
Working Draft

**Identification of Groundwater
Likely to Benefit from
Additional Water Inputs**

September 2009



King County

Department of
Natural Resources and Parks
Wastewater Treatment Division

For comments or questions, contact:

Mark Buscher
King County Wastewater Treatment Division
201 South Jackson Street
KSC-NR-0512
Seattle, WA 98104-3856
206-684-1242
Mark.Buscher@kingcounty.gov

This information is available in
alternative formats on request at
206-684-1280 (voice) or 711 (TTY).

Working Draft:

Identification of Groundwater Likely to Benefit from Additional Water Inputs

September 2009

Prepared for:

Environmental and Community Services Section
Wastewater Treatment Division
Department of Natural Resources and Parks

Submitted by:

Science and Technical Support Section
King County Water and Land Resources Division
Department of Natural Resources and Parks

Citation:

King County. 2009. *Working Draft: Identification of Groundwater Likely to Benefit from Additional Water Inputs*. Water and Land Resources Division. Seattle, Washington.



King County

Department of
Natural Resources and Parks

Wastewater Treatment Division

Table of Contents

Executive Summary	1
1.0. Introduction.....	2
2.0. Methods.....	5
3.0. Findings and Recommendations	8
3.1 References to Lowered Water Levels	8
3.1.1 East King County.....	9
3.1.2 Eastside and Lake Sammamish	10
3.1.3 Seattle and North	11
3.1.4 South King County	11
3.2 Information Gaps.....	12
3.2.1 Surface Water and Groundwater Interactions	12
3.2.2 Water Level Trends	12
3.2.3 Groundwater Flow	13
3.2.4 Geology and Hydrogeology	13
3.3 Future Changes and Assessments	14
4.0. Literature Cited	16

Tables

Table 1. Documents Reviewed for the Groundwater Assessment	5
--	---

Figures

Figure 1. Approximate Boundaries of Literature Review Assessment Areas	4
Figure 2. King County Groundwater Management Areas.....	10

Appendices

Appendix A. Summary of Reviewed Documents

Appendix B. Additional References

EXECUTIVE SUMMARY

King County has conducted a preliminary assessment of certain water resource conditions to support the preparation of a reclaimed water comprehensive plan. The assessment focused on identifying streams and rivers, wetland areas, and groundwater resources in the reclaimed water planning area that could potentially benefit from additional water inputs.

This report documents the groundwater preliminary assessment. There are many ways to evaluate where groundwater is likely to benefit from additional water inputs in King County. Possible methods to undertake are: noting trends of declining water levels, reviewing groundwater well usage through metering, measuring stream baseflows, discharge, and depletion, studying or modeling drought effects on groundwater resources, modeling possible climate change impacts on groundwater levels or freshwater discharges, reviewing proliferation of wells, and forecasting water supply demands based on projected population growth trends for the region.

For this preliminary assessment of groundwater, a partial literature review was completed of readily available literature for references to areas where groundwater levels are lower than in the past or aquifers were known to be producing less water than before. No attempt was made to review water level data, well discharge data, water supply data, well logs, geologic and hydrogeologic maps, or compare historical to current water levels. Many of these data are not systematically available for either the entire County or for the study area of the Reclaimed Water Comprehensive plan for which this assessment is being done.

Results of this partial literature review reveal that multiple studies have documented lowered groundwater levels in specific locations of the study area. However, groundwater levels, both current and trends, are poorly documented in relatively large areas of the reclaimed water planning area. No regional groundwater monitoring program is currently in place from which general statements can be made regarding trends in groundwater levels, and much is left to learn regarding factors that may influence the levels such as the availability of the resources, the response to urban/suburban development, the effects of increases in groundwater pumping and interbasin transfer, and the effects of climate change on the shallow aquifers. For example, in many of the documents reviewed, references to the lateral and vertical extent of aquifers are general and often one-time water levels are given without discussion of historical trends.

Other results of the assessment were identification of many data and information gaps, discrepancies, and inaccuracies. Comprehensive, site-specific follow-up studies to address information gaps are recommended to be done prior to developing a proposal to provide water that would benefit groundwater resources.

1.0. INTRODUCTION

King County has conducted a preliminary assessment of certain water resource conditions to support the preparation of a reclaimed water comprehensive plan. The assessment focused on identifying streams and rivers, wetland areas, and groundwater resources in the reclaimed water planning area that could potentially benefit from additional water inputs. Groundwater resources were evaluated because Washington State code (RCW 90.46.080) specifically allows for reclaimed water to be

“beneficially used for surface percolation provided the reclaimed water meets the groundwater recharge criteria as measured in groundwater beneath or down gradient of the recharge project site, and has been incorporated into a sewer or water comprehensive plan, as applicable, adopted by the applicable local government and approved by the department of health or department of ecology as applicable used.”

This report documents the groundwater preliminary assessment. There are many ways to evaluate where groundwater is likely to benefit from additional water inputs in King County. Possible methods to undertake are:

- noting trends of declining water levels (various reports from 1960s to present),
- reviewing groundwater well usage through metering (Geller, 2007; WA Ecology, 2009),
- measuring stream baseflows, discharge, and depletion (Cuo et al, 2008; Dai et al., 2009; Keta Waters, 2008; Vaccaro et al., 1998),
- studying or modeling drought effects on groundwater resources (WA Ecology, 2006; CDM, 2008),
- modeling possible climate change impacts on groundwater levels or freshwater discharges (Alexander et al., 2007; CDM, 2008; Dai et al., 2009),
- reviewing proliferation of wells (KCDNRP, 2007; SWSTC, 2007), and
- forecasting water supply demands based on projected population growth trends for the region (CPSWSF et al., 2001, Boland et al., 2008; CDM, 2008).

A partial literature review was completed of readily available literature for references to areas where groundwater levels are lower than in the past or are known to be producing less water than before. The type and amount of information on groundwater resources is more limited than for the streams and wetlands in the reclaimed water planning area. This report does not review water level data, well discharge data, water supply data, well logs, geologic and hydrogeologic maps, or compare historical to current water levels. Many of these data are not systematically available for either the entire County or for the study area of the Reclaimed Water Comprehensive plan for which this assessment is being done.

The reclaimed water planning area includes the county’s wastewater service area and areas immediately surrounding the service area. The information presented in this report is organized

according to four geographic areas in and near the reclaimed water planning area: East King County, Eastside and Sammamish, Seattle and North, and South King County. Some documents represented regionally areas such as the entire Puget Sound region or King County. Information from these documents is included within the five areas where applicable. As shown in Figure 1, the boundaries of these areas overlap in some places because of the geographic extent of documents reviewed.

Comprehensive follow-up studies to address information gaps are recommended prior to developing any proposal to provide water that would benefit groundwater resources.

This assessment surveyed groundwater reports for the entire County geographic area. As noted in the Appendices, there are numerous studies focused on much smaller areas that could be useful in determining whether there may be opportunities for groundwater recharge or inputs in these smaller areas. Once these areas are identified, these studies, as well as existing or new data could be evaluated to help evaluate the likelihood that additional water inputs could improve the status of groundwater resources.

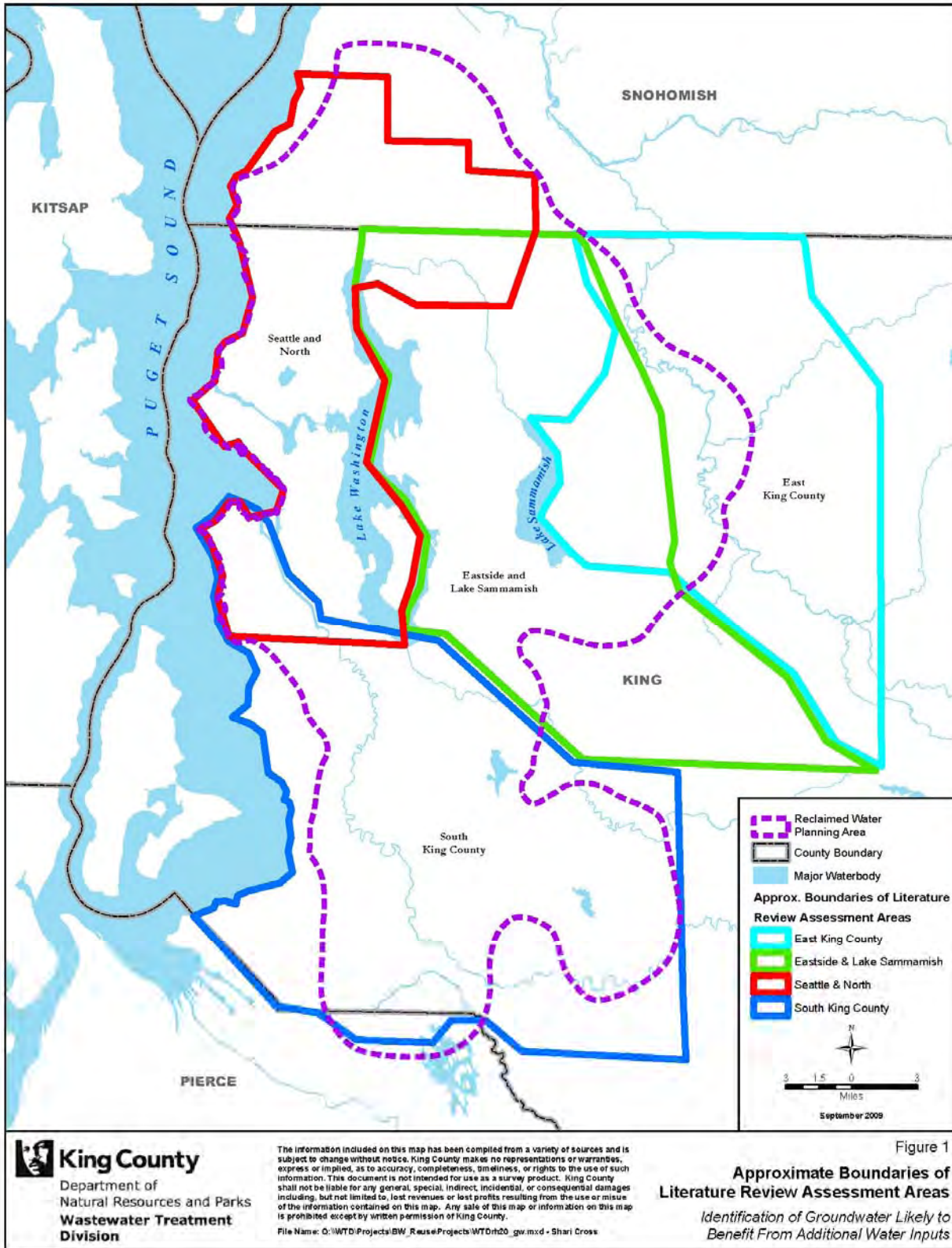


Figure 1. Approximate Boundaries of Literature Review Assessment Areas

2.0. METHODS

King County staff completed a partial review of documents that were readily available, either in hardcopy form in the King County Water and Land Resources Division’s offices or in electronic form on King County’s Web site, for references to changes in groundwater levels. This partial review documents reports by consultants, local and state government agencies, and academic researchers, that have completed studies or reviews related to groundwater in the King County area and Puget Sound region. The 39 documents reviewed are listed in Table 1. Five of the documents reviewed assessed groundwater conditions over the entire region, while the remaining assessed conditions in specific locations within the study area.

