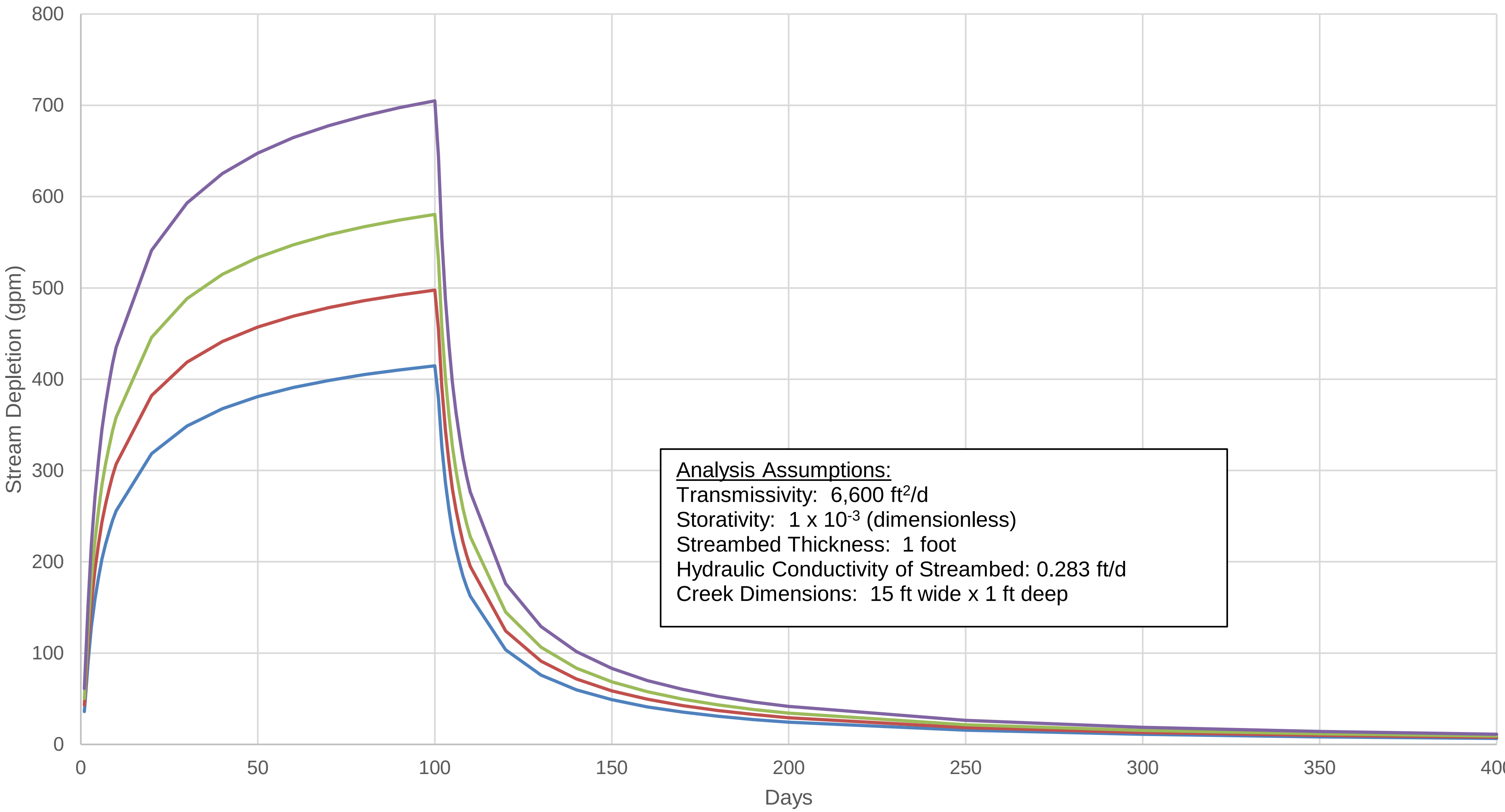


LEGEND

- Scenario 1a (500 gpm)
- Scenario 1b (600 gpm)
- Scenario 1c (700 gpm)
- Scenario 1d (850 gpm)