Only references to lowered water levels found in the literature are documented in this report. No attempt was made to review water level data, well discharge data, water supply data, well logs, geologic and hydrogeologic maps, or compare historical to current levels. References to areas not having enough information to evaluate an aquifer, wells having a lack of long-term water level data, studies not having enough data to evaluate flow directions, and documentation about unclear relationships between surface water bodies (lakes and streams) with groundwater were noted as information gaps and are also documented in this report.

Table 1. Documents Reviewed for the Groundwater Assessment

EAST KING COUNTY
Golder Associates. 1995. Geophysical and Hydrogeologic Investigations in East King County Groundwater Management Area. Prepared for Public Health–Seattle & King County.
Golder Associates. 2001. <i>Sampling and Analysis Plan for the East King County Groundwater Management Area</i> . Prepared for KCDNR. Prepared for King County Department of Natural Resources.
Hart Crowser. 1988. <i>Tolt River Pipeline Groundwater Development Study, King County, Washington</i> . Prepared for Seattle Water Department and CH2M HILL Northwest.
King County Department of Natural Resources. 1998. <i>East King County Ground Water Management Plan: Management Strategies-Final</i> . Prepared for East King County Ground Water Advisory Committee.
King County Department of Natural Resources. 1998. <i>East King County Ground Water Management Plan: Supplement 1: Area Characterization-Final</i> . Prepared for East King County Ground Water Advisory Committee.
King County Department of Natural Resources and Parks, Water and Land Resources Division. 2005. <i>East King County Groundwater Level Survey: Fall 2005</i> .
PEI/Barrett Consulting Group. 1991. <i>Lake Alice Plateau: Neighboring Water User Study for Snoqualmie Ridge Parkway</i> . Prepared for Snoqualmie Ridge Associates.
Turney G.L., S.C. Kahle, and N.P. Dixon. 1995. <i>Geohydrology and Ground-Water Quality of East King County, Washington</i> . U.S. Geological Survey Water-Resources Investigations Report 94-4082. 123 pp.
EASTSIDE AND LAKE SAMMAMISH
AGI Technologies. 1998. Sammamish Plateau Water and Sewer District: Artificial Recharge Testing of the Plateau Aquifer System Zone IV (through Well 5), Phase III. Prepared for Sammamish Plateau Water and Sewer District.
Golder Associates, Inc. 1995. Preliminary Evaluation of Aquifer Storage and Recovery in the (Little) Bear Creek Drainage. Prepared for Northshore Utility District, Kenmore, Washington

Golder Associates. 2000. Sampling and Analysis Plan for the Issaquah Creek Valley Groundwater Management Area. King County Department of Natural Resources.

Golder Associates. 2000. Groundwater Exploration and Pumping Test: Lower Issaquah Valley. Prepared for City of Issaquah

Golder Associates. 2001. Sampling and Analysis Plan for the Redmond--Bear Creek Groundwater Management Area. Prepared for King County Department of Natural Resources.

King County Department of Natural Resources. 1999. Issaquah Creek Valley Ground Water Management Plan: Area Characterization. Supplement 1: Area Characterization – Final. Prepared for Issaquah Creek Valley Ground Water Advisory Committee.

King County Department of Natural Resources. 1999. Issaquah Creek Valley Ground Water Management Plan: Management Strategies – Final. Prepared for Issaquah Creek Valley Ground Water Advisory Committee.

King County Department of Natural Resources. 1999. Redmond – Bear Creek Valley Ground Water Management Plan: Management Strategies – Final. Prepared for Redmond – Bear Creek Ground Water Advisory Committee.

King County Department of Natural Resources. 1999. Redmond – Bear Creek Valley Ground Water Management Plan. Supplemental 1: Area Characterization – Final. Prepared for Redmond – Bear Creek Ground Water Advisory Committee..

King County Department of Natural Resources and Parks, Water and Land Resources Division. 2005. Sammamish River Valley Groundwater Study: 2003–2004 Data Report.

Pacific Groundwater Group, Inc. 1992. Issaquah Ground Water Management Program: Data Collection and Analysis Plan (DCAP)–Final. Prepared for Seattle–King County Department of Environmental Health.

Robinson & Noble, Inc. 1979. Ground Water Evaluation of East Lake Sammamish Area. Prepared for King County Water District 82. Prepared for King County Water District 82.

Sweet-Edwards/EMCON, Inc. 1990. Redmond-Bear Creek Ground Water Management Area: Data Collection and Analysis Plan (DCAP)-Revision 3. Prepared for Public Health–Seattle & King County.

SEATTLE AND NORTH

Liesch, B. A., C. E. Price, and K. L. Walters. 1963. *Geology and Ground-Water Resources of Northwestern King County, Washington*. Water Supply Bulletin Number 20. Prepared by State of Washington Department of Conservation, Division of Water Resources, in cooperation with U.S. Geological Survey Ground-Water Branch. 241 pp.

SOUTH KING COUNTY

Brown and Caldwell Consultants. 1992. *Effluent Reuse Pilot Project Report*. Prepared for Cities of Renton and Tukwila

City of Auburn Water Division Web site: <http://www.ci.auburn.wa.us/utilities/water/index.asp>. Accessed 2008.

City of Renton Aquifer Protection Program Web site: <http://www.renton-wa.gov/living/default.aspx?id=144>. Accessed 2008.

CH2M HILL. 1988. *Well Field Monitoring Study*. Prepared for City of Renton.

Covington Water District. 1995. *Lake Sawyer Wellhead Protection Plan: Covington Water District*. In association with Robinson & Noble, Inc., and Economic & Engineering Services, Inc.

Harper-Owes. 1985. *Duwamish Ground Water Studies: Waste Disposal Practices and Dredge and Fill History*. Prepared for Sweet Edwards and Associates.

Hart Crowser. 1996. *Wellhead Protection Program: Clark, Kent, and Armstrong Springs; City of Kent*. Prepared for City of Kent

RH2 Engineering. 1987. *Analysis Report for the City of Renton Cedar River Valley Aquifer Test*.

Robinson & Noble, Inc. 1992. *Hydrogeologic Analysis of the Federal Way Area, Washington. Volume 1*.

Sweet-Edwards & Associates, Inc. 1985. *Duwamish Ground Water Studies*. Prepared for Municipality of Seattle.

TCW Associates, Inc., HLA/Harper-Owes, University of Washington College of Forest Resources, and Municipality of Metropolitan Seattle. 1989. *Hydrogeology & Water Quality Evaluation: Metro Section 16 Silvigrow Project*. Prepared for Public Health–Seattle & King County.

Woodward, D.F., F.A. Packard, N.P. Dion, and S.S. Sumioka. 1995. *Occurrence and Quality of Ground Water in Southwestern King County, Washington*. U.S. Geological Survey Water-Resources Investigations Report 92-4098. 69 pp.

REGION-WIDE DOCUMENTS

Bauer, H. H, and M. C. Mastin. 1997. *Recharge from Precipitation in Three Small Glacial-Till-Mantled Catchments in the Puget Sound Lowland, Washington*. U.S. Geological Survey Water-Resources Investigations Report 96-4219. Prepared in cooperation with Washington State Department of Ecology.

King County Department of Development and Environmental Services, Environmental Division, Regional Planning Section, and Public Health–Seattle & King County, Environmental Health Division, Drinking Water and Ground Water Section. 1995. *Mapping Aquifer Susceptibility to Contamination in King County*.

King County Department of Natural Resources and Parks, Water and Land Resources Division. 2005. *Ambient Groundwater Monitoring 2001–2004 Results*.

Vaccaro, J. J., A. J. Hansen, and M. A. Jones. 1998. *Hydrogeologic Framework of the Puget Sound Aquifer System, Washington and British Columbia: Regional Aquifer System Analysis—Puget-Willamette Lowland*. U.S. Geological Survey Professional Paper 1424-D.

Washington State Department of Ecology Water Quality Program. 2005. *Critical Aquifer Recharge Areas: Guidance Document*. Publication Number 05-10-028.

3.0. FINDINGS AND RECOMMENDATIONS

This section summarizes the findings of this partial literature review of readily available documents for references to areas where groundwater levels were reported as lower than in the past or aquifers were known to be producing less water than before and then presents information gaps reported in the documents. No attempt was made to review water level data, well discharge data, water supply data, well logs, geologic and hydrogeologic maps, and compare historical to current water levels. More detailed, site-specific assessments are recommended prior to developing a proposal to provide water that would benefit groundwater resources.

3.1 References to Lowered Water Levels

Groundwater is the portion of precipitation that soaks into the ground and gets stored in underground geological water systems called aquifers. Every groundwater system is unique and depends on both internal and external factors. Examples of internal factors include the type of geologic formation (such as loose sand and gravel or volcanic rock), the mineral composition of the formation, the size of the material that makes up the aquifer (such as sand grains versus pebbles), and the amount of water in the aquifer. Examples of external factors include the rate of precipitation, the interaction of groundwater with streams and other surface water bodies, the rate of evapotranspiration, and, in the case of an island, interactions with the surrounding surface water.¹

Results of this assessment reveal that in general, groundwater conditions are poorly understood in relatively large areas of the reclaimed water planning area. While numerous studies have been completed on groundwater resources in the area, no comprehensive groundwater monitoring program exists and much is left to learn regarding the availability of the resources, the responses to urban/suburban development, the effects of increases in groundwater pumping and interbasin transfer, and the effects of climate change on the shallow aquifers. Multiple studies note lowered groundwater levels at specific locations within the study area associated with groundwater withdrawals. Although Ecology has demonstrated that there is hydraulic continuity between groundwater and surface waters (WA Ecology 1998), the details can vary greatly between different locations, and highly disparate levels of information are available within the reclaimed water planning area. In many of the documents reviewed, references to the lateral and vertical extent of aquifers are general and often one-time water levels are given without discussion of historical trends.

The planning area is known to have several water-bearing geologic units, with most, if not all, used for water supplies to some degree. However, because groundwater levels are not usually regularly recorded (unless part of an ongoing funded program), it is difficult to identify trends, whether related to development or to natural processes, and to ascertain whether water levels are

¹ Evapotranspiration = the sum total of loss of water primarily from water bodies, wet soil, and wet plants (evaporation) and their respective vegetation (transpiration).

lower than in the past. It is likely that the more shallow aquifers would be most affected by climate change and development. However, increased pumping may be lowering levels in the deeper aquifers. Where lowering of aquifer levels has been documented, further assessment of existing data and additional site-specific studies could help determine whether the aquifers would benefit from additional water inputs.

The information in this subsection is organized according to the four geographic areas described earlier in this report. Further detail on results of the document review are included in Appendix A.

3.1.1 East King County

Eight studies were reviewed that assessed groundwater conditions in East King county. A study conducted by the USGS in eastern King County (Turney et al., 1995) noted that not only were wells in some areas showing declining water levels but also wells receiving water from bedrock aquifers can go dry in the summer or when under high use. Since then, new development and consequent demand on groundwater supplies have increased.

In 1998, the King County Department of Natural Resources (KCDNR) completed a groundwater management plan and an area characterization for the East King County Groundwater Management Area (GWMA)². (Figure 2 shows the locations of King County GWMAs.) KCDNR concluded that based on estimated future demands, the major shallow aquifers have the potential for overuse (KCDNR, 1998a and 1998b). Some wells were reported as having gone dry or as having declining water levels. In addition, the deeper bedrock aquifers east of the Duvall area were reported to go dry, even though use as a water supply was limited.

Early in 2005, a King County report on ambient groundwater monitoring from 2001 through 2004 of 14 wells in the East King County GWMA found that water levels were generally stable with no significant declines (KCDNRP, 2005a). However, another King County study in late 2005 found that water levels in 19 out of 20 wells in areas of the shallow Vashon advance outwash sand and gravel aquifer in East King County had declined since 1995 between one to five feet (KCDNRP, 2005b). The study also found that in the alluvium and Vashon recessional outwash sand and gravel aquifer, four out of 25 wells showed significantly lower water levels than in 1995. The study found that some well owners had recently deepened their wells to address the lowering water levels and others had reported that at times when a nearby river or stream was lower than usual, the water level in their well was also lower than usual.

² Five Groundwater Management Areas (GWMA) were proposed and designated in King County in 1986-1987 under the provisions of a Washington State regulation. The GWMAs were initiated to ensure long-term water quality and quantity issues were addressed in areas where no coordinated groundwater management occurred. Each GWMA in King County consisted of a committee of local stakeholders and created groundwater management plans. The only active GWMA is the Vashon-Maury Island GWMA due to lack of funding for continued activities in the other areas. The Vashon-Maury Island GWMA is not discussed in this report as it is outside the reclaimed water planning area.



Figure 2. King County Groundwater Management Areas

3.1.2 Eastside and Lake Sammamish

A total of 13 reports and studies were reviewed that assessed groundwater conditions on the eastside of Lake Washington and the Lake Sammamish region. A 1963 report on geology and groundwater resources in northwestern King County indicated that withdrawals in the Newcastle Hills area had exceeded the recharge of the principal aquifer and also expressed concern about meeting the water supply demands of projected increases in population (Leisch et al., 1963).

In 1999, KCDNR completed a groundwater management plan and an area characterization for the Issaquah Creek Valley GWMA (Figure 3). The characterization found that although the deeper bedrock aquifers are usable, they do not yield high quantities (KCDNR, 1999a and 1999b). Long-term water level data for the lower Issaquah Creek Valley aquifer indicate a downward trend in water table elevations, possibly from being pumped too much or from climatic influences (KCDNR, 1999b).

Similar documents for the Redmond–Bear Creek Valley GWMA (Figure 3), also published in 1999, reported that the East King County Coordinated Water System Plan had concluded that the water supply potential for the Redmond, Evans Creek, and Sammamish Plateau aquifers was not sufficient to meet future regional demands (KCDNR, 1999c and 1999d). In addition, it was recommended that new water sources in some areas of these aquifers should not be developed because over pumping would reduce water levels and that continued growth will require additional water supply and land use control to recharge areas to maintain aquifer quantity (KCDNR, 1999d). The reports also indicated that according to consultants the planned changes to land use would impact both water quantity and quality (i.e. Novelty Hill area) (KCDNR, 1999d). In early 2005, however, water level monitoring of 16 wells in the same GWMA indicated that from 2001 through 2004, water levels were generally stable with no significant

declines (KCDNRP, 2005a), although this monitoring was conducted where access was available, mostly at privately-owned wells, but also at some public water purveyor wells, and results from these wells are not necessarily representative of conditions throughout the entire GWMA.

As of 1999 there was not much data recorded to substantiate concerns that private wells established in Vashon till in the Redmond–Bear Creek area were “drying out” (KCDNR, 1999d).

3.1.3 Seattle and North

Only a few documents were available for the Seattle and North area. A report produced by the State of Washington Department of Conservation in 1963 discussed the geology and groundwater resources for northwestern King County (Liesch et al., 1963). Much of the report focused on geologic and well data about the area.

3.1.4 South King County

Although many reports are available on Auburn, Kent, Covington, Black Diamond, Renton, Federal Way, and Tacoma area aquifers, only a few of the reports provided information relevant to this assessment. A total of 12 reports were reviewed that assessed groundwater conditions in South King county.

A hydrogeologic analysis of the Federal Way area in 1992 indicated declines in one wells water levels by up to 12 feet over the last 14 years (Robinson & Noble, 1992). In addition, in response to moderate production of the Valley aquifer system, water level records from another well showed 10 feet of water level decline.

It was also reported that production and land use changes had induced water level declines from the major shallow aquifer (beneath the upper confining unit) but that the water levels had stabilized by 1987. However, stabilization of water levels did not continue past 1987, as they declined through 1988 to about seven feet lower than in end of 1987. Water levels had recovered slightly since then by the time of the report in 1992 (Robinson & Noble, 1992).

Robinson & Noble also reported that when production began (1981) in Well20 in the Mirror Lake aquifer, water levels had declined 50 feet by 1987 and slightly less by 1992. The Eastern Upland aquifer was also reported as affected by production, but not as much as in Mirror Lake aquifer (Robinson & Noble, 1992).

The Lake Sawyer Wellhead Protection Plan indicated that portions of the Lake Sawyer wellfield (Covington Water District) in the shallow aquifer may completely drain by late summer (CWD et al., 1995). The regional aquifer that supplies water to the Lake Sawyer wellfield also supplies the Kent and Clark Springs aquifer systems for the City of Kent.

A USGS study in southwestern King County looked at the occurrence and quality of groundwater (Woodward et al., 1995). The study noted that some wells showed declining water levels over decades and that some wells in the Vashon till may go dry in late summer. Since

completion of this study, the area has experience increased development and demand on groundwater supplies.

3.2 Information Gaps

This assessment identified many information gaps, both in time (water level data) and space (data coverage across King County). The following subsections describe information gaps in four categories:

- Surface water and groundwater interactions
- Water level trends
- Groundwater flow
- Geology and hydrogeology

3.2.1 Surface Water and Groundwater Interactions

Many streams and lakes may be receiving or losing water depending on groundwater levels, but accurate locations along stream reaches or lake shores were not identified in reports. In a report by the USGS in 1995, the Tolt and Raging Rivers were called out as losing reaches (Turney et al., 1995). In addition, between Carnation and Monroe, the Snoqualmie River was noted as seeming to be a losing reach (KCDNR, 1998b). A report by Golder of the Lower Issaquah Valley documented losing and gaining reaches of Issaquah Creek at differing times (Golder Associates, 2000). Additional withdrawals in the area could result in lower groundwater levels and in decreases to springs and other surface water bodies.

A document by Hart Crowser on the Wellhead Protection Program for the City of Kent reported that flow patterns north of Armstrong Springs, Lake Sawyer, and Ravensdale Lake were unclear. The effect of Lake Sawyer on groundwater flow was noted as not well studied, nor was the relationship clear between Jenkins Creek and the aquifer (Hart Crowser, 1996).

Available information suggests a limited stream-groundwater connection south of the gap in the upper valley of Issaquah Creek, but was not confirmed (KCDNR, 1999b).

3.2.2 Water Level Trends

The literature contains little information on long term water level trends, and the records in the databases reported are not consistent enough to establish trends. Data is too sparse to establish trends and to substantiate references to wells drying out (wells in till in the Redmond–Bear Creek (KCDNR, 1999d) and Southwestern King County (Woodward et al., 1995) areas), seasonal variations in the Lake Sawyer wellfield shallow system (CWD et al., 1995), and downward trends seen in water level data (lower Issaquah Creek valley aquifer) (KCDNR, 1999b). In the lower Issaquah Creek valley aquifer, it was noted that more data was needed over time to evaluate trends to clarify areas that had missing information (KCDNR, 1999b).

Early in 2005, a King County report on ambient groundwater monitoring from 2001 through 2004 of wells in the East King County, Issaquah Creek Valley, Redmond-Bear Creek, and Vashon-Maury Island GWMA's monitored both private and public water levels (KCDNRP, 2005a). Information gaps noted were that there were more shallow wells than deep wells in the study, the frequency of the monitoring was limited and the pump usage prior to measurement was unknown.

Similarly, another King County study in late 2005 studied water levels taken during a one-time measurement in late 2005 and compared to measurements made by USGS at the same wells in 1995 (KCDNR, 2005b). While some wells had lower water levels relative to 1995, the lack of routine water level measurements made an assessment of long-term trends that also account for annual differences in water use and weather impossible to assess.

3.2.3 Groundwater Flow

Groundwater flow directions and patterns are evaluated using water level measurements in wells and surface water bodies. When a document references information related to flow direction or patterns are unknown or unclear, it is likely that water level data is sparse over time and/or space.

Flow in alluvium and Vashon recessional outwash units on the Sammamish Plateau and in some areas of south King County is not well defined because much of it is unsaturated (KCDNR 1998b). The flow direction in the deeper aquifers in the Issaquah Creek area are not fully understood (KCDNR, 1999b). The population in the upper Issaquah Creek area is sparse, and there are no known high-capacity wells.

Flow to the deeper regional system in East King County is unknown, but may be significant (Turney et al., 1995) and upward flow is likely in many areas (KCDNR, 1998b). The 1995 USGS report recommended that a groundwater model of the Snoqualmie Valley would help to determine the capacity of the aquifers (Turney et al., 1995; KCDNR, 1998b).

Other places where information on flow is limited include the Grand Ridge and Tradition Lake area (flow direction) (KCDNR, 1999b) and the Clark Springs area (undefined groundwater divide) (Hart Crowser, 1996).

3.2.4 Geology and Hydrogeology

The documentation and accuracy of characteristics, extent, and presence of geologic and hydrogeologic features in the planning area is varied and limited. Having a clear understanding of the geology and hydrogeology improves evaluation of a groundwater resources need for additional water. In order to obtain this understanding, it often involves drilling wells, identifying geologic units in the underlying units, reviewing maps, mapping saturation of geologic units, measuring water levels in wells, and correlating geologic and hydrogeologic information across wells and across large areas. When a document references that the geology and hydrogeology are unknown or unclear, it is possible that water level and saturated geologic units information are missing.