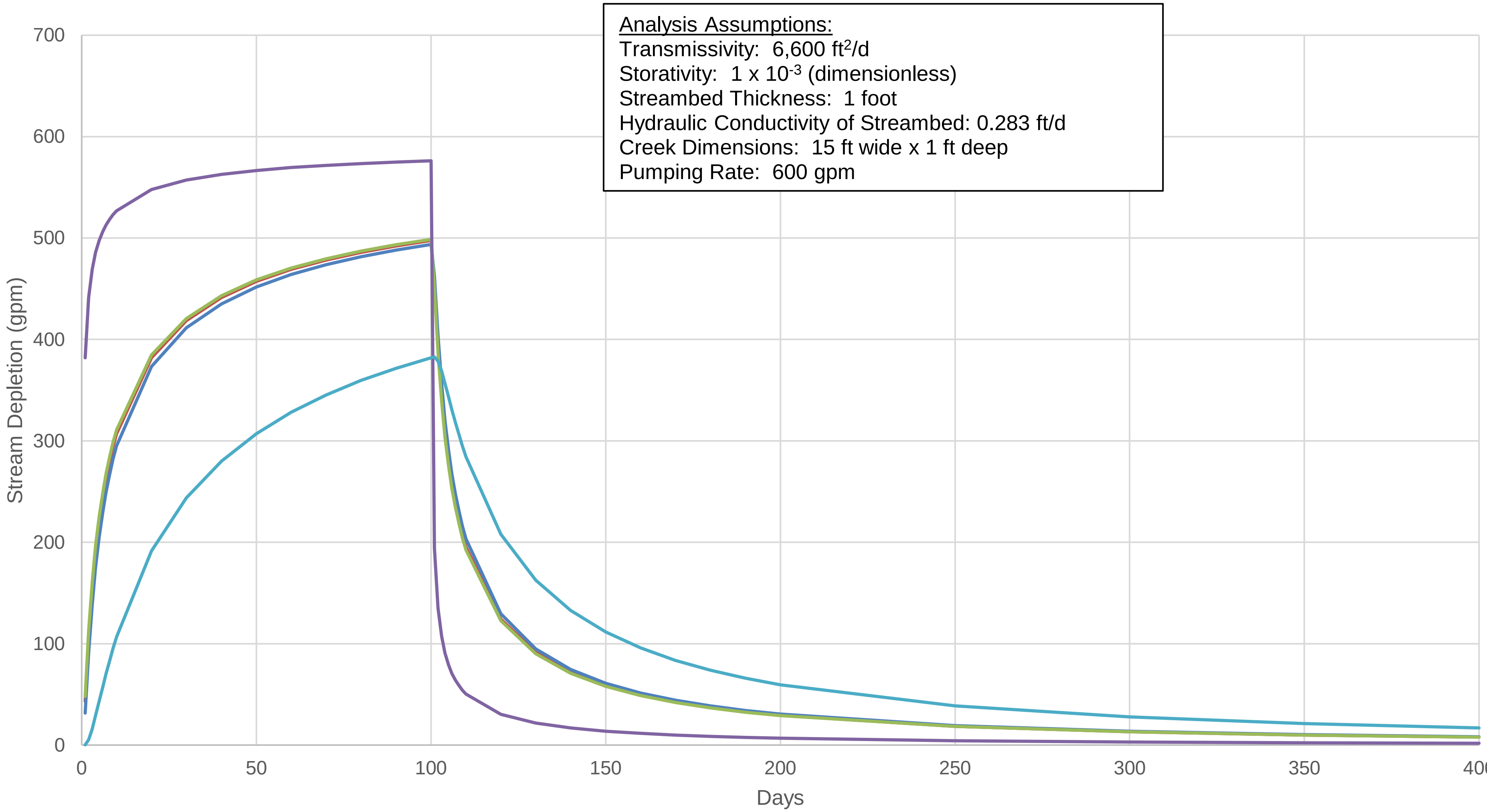
CLIENT
STANTEC

CONSULTANT
GOLDER

PROJECT
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

TITLE
AQUIFER-STREAM EVALUATION
STREAM DEPELETION ANALYSIS - LAKE SAMMAMISH TRIBUTARY
SINGLE WELL 100 DAYS PUMPING

PROJECT NO.	PHASE	REV.	FIGURE
177-5477.3.1		A	15



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)

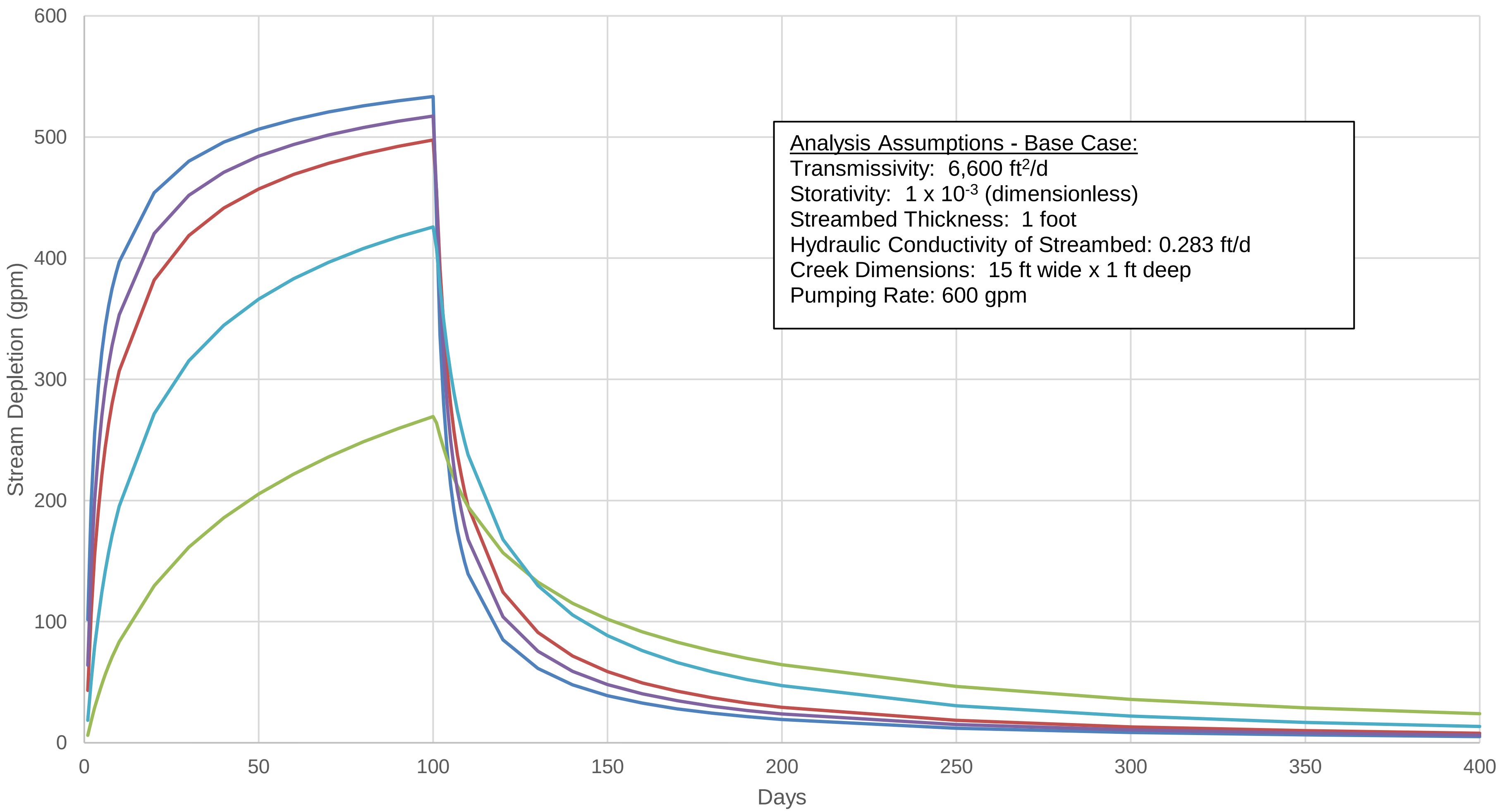
CLIENT
STANTEC

CONSULTANT
GOLDER

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
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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