The following reports commented on general lack of information available for purpose of developing an understanding of the aquifer systems, and/or noted on sparseness of geologic or hydrogeologic data:

- Cedar River valley (RH2 Engineering, 1987; Woodward et al., 1995)
- Cascade foothills and Cherry Creek valley (KCDNR, 1998b)
- Duwamish River area (Sweet-Edwards & Associates, Inc., 1985)
- east Lake Sammamish area (Robinson & Noble, 1979)
- northeast Snoqualmie Valley & eastern East King County (KC DDES & SKCPH, 1995)

Little information is available on the pre-Vashon deposits (lower coarse-grained unit and deep undifferentiated unit) in areas like Issaquah Creek, on the yields of the same deep undifferentiated unit in East King County (Turney et al., 1995; KCDNR, 1998b) and Southwest King County (Woodward et al., 1995), and on the capacity of some aquifer systems in the area served by the Sammamish Plateau Water and Sewer District, the City of Issaquah, and the Snoqualmie Valley aquifer (KCDNR, 1999b).

Various studies identified geologic and hydrogeologic data gaps data from deep wells in the lower Snoqualmie River Valley, Sammamish Plateau, and Cascades foothill areas (Turney et al., 1995), Des Moines Plains areas (Woodward et al., 1995), and Puget Sound lowlands (Vaccaro et al., 1998).

Information on deep aquifer systems are limited (Hart Crowser, 1988). A report by CWD in 1995 indicated that the deep aquifer in the Covington area is poorly delineated. Further, it is not known whether a deeper aquifer exists at bedrock interface at Carnation (KCDNR, 1998b) and whether an aquifer exists beneath the artesian aquifer in the East Lake Sammamish area (Robinson & Noble, 1979). The Redmond-Bear Creek GWMA management plan indicated that there was not enough data to determine whether impacts would occur from large-scale developments on deep aquifer systems in the Redmond-Bear Creek area (KCDNR, 1999c). The Federal Way deep aquifer was noted as having not been adequately studied (Robinson & Noble, 1992).

3.3 Future Changes and Assessments

In the future it is likely that in King County the trend of a population increase along with increased demands on water supply will continue (Boland et al., 2008; CDM, 2008; CPSWSF et al., 2001), as well as increased development and the resulting likely reduction of infiltration into the shallow aquifers (Turney et al., 1995; Woodward et al., 1995). In addition, future changes in the climate may have a lowering effect on groundwater levels (WA Ecology, 2006; Geller, 2007; Alexander et al., 2007) and reduction in stream baseflows. As there are no ongoing long-term Puget-Sound region or county-wide programs studying groundwater levels, it is difficult to assess where and how much of an effect these future changes may have on groundwater in the reclaimed water planning area without further review of assessments.

Future assessments could include resolving differences in the studies reviewed and reviewing other documents. An additional 145 reports were inventoried and are referenced in Appendix B. The information presented in these reports may be helpful in identifying groundwater likely to benefit from additional water inputs.

Many other sources can be obtained, if necessary, for more in-depth future assessments of groundwater in specific locations of the reclaimed water planning area. Comprehensive follow-up studies to address information gaps, or identify alternative approaches for providing additional water inputs is recommended to be done prior to developing a proposal to provide water that would benefit groundwater resources in the reclaimed water planning area.

The following are various methods to evaluate groundwater and may be considered for further assessment of groundwater in the reclaimed water planning area of King County:

- reviewing groundwater well usage through metering (Geller, 2007; WA Ecology, 2009);
- measuring stream baseflows, discharge, and depletion (Cuo et al, 2008; Dai et al., 2009; Keta Waters, 2008; Vaccaro et al., 1998);
- studying or modeling drought effects on groundwater resources (WA Ecology, 2006; CDM, 2008);
- modeling possible climate change impacts on groundwater levels (Alexander et al., 2007; CDM, 2008; Dai et al., 2009);
- reviewing proliferation of wells (KCDNRP, 2007; SWSTC, 2007); and
- forecasting water supply demands based on projected population growth trends for the region (CPSWSF et al., 2001, Boland et al., 2008; CDM, 2008).

4.0. LITERATURE CITED

- Alexander, D., and R.N. Palmer (Alexander et al.). 2007. Technical Memorandum #8: *Impacts of Climate Change on Groundwater Resources- A Literature Review*. Prepared by the Climate Change Technical Subcommittee of the Regional Water Supply Planning Process, Seattle, WA. December 13. [[http://www.govlink.org/regional-water-planning/tech-committees/climate-change/UWreports/TechMemo8\(12-13-07\).pdf](http://www.govlink.org/regional-water-planning/tech-committees/climate-change/UWreports/TechMemo8(12-13-07).pdf)]
- Boland, J. J. and B. K. Boland (Boland et al.). 2008. *Central Puget Sound Water Suppliers' Forum Independent Review of Water Demand Forecast Model: Final Report*. June 9. [<http://www.govlink.org/regional-water-planning/docs/FinalReport.pdf>]
- CDM. 2008. *Central Puget Sound Regional Water Supply Outlook: Water Demand Forecast. Technical Appendix (Draft Report)*. April 7.
- Central Puget Sound Water Suppliers Forum and R. W. Beck (CPSWSF et al.). 2001. *2001 Central Puget Sound Regional Water Supply Outlook*. Prepared in association with Daily Environmental and Economic and Engineering Services, Inc. July. [<http://cpswatersuppliersforum.org/Outlook/outlookcomplete/title.pdf>]
- Covington Water District (CWD et al.). 1995. *Lake Sawyer Wellhead Protection Plan: Covington Water District*. Covington Water District in association with Robinson & Noble, Inc and Economic & Engineering Services, Inc. December.
- Cuo, Lan and D. P. Lettenmaier, B. P. Mattheussen, P. Storck, and M. Wiley (Cuo et al.) 2008. *Hydrologic prediction for urban watersheds with the Distributed Hydrology–Soil–Vegetation Model*. *Hydrological Processes*, 22, 4205–4213. [Published online 20 March 2008 in Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/hyp.7023].
- Dai, Aiguo and T. Qian, K. E. Trenberth, J. D. Milliman. (Dai et al.). 2009. *Changes in Continental Freshwater Discharge from 1948 to 2004*. *Journal of Climate*, 22, 2773-2792. May 15.
- Geller, L. 2007. *Water Resources Program 2006-2007 Annual Report*. Publication #07-11-036. Prepared for Washington State Department of Ecology. December. [<http://www.ecy.wa.gov/pubs/0711036.pdf>]
- Golder Associates. 2000. *Groundwater Exploration and Pumping Test: Lower Issaquah Valley*. Prepared for City of Issaquah. October 30.
- Hart Crowser. 1988. *Tolt River Pipeline Groundwater Development Study, King County, Washington*. Prepared for Seattle Water Department and CH2M Hill Northwest. January 18.
- Hart Crowser. 1996. *Wellhead Protection Program: Clark, Kent, and Armstrong Springs; City of Kent*. Prepared for City of Kent. April 2.

- Keta Waters. 2008. *Improving The Quality and Quantity of In-stream Habitat by Resting Groundwater Extraction Wells*. Prepared in association with Aspect Consulting, RH2 Engineering, Inc., and A. Slavery. Prepared for King County Regional Water Supply Planning Process; Tributary Streamflow Technical Committee. May.
[<http://www.govlink.org/regional-water-planning/docs/groundwater-extraction-well-report/RestingGWWellsFinalReport.pdf>]
- King County Department of Development and Environmental Services/Environmental Division/ Regional Planning Section and Seattle-King County Health Department/ Environmental Health Division/Drinking Water and Ground Water Section (KC DDES & SKCPH).1995. *Mapping Aquifer Susceptibility to Contamination in King County*. October 4.
- King County Department of Natural Resources (KCDNR). 1998a. *East King County Ground Water Management Plan: Management Strategies-Final*. Prepared by King County Department of Natural Resources for East King County Ground Water Advisory Committee. December.
- KCDNR. 1998b. *East King County Ground Water Management Plan, Supplement 1: Area Characterization-Final*. Prepared by King County Department of Natural Resources for East King County Ground Water Advisory Committee. December.
- KCDNR. 1999a. *Issaquah Creek Valley Ground Water Management Plan: Management Strategies-Final*. Prepared by King County Department of Natural Resources for Issaquah Creek Valley Ground Water Advisory Committee. March.
- KCDNR. 1999b. *Issaquah Creek Valley Ground Water Management Plan: Area Characterization, Supplement 1: Area Characterization-Final*. Prepared by King County Department of Natural Resources for Issaquah Creek Valley Ground Water Advisory Committee.
- KCDNR. 1999c. *Redmond – Bear Creek Valley Ground Water Management Plan: Management Strategies-Final*. Prepared by King County Department of Natural Resources for Redmond – Bear Creek Ground Water Advisory Committee. February.
- KCDNR. 1999d. *Redmond – Bear Creek Valley Ground Water Management Plan, Supplemental 1: Area Characterization-Final*. Prepared by King County Department of Natural Resources for Redmond – Bear Creek Ground Water Advisory Committee.
- King County Department of Natural Resources and Parks (KCDNRP). 2005a. *Ambient Groundwater Monitoring; 2001 – 2004 Results*. King County Department of Natural Resources and Parks, Water and Land Resources Division. February.
- KCDNRP. 2005b. *East King County Groundwater Level Survey: Fall 2005*. King County Department of Natural Resources and Parks, Water and Land Resources Division. December.
- KCDNRP. 2007. *Exempt Wells in the Issaquah Creek Valley Groundwater Management Area*. Prepared by Ken Johnson. Water and Land Resources Division. Seattle, Washington. Final. November.

King County GIS Center's Web site. <http://your.kingcounty.gov/gis>

Liesch, B. A., C. E. Price, and K. L. Walters (Liesch et al.). 1963. *Geology and Ground-Water Resources of Northwestern King County, Washington*. Water Supply Bulletin No. 20. Prepared by State of Washington Department of Conservation, Division of Water Resources, in cooperation with United States Geological Survey Ground-Water Branch. pp 241.

RH2 Engineering. 1987. *Analysis report for the City of Renton Cedar River Valley Aquifer Test*.

Robinson & Noble. 1979. *Groundwater Evaluation of East Lake Sammamish Area*. Prepared for King County Water District 82. June.

Robinson & Noble, Inc. 1992. *Hydrogeologic Analysis of the Federal Way Area, Washington*. Volume 1. December.

Small Water Systems Technical Committee (SWSTC). 2007. *Report from the Small Water Systems in King County*. Prepared for the Regional Water Supply Planning Process. October. [<http://www.govlink.org/regional-water-planning/tech-committees/small-systems/071101SmallSystems.pdf>]

Sweet-Edwards & Associates, Inc. 1985. *Duwamish Ground Water Studies*. Prepared for Municipality of Seattle. May 13.

Turney, G. L., S. C. Kahle, and N. P. Dion (Turney et al.). 1995. *Geohydrology and Ground-Water Quality of East King County, Washington*. U. S. Geological Survey Water-Resources Investigations Report 94-4082. 123 pp.

Vaccaro, J. J., A. J. Hansen, and M. A. Jones (Vaccaro et al.). 1998. *Hydrogeologic Framework of the Puget Sound Aquifer System, Washington and British Columbia: Regional Aquifer System Analysis—Puget-Willamette Lowland*. U. S. Geological Survey Professional Paper 1424-D

Washington Department of Ecology (WA Ecology). 1998. Draft Report of Technical Advisory Committee on the Capture of Surface Water by Wells. Prepared by D. McChesney. January. Olympia, Washington.

WA Ecology. 2006. *2005 Drought Response Report to the Legislature*. Publication No. 06-11-001. February. [<http://www.ecy.wa.gov/pubs/0611001.pdf>]

WA Ecology. 2009. *Water Resources: Measuring Water Use* website. Accessed August 2009. [<http://www.ecy.wa.gov/programs/wr/measuring/measuringhome.html>]

Woodward, D. G., F. A. Packard, N. P. Dion, and S. S. Sumioka (Woodward et al.). 1995. *Occurrence and Quality of Ground Water in Southwestern King County, Washington*. U. S. Geological Survey Water-Resources Investigations Report 92-4098. 69 pp.

Appendix A
Summary of Reviewed
Documents

Documents Reviewed	Information Presented Supporting Additional Water Inputs	Information Gaps	Notes
EAST KING COUNTY			
<p>KCDNR, 1998. <i>East King County Ground Water Management Plan: Management Strategies-Final.</i></p>	<ul style="list-style-type: none"> Major aquifers have potential for over-use based on future demands. 	<ul style="list-style-type: none"> Need to address interaction between shallow groundwater and stream flow. Additional withdrawals could result in lower levels/ decreases to springs and other surface water. 	<ul style="list-style-type: none"> A large potential regional groundwater supply is located in this GWMA. >50% precipitation falls on land and recharges groundwater. 1% from wells and 2% to springs. Almost 90% water from groundwater is used for private, municipal, industrial and agricultural purposes. Principal sources of groundwater are Qal, Qvr, Qva, Qac and bedrock. Most productive aquifers are the high permeability sand and gravel outwash deposits. Snoqualmie Valley alluvial aquifer is being investigated as potential water supply (North Bend aquifer). More than half of the precipitation falls on land and recharges groundwater.
<p>KCDNR, 1998. <i>East King County Ground Water Management Plan: Supplement 1: Area Characterization-Final.</i></p>	<ul style="list-style-type: none"> Little water is available in thin unit in east Snoqualmie Valley Bedrock wells can go dry northeast of Duvall. Some wells had groundwater decreases and dry wells. Single source (Mt. Si spring) for North Bend is vulnerable. Does not meet future demands. Between Carnation and Monroe. Snoqualmie River seems to be a losing reach. Raging and Tolt Rivers are losing reaches. (Turney-USGS Report) Many streams may receive/lose, but were not measured. 	<ul style="list-style-type: none"> Data gaps identified in the U.S. Geological Survey study seen in lower Snoqualmie River valley, Sammamish Plateau and Cascade foothills. Recommended a groundwater model of Snoqualmie Valley to determine capacity of aquifer. (Turney-USGS Report) Flow in Qal-Qvr unit on the Sammamish Plateau is not well defined because much of it is unsaturated. Lack of data points on foothills and in Cherry Creek Valley. Upward flow is likely in many areas. Too short of a period to note long term trend for water levels Still unknown about whether deeper aquifer exists at bedrock interface at Carnation. Qbc and Qc were not mapped. Qc - Little data available to say what yield. Aquifer in Carnation Farms area has channel like shape; may extend beneath Tolt Hill. Recharge is slow in relation to ability to draw from them. Water is as old as when deposited. If aquifers were pumped the recharge would be much later. 	<ul style="list-style-type: none"> Primary source of drinking water is stored precipitation recharged through permeable soil. ~54% of precipitation recharges groundwater. 73% of total recharge in water budget flows out of the area as groundwater or recharges local surface water. Three aquifers identified=Fall City, Tolt Delta and Cedar Falls Aquifer. Fall City did not meet requirement of 5MGD. Tolt Delta met the requirement, but is remote from the network. Cedar Falls is too far south. Two subregional aquifers are in Snoqualmie Flats and Falls areas. In 1992, confluence of Snoqualmie, Middle Fork and the North Fork. North Fork was 5 MGD. It was estimated that 20MGD could be provided by Snoqualmie Aquifer and another 20 MGD where North Fork converges. Middle Fork has good quality and quantity. Golder has groundwater model of this area. Principal sources of groundwater are Qal along Snoqualmie River and glacial deposits underlying plateaus to east and west of the alluvial lowlands. (Qvr, Qva, Qac and bedrock). Usable amounts of groundwater can be obtained from Qvt, Qaf, Qbf and Qbc. Most productive aquifers are the high permeability sand and gravel outwash deposits. Buried valleys in Snoqualmie Valley, evidenced from geophysics surveys. <p>HYDROSTRATIGRAPHIC ZONES.</p> <p><i>Qal</i>- Snoqualmie River valley and tributaries; sand, gravel and silt; highly productive, unconfined upstream of Snoqualmie Falls. Downstream, the aquifer has lower permeability, wells downstream from the falls in landslide or alluvial fans have less yield and less predictable. Wells on lower valley floor are subject to periodic flooding. Flow is substantial. Recharge is mostly discharged to southwest. A fraction reaches deeper aquifers underlying till.</p> <p><i>Qvr</i>-sand, gravel, ice-contact deposits on margins in east; lacustrine deposits of ice-dammed lakes. Mostly unconfined and perched conditions. Can be productive where thick.</p> <p><i>Qvt</i>-low permeability barrier. Soils above the till serve as aquifer due to slow rate of infiltration. Perched aquifer with limited use. Occasional sand lenses produce water. Considered confining bed. Upper part is more permeable and can yield more usable short term quantities. Yields are variable.</p> <p><i>Qva</i>-well graded gravelly sand – fine grained sand. Principal aquifer, mostly confined.</p> <p><i>Qaf</i>-usable amounts, mostly Qtb and Qpf. Thin lenses of sand and gravel yielding small quantities for domestic use. Serves as confining unit for Qac.</p> <p><i>Qac</i>-principal aquifer, strongly oxidized sand and gravel, mostly confined.</p> <p><i>Deepest unconsolidated units</i> Qbf-usable amounts/rarely used; Qbc-sand and gravel, some fines. Probably confined; Qc <i>Bedrock</i>-sandstone, siltstone, conglomerate. Unreliable source. Not fractured enough to yield large quantities.</p> <ul style="list-style-type: none"> Higher recharge rates in east and southeast parts of GWMA. Receives about 31 in/year of recharge.
<p>KDNR, 2005b. <i>East King County Groundwater Level Survey: Fall 2005.</i></p>	<ul style="list-style-type: none"> Water levels were either about the same or on average up to 5 ft lower. Qva-19/20 wells were 1 - 5 ft lower with one at 9 ft lower than 1995. Qal/Qvr-4/25 had significantly lower water levels than 1995. 	<ul style="list-style-type: none"> Only 45 wells were accessed, coverage was low. One time measurement compared to 1995 only. No long term trend data. 	<ul style="list-style-type: none"> Water levels in Qal, Qva, Qvr for a one time measurement to compare to U.S. Geological Survey report. Qal and Qvr were considered one unit due to hydrologic connection.

Documents Reviewed	Information Presented Supporting Additional Water Inputs	Presented Information Gaps	Notes
EAST KING COUNTY (continued)			
<p>Turney et al., 1995. <i>Geohydrology and Ground-Water Quality of East King County, Washington.</i></p>	<ul style="list-style-type: none"> Some declining water levels in wells, may be due to pumping. Bedrock wells can go dry in summer or under high use. Raging and Tolt rivers lose water to groundwater. 	<ul style="list-style-type: none"> Flow to deeper regional system is unknown, but may be significant. Not many long term water level data sets. Unknown depth to bedrock in many areas of Snoqualmie River valley. Snoqualmie River valley, Cascade foothills and Sammamish Plateau has lack of deep well data (500-1000 deep). Qc—has few wells, unknown productivity. Groundwater model of entire Snoqualmie valley would help estimate effects of development. The modeled amount discharged to north and west out of study area is high due to lack of information. 	<ul style="list-style-type: none"> Some flowing wells in Snoqualmie Valley. Withdrawn water used for aquaculture, beneficial use, class ½ public supply systems, domestic, irrigation, dairy cattle. <p>HYDROGEOLOGY <i>Qal</i>-major aquifer, highly productive unconfined upstream of falls, less permeable and productive downstream. <i>Qvr</i>-major aquifer where saturated, mostly unconfined, some local perched zones. <i>Qvt</i> -confining bed with some sand and gravel lenses that produce water, conductivity can be higher due to heterogeneity of unit and that wells in <i>Qvt</i> tend to be in more coarse units. <i>Qva</i>-major aquifer, mostly confined, flow is discontinuous. <i>Qaf</i>-confining bed with some sand and gravel lenses that produce water. <i>Qac</i>-major aquifer, confined. <i>Qbf</i>-confining bed, few wells.. <i>Qbc</i>-few wells, aquifer where saturated, probably confined <i>Qc</i>- probably confined. <i>bedrock</i>-some usable water, not reliable source, low hydraulic conductivity, low fracture density, likely unconfined at surface and confined when overlain. Water quality is typical of west Washington. Discharge from groundwater to rivers, Lake Sammamish, springs, etc. </p>
<p>Golder Associates. 1995. <i>Geophysical and Hydrogeologic Investigations in East King County Groundwater Management Area.</i></p>	<p>None Presented</p>	<p>None Presented</p>	<ul style="list-style-type: none"> Report presents geophysical results, test well results, and development of conceptual geologic model, near Carnation. Good correlation between wells and seismic investigation.
<p>PEI/Barrett Consulting Group. 1991. <i>Lake Alice Plateau: Neighboring Water User Study for Snoqualmie Ridge Parkway</i></p>	<p>None Presented</p>	<p>None Presented</p>	<ul style="list-style-type: none"> Presents background information on geology and groundwater. Focuses on potential water quality impacts to surface and groundwater near Snoqualmie Ridge that may results form development within Snoqualmie Ridge.
<p>Golder, 2001. <i>Sampling and Analysis Plan for the East King County Groundwater Management Area.</i></p>	<p>None Presented</p>	<p>None Presented</p>	<ul style="list-style-type: none"> Water quality generally excellent. Goal is to evaluate regional scale water quality and overall conditions of groundwater. Emphasis on most susceptible, which was based on land use.
<p>Hart Crowser. 1988. <i>Tolt River Pipeline Groundwater Development Study, King County, Washington.</i></p>	<p>None Presented</p>	<ul style="list-style-type: none"> Little data available at start of study. Results of existing data review indicated potential to develop deeper aquifers (little data available). 	<ul style="list-style-type: none"> Hydrogeologic evaluation near Tolt River Pipeline from South Fork Tolt Dam and Bothell/Kirkland area. Purpose was to develop source for peak demand groundwater supply of 10 MGD and supply Suring winter months of excess surface water turbidity. Investigations included drilling deep wells (> 200 ft deep), mapping, geophysical surveying, and well testing. Results of existing data review indicated low yields from principal aquifer.