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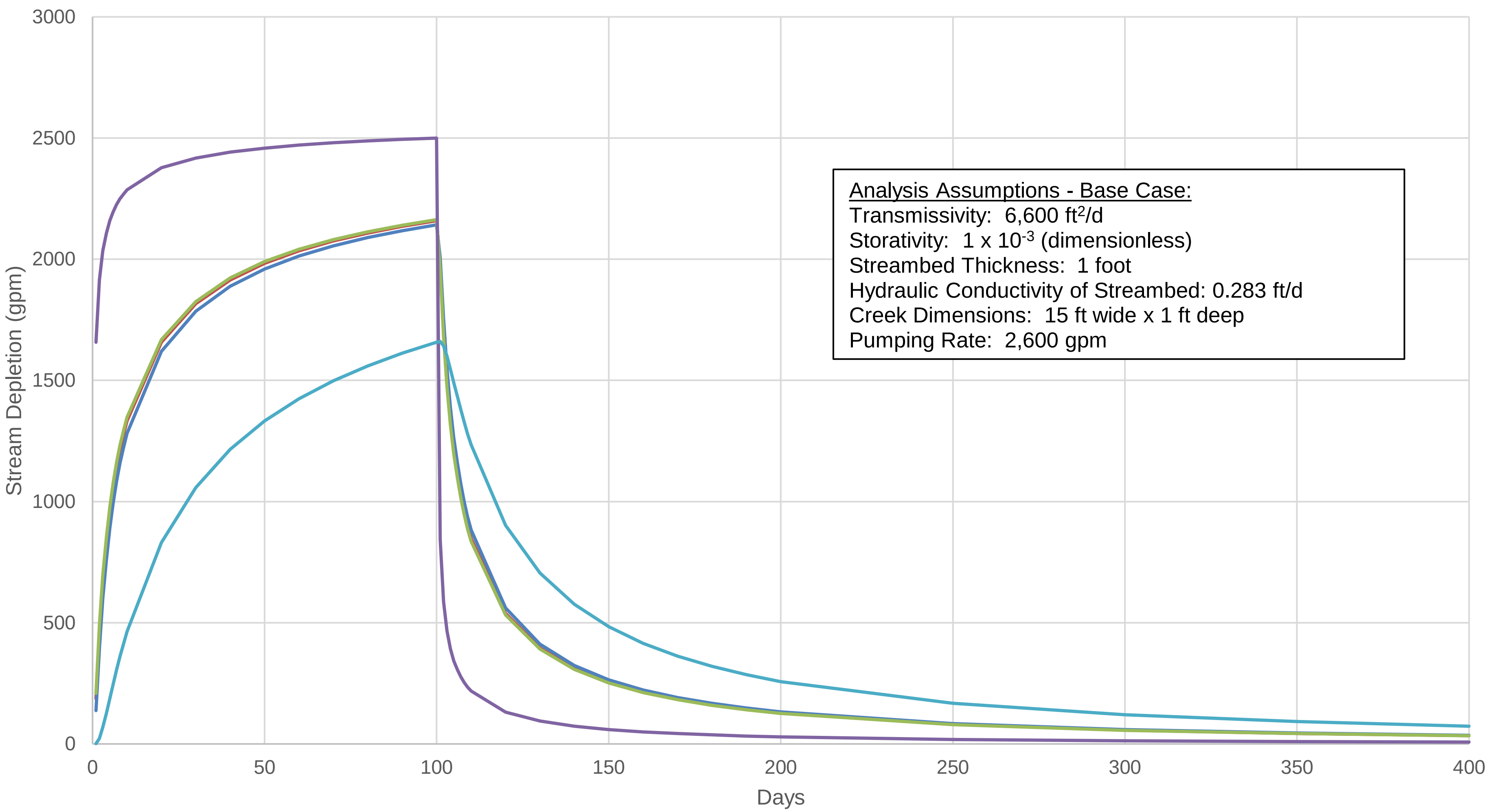

LEGEND

- 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)

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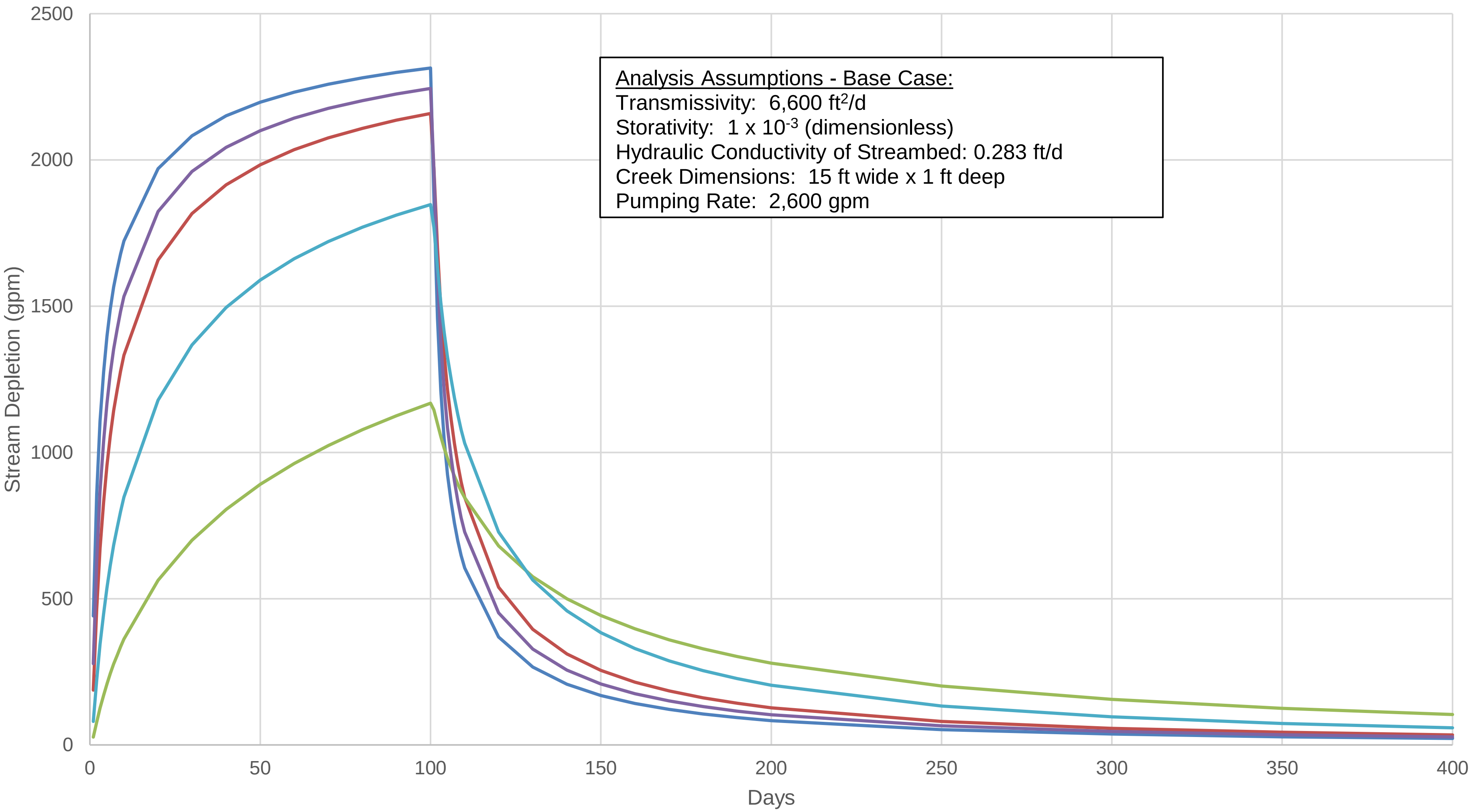
CITY OF BELLEVUE
EMERGENCY WATER SUPPLY PLAN