Documents Reviewed	Information Presented Supporting Additional Water Inputs	Presented Information Gaps	Notes
EASTSIDE AND SAMMAMISH AREAS			
<p>Robinson & Noble, Inc. 1979. <i>Ground Water Evaluation of East Lake Sammamish Area for King County Water District 82.</i></p>	None Presented	<ul style="list-style-type: none"> •Unknown potential of aquifer beneath artesian aquifer. Deeper drilling required to gain more information. •Information for area is insufficient to precisely define systems. 	<ul style="list-style-type: none"> •Presents probable extent of gravel aquifer, based on review of previous work. •Indicated notable artesian aquifer at shallow depths. •Proposes four well installations.
<p>Golder Associates. 2000. <i>Groundwater Exploration and Pumping Test: Lower Issaquah Valley</i></p>	<ul style="list-style-type: none"> •Issaquah Creek is perched in parts of year and is disconnected to water table. •Losing reaches of Issaquah Creek at times during the year (leakage form stream to groundwater) •Issaquah Creek is gaining reach at times of year when streambed elevations are lower than water table. •Losing reaches of Issaquah Creek at times during the year (leakage form stream to groundwater). 	None Presented	<ul style="list-style-type: none"> •Reports on well installation and pumping test; includes hydrogeologic and engineering information. •Indicated that at one well, W-1, no summer groundwater Baseflow discharges to Issaquah Creek in the vicinity of the City Shop site. •Recommends deep wells at City Shop area to evaluate mode and magnitude of groundwater discharge into Lake Sammamish. •Conceptual model indicated aquifers and two aquitards. Upper aquifer in close communication with ground surface. •Long term responses (since 1996) indicate maximum levels in Jan-April time period and minimum in August – September. Total fluctuations at around 10-12 ft.
<p>KCDNR, 1999. <i>Issaquah Creek Valley Ground Water Management Plan: Area Characterization. Supplement 1: Area Characterization - Final</i></p>	<ul style="list-style-type: none"> •Bedrock (not yield high quantities, but usable, declining water levels indicate recharge is slower). •Lake Tradition loses water to system. •Valley aquifers- some losing streams. •Long term water level data for lower Issaquah Creek valley aquifer indicate a downward trend in water table elevations. 	<ul style="list-style-type: none"> •Long term water level data for lower Issaquah Creek valley aquifer indicate a downward trend in water table elevations. May be being pumped too much, or maybe due to climatic influences. Need more information to evaluate reason for decrease. •Qbc and Qc (little information, rarely used as source, probably confined). •Flow direction in Grand Ridge and Tradition Lake area is less known. •Limited stream/groundwater connection, but need more data to confirm; upper valley (south of gap; no known high capacity wells, but due to sparse population, unknown) flow direction in deeper aquifers not fully understood •The capacity of aquifer systems that Sammamish Plateau Water and Sewer District and City of Issaquah get their water from is unknown. •Valley aquifers- lower valley groundwater system more work needed over time for trends and to clarify areas missing information. 	<ul style="list-style-type: none"> •More 98% of withdrawals went to public water systems. <p>STRATIGRAPHIC UNITS <i>Qb; Qal</i> Stream deposits of sand to cobble along channels, floodplains, fan yields of high quantity; landslide deposits. <i>Qvr</i> gravel, sand and some silt; delta deposits. Productive where thick and saturated. <i>Qvr lacustrine</i> leaky aquitard, discontinuous. <i>Qvi</i> (mix of Qvt and outwash, cannot generalize on hydraulic conductivity); upper portions can have perched and semi-perched water tables in isolated lenses, low yield to shallow wells, slow recharge. <i>Qva</i> sand and cobble gravel, generally high hydraulic conductivity, large quantities of water. <i>unconsolidated pre-Vashon</i> (Qtb, Qpf, Qob). <i>bedrock</i> some mineralized, saline, brackish water quality. <ul style="list-style-type: none"> •Groundwater in Issaquah basin, various outwash deposits (sand and gravel). Some shallow aquifers formed in Qvr and ice-contact deposits (high hydraulic conductivity). Soil on top of Qvt has high infiltration. In lower Issaquah valley, a ice-dammed lake formed deltaic deposits which provide recharge to the area where Issaquah and Sammamish Plateau pump wells. <p>AQUIFERS <i>Mountain aquifers</i> – mostly bedrock for individual water supplies. Some permeable glacial sediments, small public water supply is possible, steep gradients, springs. <i>Upland/Sammamish Plateau Aquifers</i> – numerous domestic wells in unconsolidated sediments with various yields; Qva, Qac, Qal-Qvr discontinuous, flow is downward; Qbc and Qc rarely used as source, probably confined; bedrock-suspect not highly fractured, low hydraulic conductivity, poor source. <i>Valley aquifers- lower valley groundwater system</i> – (north of the gap=A1 - upper fluvial, A2 - lower glacio-fluvial, A3 - deep alluvial) Several high production wells, highly permeable, flow direction not well known, deltaic sediments of North and East Forks transmit downward into lower Issaquah valley from upland areas (Flow through the Tiger Mountain Gap –limits drainage from southern part of GWMA to about 50% of total discharge; responds quickly to precipitation and pumping. <ul style="list-style-type: none"> •Water quality generally excellent </p></p>

Documents Reviewed	Information Presented Supporting Additional Water Inputs	Presented Information Gaps	Notes
EASTSIDE AND SAMMAMISH AREAS (continued)			
<p>KCDNR, 1999. <i>Issaquah Creek Valley Ground Water Management Plan: Management Strategies - Final</i></p>	<p>None Presented</p>	<p>None Presented</p>	<ul style="list-style-type: none"> •Groundwater comes from precipitation in basin. •30% of recharge to lower Issaquah Valley groundwater system is from eastern plateau (Grand Ridge and Lake Tradition).100% water used for private, municipal, industrial and agricultural purposes provided by groundwater sources. •High production wells in lower Issaquah Valley. Three major aquifer zones (upper, lower and deep zone). •Limited hydraulic connection, but some pumping in deeper wells can cause downward flow in upper aquifer. •Water quality in lower valley is generally excellent. •Most significant areas of infiltration are sand and gravel deposits east of Issaquah on the uplands between East and North Forks of Issaquah Creek.
<p>Pacific Groundwater Group, Inc. 1992. <i>Issaquah Ground Water Management Program: Data Collection and Analysis Plan (DCAP)-Final.</i></p>	<p>None Presented</p>	<p>None Presented</p>	<ul style="list-style-type: none"> •Report includes plan for long term monitoring and concern for future availability of supply. •Geophysical exploration precipitation monitoring at nine sites, stream gaging (13 sites), water sampling (25 wells), water level monitoring (50 wells), and installation of four to six wells (lower Issaquah valley) and Squak Tiger Mountain Gap area). •Some areas required more data to monitor and manage resources.
<p>Golder Associates Inc. 1995. <i>Preliminary Evaluation of Aquifer Storage and Recover in the (Little) Bear Creek Drainage</i></p>	<p>None Presented</p>	<p>None Presented</p>	<ul style="list-style-type: none"> •Documents project reviewing aquifer and storage recovery development in Bear Creek watershed. •Scope was to complete hydrogeologic evaluation (sampling, gaging, analysis), cost estimates, regulatory concerns). •Aquifer storage potential in Bear Creek was found to be potentially very good. Significant water storage capacity may exist. •Aquifer storage recovery design included 11 wells and two diversion channels at higher elevations. •Two water rights are required, one for recharge source and artificial recharge of aquifer: the other for withdrawal of stored water from aquifer.
<p>Sweet-Edward/EMCON, Inc. 1990. <i>Redmond-Bear Creek Ground Water Management Area: Data Collection and Analysis Plan (DCAP)-Revision 3.</i></p>	<p>None Presented</p>	<ul style="list-style-type: none"> •Although there were aquifers in the valley portions of study area, the overall hydrogeology of the study was not well understood at the start of study. •Lower Evan’s Creek valley, Woodinville study area had lack of deep hydrostratigraphic data 	<ul style="list-style-type: none"> •Report prepared comprehensive goals for a basin wide aquifer study (develop database, model, plan, outreach program). •Geophysical exploration, deep well borings, water sampling (20 parameters), water level monitoring (40 wells), stream monitoring (five creeks) and collection of contaminant source and land use data is planned.