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



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)

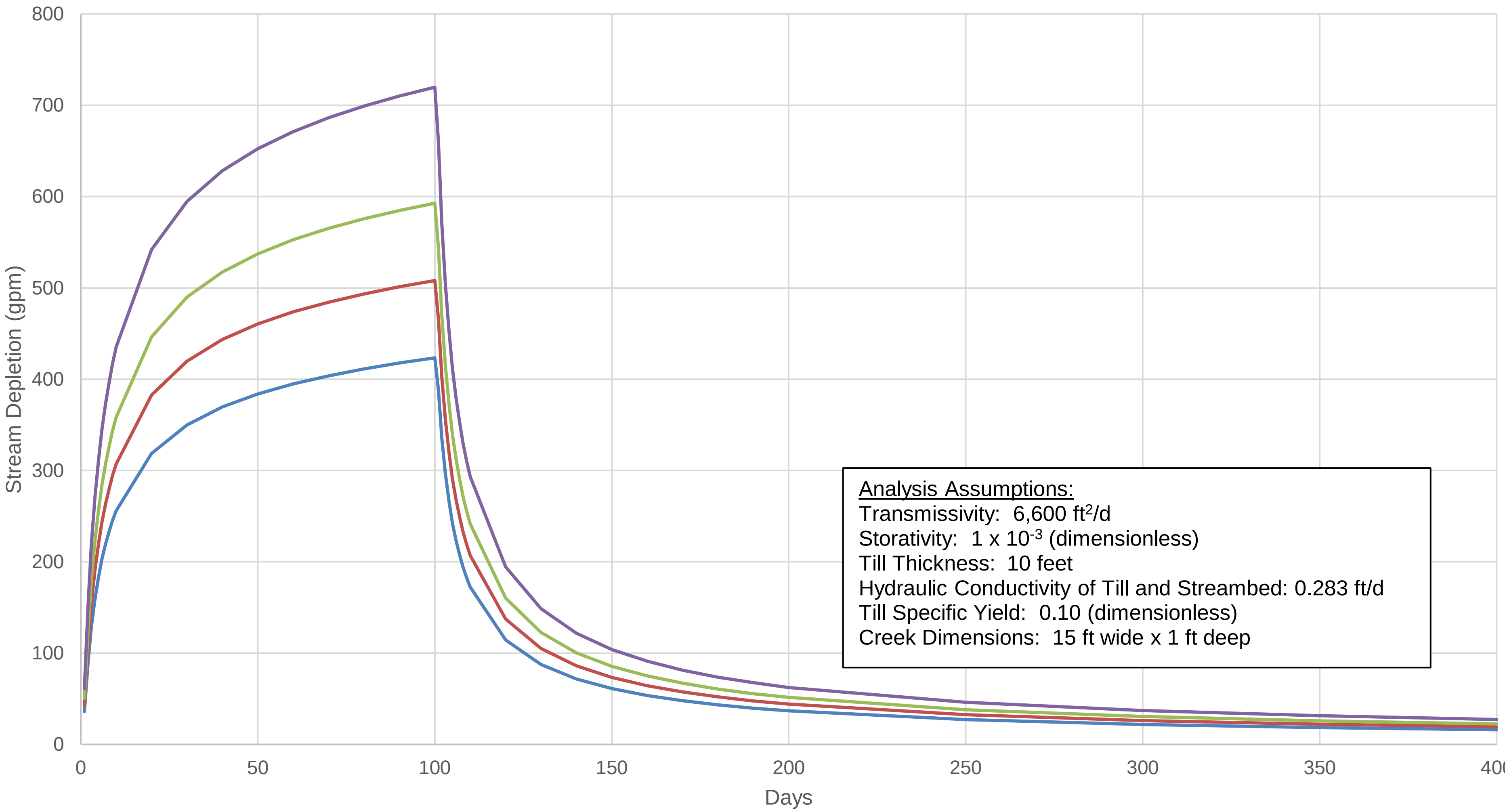
CLIENT
STANTEC

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

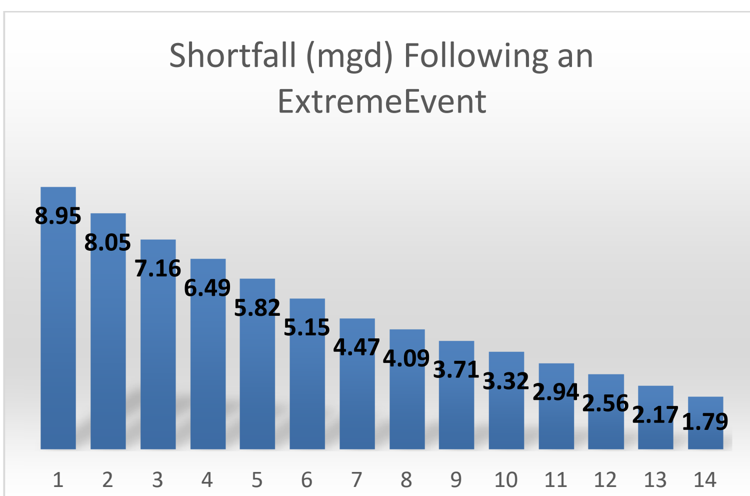
To:	Douglas Lane, P.E., City of Bellevue Laurie Fulton, P.E., Stantec
From:	Thomas Bell-Games, P.E., HDR
Date:	May 14, 2019
Subject:	Emergency Water Needs Assessment

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.