Documents Reviewed	Information Presented Supporting Additional Water Inputs	Presented Information Gaps	Notes
EASTSIDE AND SAMMAMISH AREAS (continued)			
<p>KCDNR, 1999. <i>Redmond – Bear Creek Valley Ground Water Management Plan. Supplemental 1: Area Characterization - Final</i></p>	<ul style="list-style-type: none"> •Potential other water Sources are: Redmond, Evans Creek and Sammamish Plateau aquifer. Redmond and Evans Creek are in relatively shallow deposits(<200 ft). Sammamish Plateau Aquifer is deeper (<400). Coordinated Water System Plan concluded that the water supply potential from these aquifers was not significant enough to meet future regional demands. •Private wells in Qvt (till) may dry up in summer. 	<ul style="list-style-type: none"> •Only comments on water available to remove, not where might be missing. (For areas mentioned that might be able to be pumped but need to look at base flows of streams etc, would need long term data to evaluate this.) •Too short of a period to note long term trend for water levels. •Private wells in Qvt (till) may dry up in summer. 	<ul style="list-style-type: none"> •Existing water demand – nearly all of rights have been issued for public water supply use. <p>AQUIFERS <i>Alluvial</i> Primary producing aquifer along stream channels (Cottage Lake, mostly Bear Creek and Evans Creek) <i>Sea level aquifer</i> consists of Qob and Qc near sea level. <i>Local upland aquifers</i> are discontinuous Qva and permeable zones of Qvt. <i>Upland aquifers</i> underlie ridges on east, west and south boundary. <i>Regional aquifers</i> are Qc glacial and interglacial deposits.</p> <ul style="list-style-type: none"> •GROUNDWATER SYSTEMS: Shallow groundwater systems are alluvial deposits along major streams and shallow upland aquifers. Intermediate groundwater systems are sea level aquifers and deeper portions of the local upland aquifers; deeper groundwater systems are below the int. and shallow aquifers. <p>HYDROSTRATIGRAPHIC ZONES. <i>Qal</i>-Water level at <10-100 ft bgs. Vary up to 6 ft with seasonal changes in precipitation. Unconfined and semi-confined. Flows to discharge along streams, Sammamish River and Lake Sammamish (south along Bear Creek and Cottage Lake Creek and west along Evans Creek). <i>Qvt</i>-low permeability barrier. Shallow water may occur at base of upper 8 ft of weathered till (or perched on top of the unit). Discontinuous lenses of sand/gravel. Mostly private wells at 25 gallons per minute, seasonal fluctuations. Usually causes swampy areas when near surface. <i>Local upland aquifers</i>-occurs beneath ridge and may be discontinuous. Controlled by topography. Mostly Qva and some Qvt. DTW ranges <10 in perched zones to about 350 ft bgs. Aquifers may recharge the alluvial aquifer along valley walls. Unconfined/confined. Flows from highland area north of Redmond towards alluvial. Aquifer along Sammamish River and Bear Creek. On east side of GWMA, flow towards Bear Creek and Evans Creek. <i>Qtb</i>-important unit. Aquitard, 50-100s ft of continuous lake bed deposits. Scattered sand lenses locally capable of 100GPM of water. Recharged by Qva and from below. <i>Sea level aquifers</i>-Qob and Qc are ~50-135 ft thick. Regional in size. DTW 50–400 ft bgs. Groundwater higher in autumn than spring. Seasonal variations of 10-120 ft due to precipitation. Confined. Flows west from high elevation to low elevations in east. In south end of GWMA, flows to Lake Sammamish <i>Regional aquifers</i>-Qc. > 400 ft thick. Below Qob and Qtb, usually confined. DTW 100-400 ft bgs. Confined. Discharge to Puget Sound?</p> <ul style="list-style-type: none"> • Water quality generally meets standards. Problems are elevated iron and manganese, particularly in deeper wells; bad tasting or odorous water caused by hydrogen sulfide.
<p>KCDNR, 1999. <i>Redmond – Bear Creek Valley Ground Water Management Plan: Management Strategies- Final</i></p>	<ul style="list-style-type: none"> •New water sources in some areas should not be developed due to over pumping reducing water levels. •Continued growth will require additional water supply and land use control to recharge areas to maintain aquifer quantity. •According to consultants, planned changes to land use will impact both water quality and quantity (i.e. Novelty Hill). 	<ul style="list-style-type: none"> •More data of deep aquifer system are needed to determine if there will be impacts from large scale developments. 	<ul style="list-style-type: none"> •~100% water used for private, municipal, industrial and irrigation purposes provided by groundwater sources. •Primary beneficial uses of groundwater are for domestic and public water supply, fire suppression, and recharge to streams and lakes. •Major production wells for City of Redmond and Union Hill Water Association are located in alluvial aquifers, shallow depths in deposits along Bear Creek and Evans Creek. •Production wells for NE Sammamish Sewer and Water District are located in alluvial and in deeper sea level and regional aquifers in areas of moderate infiltration. •Major aquifer zones include alluvial, local upland, sea level and regional aquifers. •Highest infiltration occurs in areas Cottage Lake Creek, Bear Creek and Evans Creek valleys. •Several City of Redmond wells located downtown. •Potential other sources are: Redmond, Evans Creek and Sammamish Plateau aquifer. Redmond and Evans Creek in relatively shallow deposits. Plateau aquifer is deeper.

Documents Reviewed	Information Presented Supporting Additional Water Inputs	Presented Information Gaps	Notes
EASTSIDE AND SAMMAMISH AREAS (continued)			
AGI Technologies. 1998. <i>Sammamish Plateau Water and Sewer District: Artificial Recharge Testing of the Plateau Aquifer System Zone IV (through Well 5), Phase III</i>	None Presented	None Presented	<ul style="list-style-type: none"> •Results of a three month testing and monitoring program indicated Plateau Aquifer Zone IV can be used to store artificially recharged water (up to 10 to 30 %). •Recommendations were to develop model and pump test monitoring. •Boundary of aquifer was about 11000 ft from well. (well 5). •Test indicated confined aquifer conditions. •Injection of 16.7 million gallons caused 13 ft of water level rise (no change in overlying aquifer zones). •Has capacity for up to 10 to 30 % of storage capacity of aquifer.
KC WLRD, 2005. <i>Sammamish River Valley Groundwater Study: 2003-2004 Data Report.</i>	None Presented	<ul style="list-style-type: none"> •Only one year of data. No long term trend data. 	<ul style="list-style-type: none"> •Installed 21 wells in Sammamish River area, took water levels along river and Evans, Bear and Little Bear Creeks during 2003-2004. •Seasonal fluctuations, responding to precipitation in all shallow wells. •Flow is towards Sammamish River and down river corridor. Seasonal upward gradient from deep to shallow. •Trends – seasonally higher in winter and lower in summer due to increased precipitation and lower evapotranspiration in winter resulting in higher recharge to groundwater and surface water. <i>Marymoor Park Subarea</i> - Sammamish River level has higher levels in winter, due to precipitation. Seasonal vertical gradients, generally during rainy season. There is downward movement, suggesting recharge from precipitation. Vice versa and may discharge to surface water. Somewhat impacted water quality. <i>60-acres Subarea</i> – Deeper units did not show clear response to precipitation. Upward gradient due to confining silt above deeper unit. Impacted water quality. <i>Woodinville Subarea</i> – Seasonally upward and downward vertical gradient. Less impacted water quality than in other subareas. Groundwater discharges to Sammamish River in eight of nine study locations. At an area north of Marymoor Subarea, surface water appears to be source for recharge to groundwater.
Golder, 2000. <i>Sampling and Analysis Plan for the Issaquah Creek Valley Groundwater Management Area.</i>	None Presented	None Presented	<ul style="list-style-type: none"> •Goal is to evaluate regional scale water quality and overall conditions of groundwater. •Emphasis on most susceptible, which was based on land use. •Water quality generally excellent.
Golder, 2001. <i>Sampling and Analysis Plan for the Redmond - Bear Creek Groundwater Management Area.</i>	None Presented	None Presented	<ul style="list-style-type: none"> •Water quality generally excellent. •Goal is to evaluate overall conditions of groundwater and compare to past studies.

Documents Reviewed	Information Presented Supporting Additional Water Inputs	Presented Information Gaps	Notes
SEATTLE AND NORTH			
Liesch, B. A., C. E. Price and K. L. Walters. 1963. <i>Geology and Ground-Water Resources of Northwestern King County, Washington</i>	<ul style="list-style-type: none"> On Newcastle Hills, withdrawal has exceeded recharge of principal aquifer (Tertiary rocks). 	None Presented	<ul style="list-style-type: none"> Includes maps and cross sections. Detailed descriptions of geology. Groundwater in consolidated rocks. For 1950-1960, no serious overdraft of unconsolidated northwestern KC.
SOUTH KING COUNTY			
RH2 Engineering. 1987. <i>Analysis report for the City of Renton Cedar River Valley Aquifer Test</i>	None Presented	<ul style="list-style-type: none"> Absence of wells in the southwest portion of the aquifer 	<ul style="list-style-type: none"> Low specific yield and decrease in aquifer hydraulic conductivity west of well field. Boundaries of aquifer described. No measurable change in river due to changes in channel of Cedar River. Pumping influence was about 1000 to 2000 ft from well into aquifer. Report included recommendations for new wells, further pump tests, additional well installation, and modeling. Describes relationship of well and river during pumping.
City of Auburn Water Division http://www.ci.auburn.wa.us/utilities/water/index.asp	None Presented	None Presented	<ul style="list-style-type: none"> Auburn's water comes from a combination of wells drawing water from deep below the City and springs located near the walls of the valley. The valley wells and springs serve customers in the valley, Lea Hill and the Forest Villa/Academy area. Additional wells are located in the Lakeland Hills area and serve customers south of the White River in the Lakeland Hills neighborhood. It is not dependent on the Cascade Mountain's snow pack replenishing open reservoirs. As per their Comp. Plan Amended 1995; Chapter 5; Goal 13: CF-51 The City shall seek opportunities where feasible to reintroduce treated urban runoff back into groundwater system as new and redevelopment occurs to minimize urbanization impacts to the hydrology of the natural river systems. CF-53 The City shall seek to minimize the impacts to the natural river system's hydrology by encouraging pre-treatment of surface flows of new development and re-introduction into the groundwater where feasible.
City of Renton Aquifer Protection Program http://www.renton-wa.gov/living/default.aspx?id=144	None Presented	None Presented	<ul style="list-style-type: none"> About 87% of water is supplied by Cedar Valley Aquifer with rest coming from Springbrook Springs, in south Renton. The aquifer is a sole source aquifer as per USEPA. The sand and gravel aquifer is about 3.5 miles long and produces about 7.3 MGD. In some areas, the water table is <25 ft bgs. The aquifer is recharged by rain and snow and from groundwater flow from Cedar Valley. Web research indicated two reports that may be of interest to King County WTD: City of Renton Water System Plan, Appendix Q, Wellhead Protection Plan, May 1999. This report include information on capture zones, the program, water supply sources, a description of the Renton Groundwater Model, Particle Tracking Approach and Model Input Parameters. "Explanation of Aquifer Code Amendments, August 2002" by City of Renton Water Utility. This document summarizes the results of a computer model simulating groundwater flow in three dimensions related to the Cedar Valley Sole Source Aquifer and the Maplewood Production Aquifer.
Harper-Owes. 1985. <i>Duwamish Ground Water Studies: Waste Disposal Practices and Dredge and Fill History</i>	None Presented	None Presented	<ul style="list-style-type: none"> Presents a review of waste disposal and dredge/fill practices in Duwamish River area. Refers to shoreline changes creating conduits for ground water movement (i.e. unconsolidated fill deposits)