<u>Water Supply Forum</u>

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

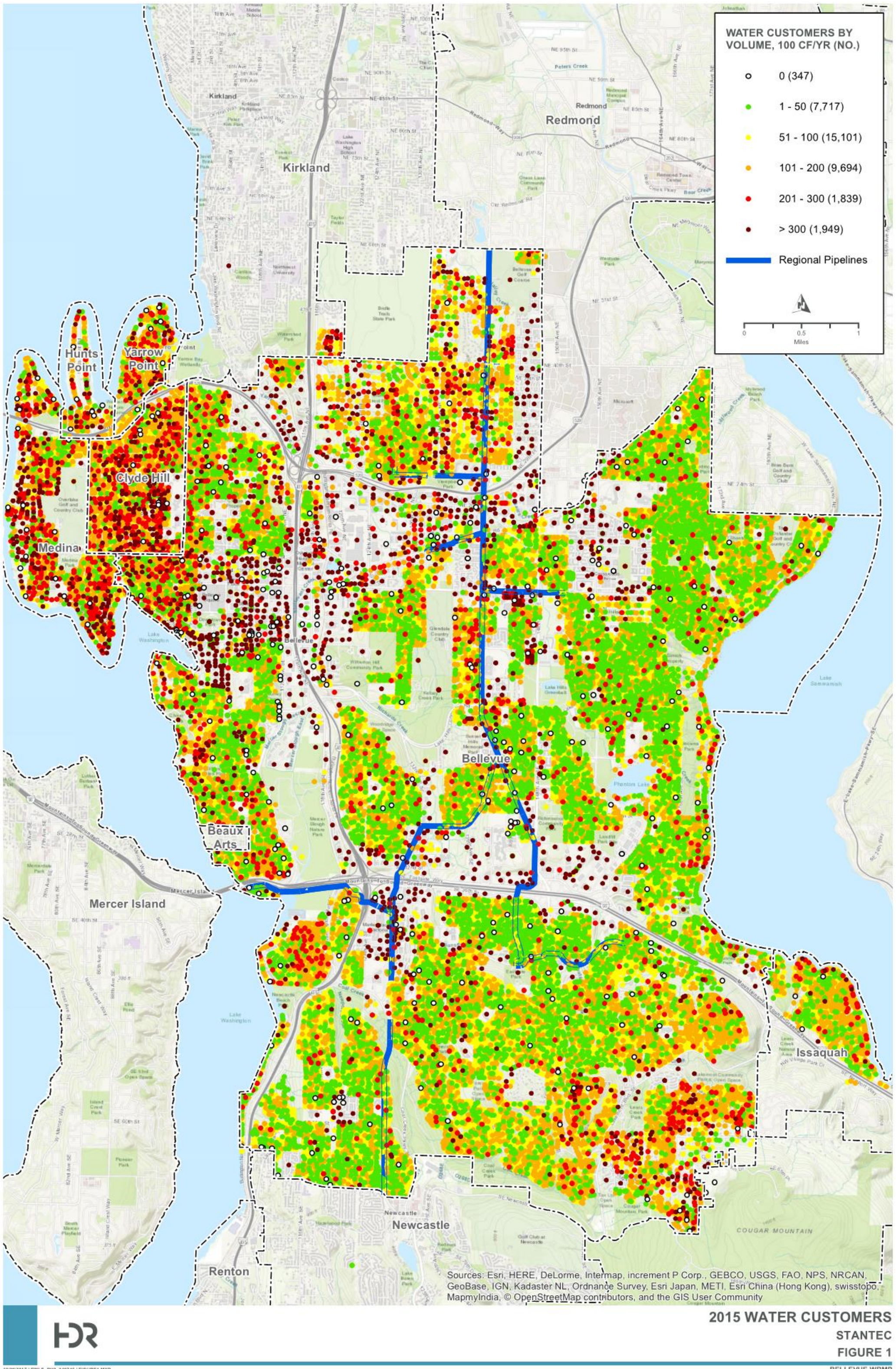
Water comes into the Bellevue system through 12 active inlets, one inactive inlet that is available for providing back-up flow, three inlets operated by adjacent utilities, and four additional inlets no longer in service, but available by re-commissioning if needed. Furthermore, the system is heavily 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.

<u>Using Oregon Resilience Plan Approach</u>

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.

<u>Using Mercer Island Approach</u>

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

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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 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).

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.

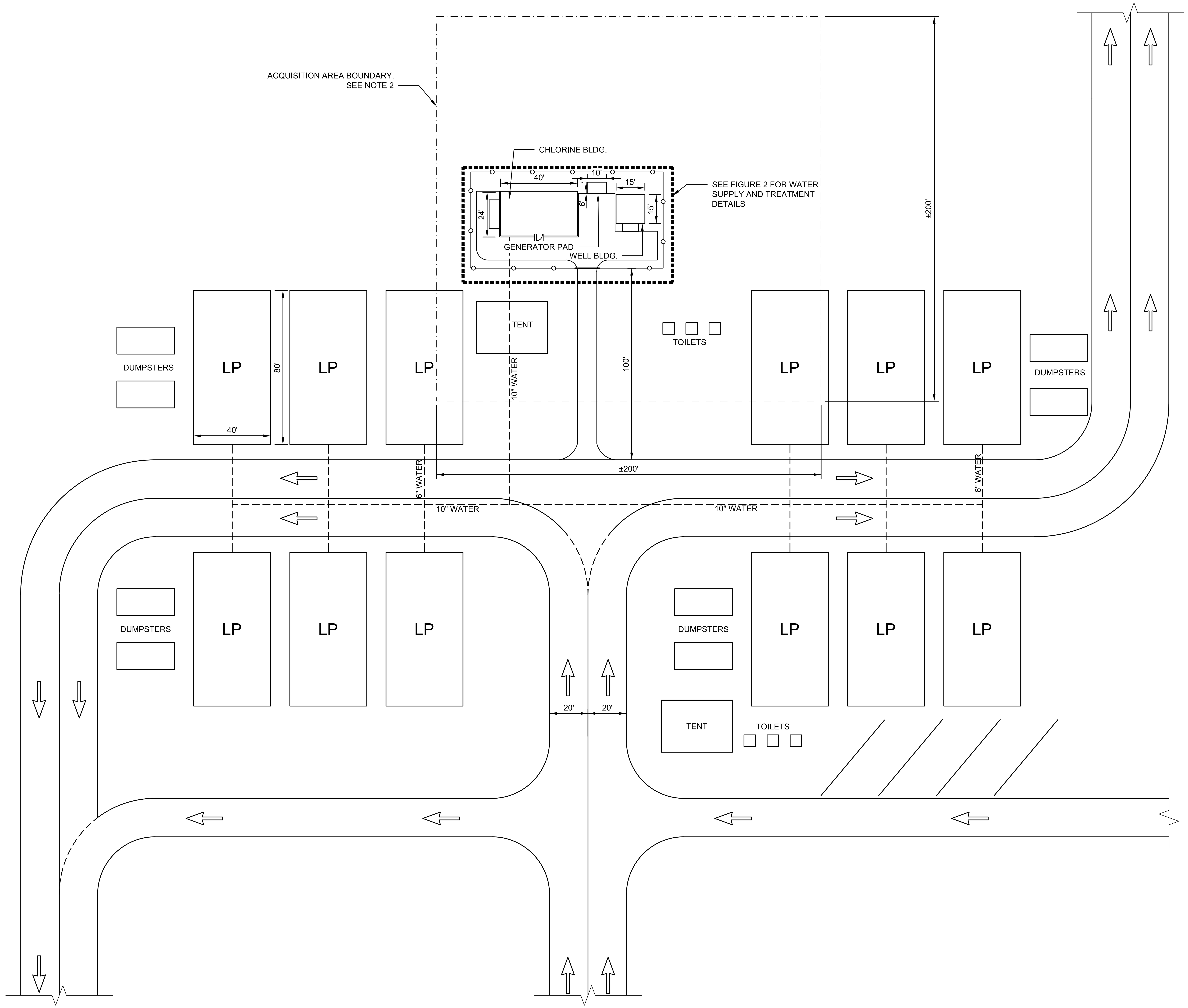
Additional treatment may be required depending on the specific well water quality; however, based on available water quality data and the recommendation presented in Table 1, no further treatment is assumed other than disinfection for the evaluation of this alternative.

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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HDR

BELLEVUE EMERGENCY WATER MASTER PLAN
OVERALL LAYOUT FOR ALTERNATIVE 1

DRIVE-UP

DATE 10-09-2018

FIGURE 1

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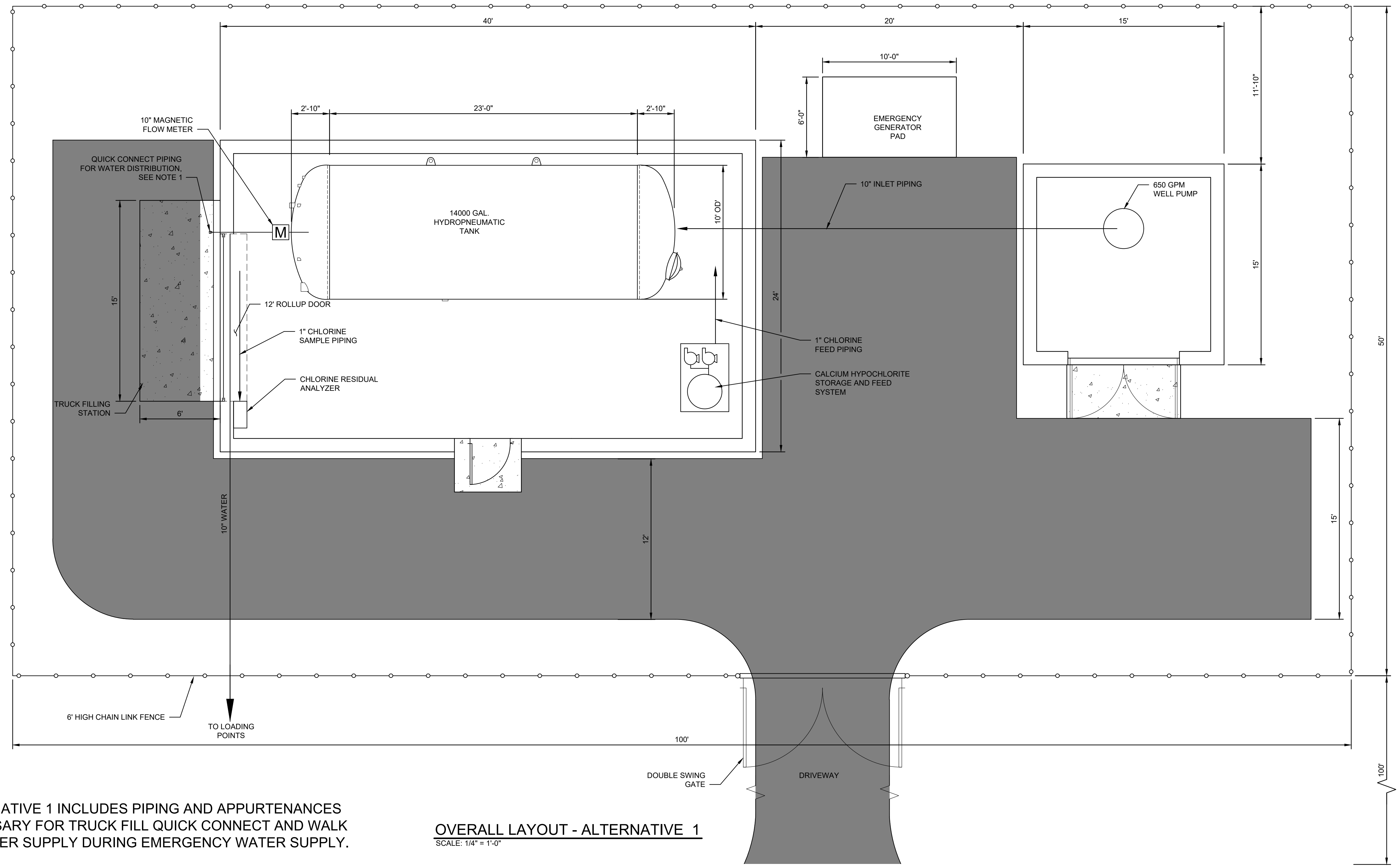

NOTES:

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"

HDR

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:

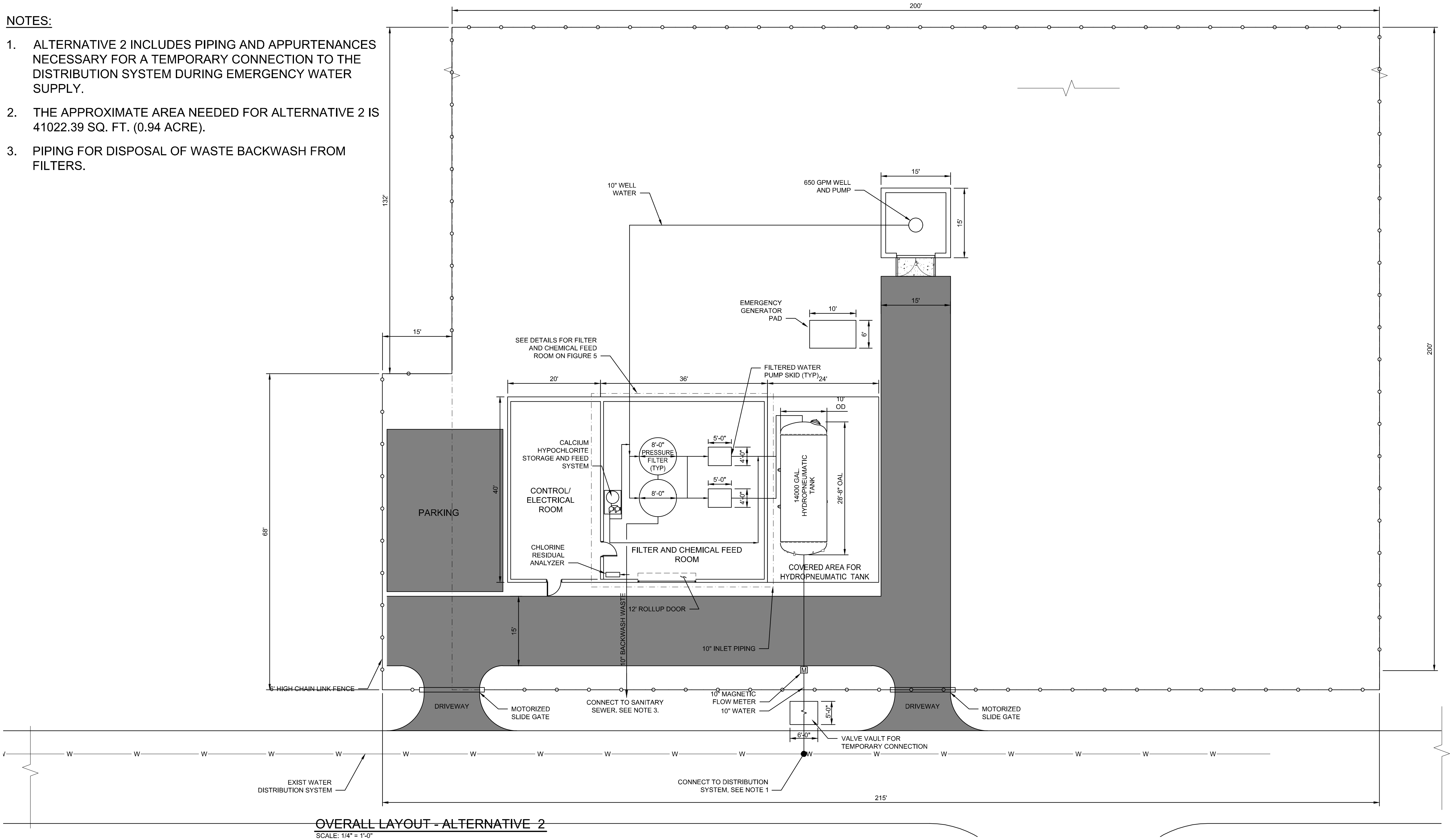
- Well house
    - Well
    - Well pump
- Disinfection storage and feed building
    - Calcium hypochlorite storage and feed system (also used for oxidation of iron and manganese)
    - Hydropneumatic tank
    - Chlorine residual analyzer
- Additional treatment for iron and manganese removal
    - Pressure 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"

BELLEVUE EMERGENCY WATER MASTER PLAN
OVERALL LAYOUT FOR ALTERNATIVE 2

TEMPORARY CONNECTION

DATE 10-09-2018

FIGURE 3

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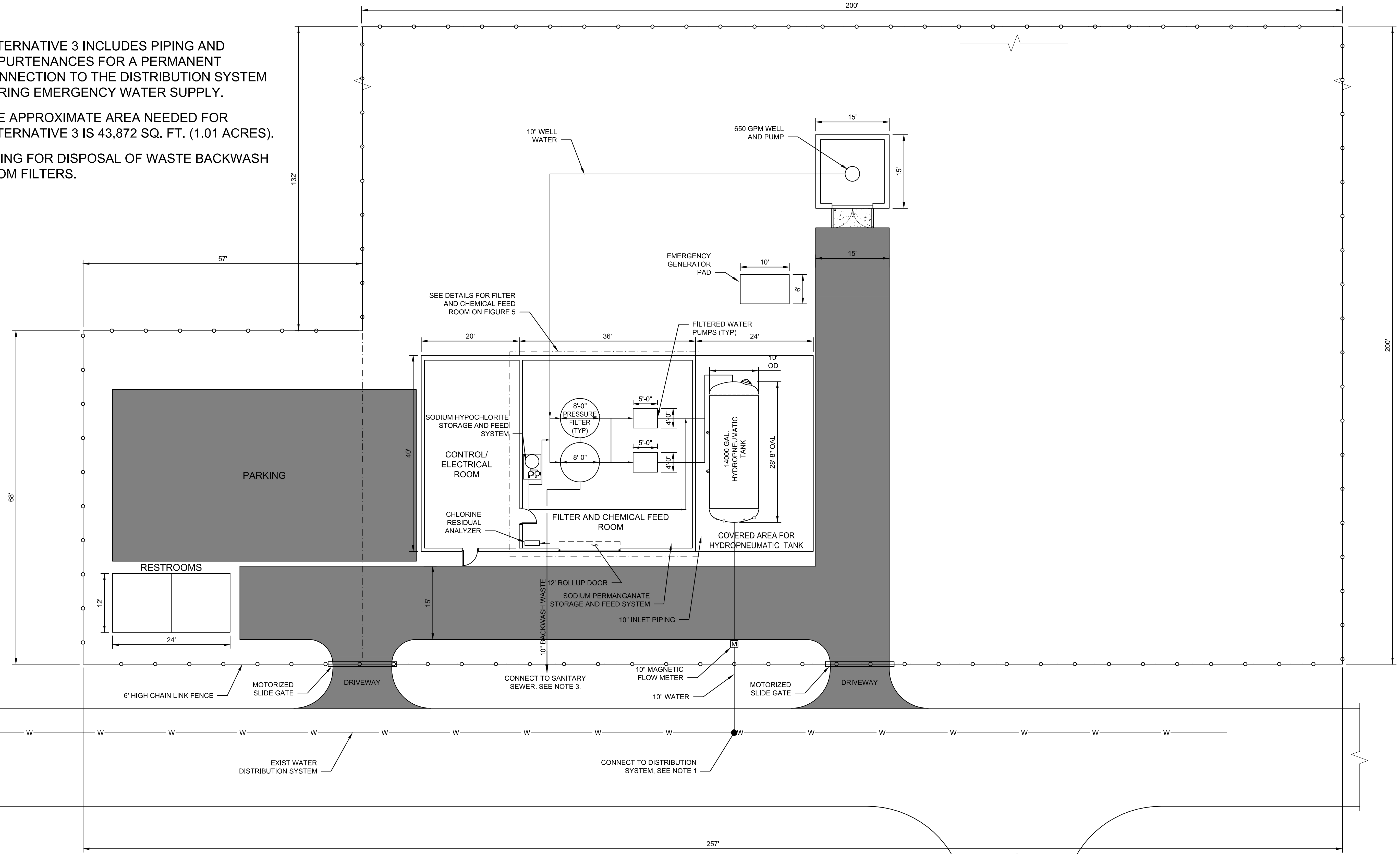
NOTES:

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"

BELLEVUE EMERGENCY WATER MASTER PLAN
OVERALL LAYOUT FOR ALTERNATIVE 3

PERMANENT CONNECTION

DATE 10-09-2018

FIGURE 4

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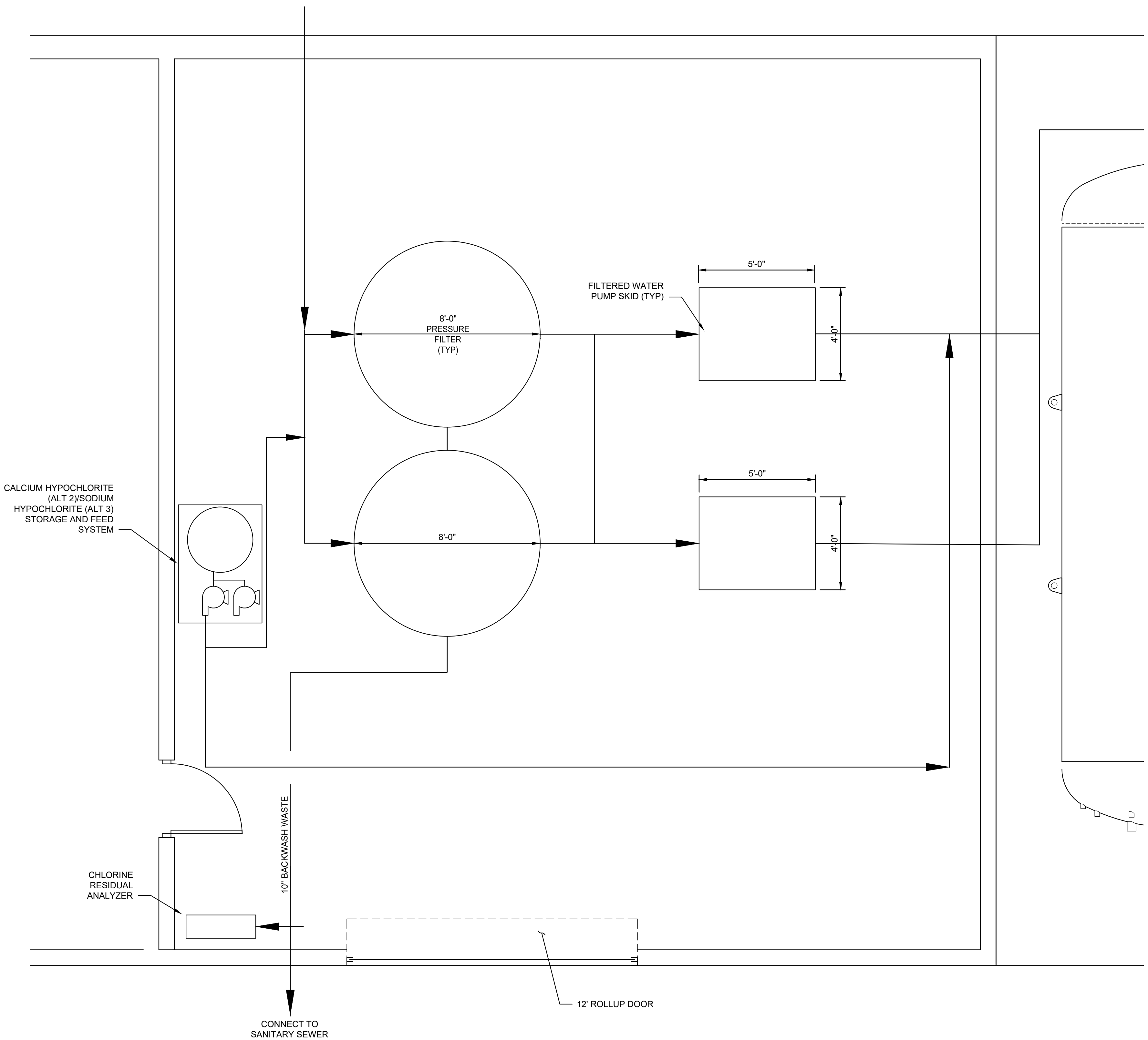

OVERALL LAYOUT - ALTERNATIVE 2 & 3

SCALE: 3/8" = 1'-0"

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.

UTILITIES

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

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.

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**		
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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.

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

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

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.

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 excavatic
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**	Excluding land acquisition
GC Mobilization/Demobilizatior	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**	Excluding land acquisition
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**	

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**	

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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