Documents Reviewed	Information Presented Supporting Additional Water Inputs	Presented Information Gaps	Notes
SOUTH KING COUNTY (continued)			
Sweet-Edwards & Associates, Inc. 1985. <i>Duwamish Ground Water Studies</i>	None Presented	<ul style="list-style-type: none"> • Initial data review indicated little relevant groundwater data. • Insufficient data to define number of aquifers. • No wells in bedrock of upland regime. • Unsure of groundwater flow directions. 	<ul style="list-style-type: none"> • Investigation to evaluate contaminant contribution to river from groundwater between Elliot Bay and Black River. • No regional ground water studies of Duwamish had been completed at the time of the report. • Goals: provide general characterization of surface and groundwater, identify hydraulic parameters and data gaps and develop ground water monitoring and analysis strategy. • Model based on limited data and assumptions on the groundwater flow in the basin. • Two groundwater regimes. (upland glacial and interglacial material and bedrock (no wells in bedrock); valley floor regime is primary focus of study, thick sand and gravels). • Includes hydraulic parameters.
Brown and Caldwell Consultants. 1992. <i>Effluent Reuse Pilot Project Report</i> .	None Presented	None Presented	<ul style="list-style-type: none"> • Provides city demands and potential uses of effluent water, including design criteria and alternatives.
Robinson & Noble Inc. 1992. <i>Hydrogeologic Analysis of the Federal Way Area, Washington. Volume 1.</i>	<ul style="list-style-type: none"> • Valley aquifer system: water level records of Well16 shows aquifer has lost 10 ft of head in response to moderate production and is now under water table conditions. • Production and land use changes have induced water level declines from the major shallow aquifer (beneath the upper confining unit) but has stabilized by 1987. Stabilization of water levels did not continue past 1987, they declined through 1988, about seven ft lower than in end of 1987. Water level shave recovered slightly since then. • Water level at Well23A has declined about 12 ft over the last 14 years. • Water levels in Mirror Lake aquifer (deep) are greatly affected. (up to 50 ft by 1987) and slightly less by now. • Eastern Upland Aquifer is affected by production, but not as much as in Mirror Lake aquifer. 	<ul style="list-style-type: none"> • Federal Way deep aquifer not adequately studied due to lack of data. 	<ul style="list-style-type: none"> • Presents a numerical groundwater flow model for Federal Way area. Developed conceptual geohydrologic model. • 230 wells and springs used for database. • Upland geology was simplified for model. Report presents detailed destructions of geology and layers. • Model indicated septic system recharge component was recognized as important for regional water balance; magnitude that leakage occurs in upper aquifers when deeper aquifer levels are reduced was larger than exacted, and Puyallup Valley was realized as natural drain for Federal Way aquifers. • Eastern Upland Aquifer is affected by production, but not as much as in Mirror Lake aquifer. There has been a general rise in water levels in central and northern portions since 1960s.
TCW Associates, Inc., HLA/Harper-Owes, University of Washington College of Forest Resources, and Municipality of Metropolitan Seattle. 1989. <i>Hydrogeology and Water Quality Evaluation: Metro Section 16 Silvigrow Project</i>	None Presented	None Presented	<ul style="list-style-type: none"> • Report presents information and data for application of a sludge fertilizer and results of a study of application of the sludge and environmental effects. • Groundwater flows to north and discharges to springs along Green River. • Worst case scenario of application and impacts was an extremely small impact to groundwater quality. • Groundwater at site recharged by precipitation in vicinity. Shallow groundwater levels (about 13 ft deep). • Discharge rates of springs vary. • Rivers and aquifers are very closely connected.

Documents Reviewed	Information Presented Supporting Additional Water Inputs	Presented Information Gaps	Notes
SOUTH KING COUNTY (continued)			
<p>CWD, 1995. <i>Lake Sawyer Wellhead Protection Plan: Covington Water District - Final</i></p>	<ul style="list-style-type: none"> • In portions of study area, shallow system unit may completely drain by late summer. 	<ul style="list-style-type: none"> • Deep aquifer poorly delineated • Water levels in shallow system have seasonal variation of several feet. In portions of study area, unit may completely drain by late summer. 	<ul style="list-style-type: none"> • Former studies indicated prolific aquifers at both Kent Springs and Lake Sawyer Wellfield sites. • Plan is divided into three areas: wellhead protection area delineation; existing and potential hazards and strategies and implantation tasks. • Used 426 wells to develop conceptual model. Aquifer area that contributes is 11 square miles. • Regional aquifer that supplies Lake Sawyer Wellfield also supplies Kent and Clark Springs for the City of Kent. Capture zones can not be separated. • Basin boundaries formed by Green and possibly Cedar Rivers, by groundwater divides, and bedrock. • Western portion of aquifer, leakage to deeper aquifers can occur. • 74% of wells are installed in the shallow aquifer system (mostly unconfined) • Report has detailed descriptions of hydrostratigraphic units.
<p>Woodward et al., 1995. <i>Occurrence and Quality of Ground Water in Southwestern King County, Washington</i></p>	<ul style="list-style-type: none"> • Some wells showed reducing water levels over decades. • Qvt may go dry in late summer. • Some areas of Green and White Rivers near Auburn have losing reaches in the Qal. 	<ul style="list-style-type: none"> • Data lacking in the Des Moines Plains area • Mapping in Cedar River Valley was difficult, less confidence in map results in this area. • Qbc-not much information • Qc-unknown hydraulic characteristics • Qvt may go dry in late summer. 	<ul style="list-style-type: none"> • 80% of recharge to shallow groundwater in Big Soos Creek basin is returned to streams as baseflow. • ~97% of total groundwater pumped used for public and domestic water supply, < 3% used for irrigation, the rest for commercial, industrial/institutional. Mostly from the Qal aquifer, then Qva and Qac. • No widespread water quality degradation • HYDROGEOLOGIC UNITS • Qal water table aquifer at land surface, generally low yield. Fan deposits in the Cedar River Valley near Renton and the southern part of the Green-Duwamish Valley near Auburn yield lots of water to wells, many wells in these units. • Qvr water table aquifer at land surface, minor aquifer because thin and sporadically located, sometimes hard to find with respect to sand rich Qvt/till areas. • Qvt confining bed, some areas are sandy and friable, can have small producing zones of sand lenses, some dug wells still in use. • Qva sand and gravel, confined, important aquifer where saturated, several cities have wells in this unit, can merge with Qac. • Qaf confining bed with some sand and gravel lenses with water. • Qac contains silt lenses, saturated, heterogeneous, in direct connection with Qva in parts of the Covington and Des Moines Plains; confined. • Qbf confining bed. • Qbc deepest units studied, King County Water District and City of Federal Way have wells in this aquifer: confined. • Bedrock relatively impermeable units (sandstone with shale / coal), some volcanic and intrusive igneous rocks. • GROUNDWATER FLOW SYSTEMS Local; intermediate-flow above bedrock and below deep part of local system; regional controlled by Cascades, Olympic Mountains and Puget Sound and starts at the crest of the Cascades.
<p>CH2M Hill. 1988. <i>Well Field Monitoring Study City of Renton</i></p>	<ul style="list-style-type: none"> • When well field is active, groundwater movement on south side of river is influenced (especially when wells PW1 & PW2 are operating). 	<p>None Presented</p>	<ul style="list-style-type: none"> • Objectives of report are to determine rate and direction of groundwater movement under differing pumping conditions and to determine the interactions between Cedar River and aquifer, delineate boundaries of aquifer and well field, and to sample to evaluate exiting conditions. • General flow direction to southwest and west, with a component to the northwest. • Cedar River acts as minor source of recharge for aquifer: In vicinity of well field , amount of recharge is small compared to flow.

Documents Reviewed	Information Presented Supporting Additional Water Inputs	Presented Information Gaps	Notes
SOUTH KING COUNTY (continued)			
<p>Hart Crowser. 1996. <i>Wellhead Protection Program: Clark, Kent, and Armstrong Springs; City of Kent</i></p>	<p>None Presented</p>	<ul style="list-style-type: none"> •The effect of Lake Sawyer on groundwater flow is not well-studied. •Interaction between aquifer and surface waters needs better understanding. •Relationship of Jenkins Creek and aquifer is unknown. •Flow patterns north of Armstrong Springs, Lake Sawyer and Ravensdale Lake needs better understanding. •Groundwater divide for Clark Springs area is undefined. 	<ul style="list-style-type: none"> •Plan presents wellhead protection area delineation, contaminant sources, and management strategies. •City gets water from shallow, highly transmissive glacial outwash aquifers. •Main recharge is infiltration in study area, with additions from Lake Sawyer and runoff from uplands. •Groundwater flow is towards the east and west from high recharge area of foothills east of Clark Springs through Vashon recessional outwash and deeper glacial deposits. •City of Kent coordinates with Covington Water District and Water District No. 111 due to proximity of aquifer. •Kent’s water sources are a combination of spring infiltration galleries and wells from Clark Springs, Kent Springs and Armstrong Springs. •Kent Springs usage is primarily during wetter months and in drier summer and early fall months the deeper coarse aquifer is more reliable. •Clark Springs 1year WHPA is about 11000 ft; Kent and Armstrong Springs have 1 year WHPA is about 5000 ft. •Clark Springs was closed due to water quality degradation. •Plan proposes potential sources: Georgetown area, Ravensdale area, Ranney well field (near Green and White Rivers). •Water level changes are seasonal (up to 10 ft).

REGION-WIDE DOCUMENTS			
<p>KCDNR 2005. <i>Ambient Groundwater Monitoring 2001-2004 Results.</i></p>	<ul style="list-style-type: none"> •East King County, Redmond-Bear Creek and Vashon-Maury Island water level plots indicated groundwater depths were generally stable during the period of record, with no significant declines. 	<ul style="list-style-type: none"> •Frequency of water level monitoring and the unknown pump usage prior to measurement. •More shallow wells than deep wells. 	<ul style="list-style-type: none"> •Sampling focused on East King County, Issaquah Creek Valley, Redmond Bear Creek and Vashon-Maury Island GWMA. •Monitors private and public wells. Some volunteers do the level measuring. •92 wells had water levels and sampling. •EKC had 14 wells and Redmond-Bear Creek had 16 wells, VMI had 16 wells: showing unchanged water levels. •Issaquah had 11 wells, showing seasonal changes in water levels. •Results in dictated water levels were stable in areas monitored.
<p>Washington Department of Ecology Water Quality Program. 2005. <i>Critical Aquifer Recharge Areas: Guidance Document. Publication Number 05-10-028.</i></p>	<p>None Presented</p>	<p>None Presented</p>	<ul style="list-style-type: none"> • Provides guidance to regulators and private land and well owners on requirements for protecting local groundwater resources under Growth Management Act. •Best available science, resources, and contacts are provided.

Documents Reviewed	Information Presented Supporting Additional Water Inputs	Presented Information Gaps	Notes
REGION-WIDE DOCUMENTS (continued)			
Vaccaro, J. J., A. J. Hansen, and M. A. Jones. 1998. <i>Hydrogeologic Framework of the Puget Sound Aquifer System, Washington and British Columbia: Regional Aquifer System Analysis—Puget-Willamette Lowland</i>	None Presented	<ul style="list-style-type: none"> • Sparse data for deep wells (>250 ft) in Puget Sound Lowlands. • Methods, descriptions, and division of aquifer systems in have varied widely. • Extrapolation of local results to regional scale is problematic and difficult. • Water level maps in report are compilations and represent composite water levels. 	<ul style="list-style-type: none"> • Presents simplified conceptual model (included nine alluvial valley aquifers, the surficial semi-confining unit, Fraser aquifer, confining aquifer, Puget aquifer, and the basement confining unit. • Goals were to describe geology, hydrogeology of aquifer systems, regional groundwater flow system and major hydrologic controls. • Water quality review included. • Review of bibliography included (First time review was conducted of entire area was in 1970s). • Thicknesses are highly variable, flow direction is generally horizontal within aquifer units and vertical within semi- confining and confining units. • Seasonal water level fluctuations of 1-10 ft are in uppermost aquifer and show rapid recharge. Deeper aquifers have fluctuations less than 4 ft and lag about three months in response to recharge. • Reports on hydraulic parameters, water budget parameters, model results.
KC DDES & SKCPH. 1995. <i>Mapping Aquifer Susceptibility to Contamination in King County.</i>	None Presented	<ul style="list-style-type: none"> • A few wells existed in the northeast portion of Snoqualmie Valley and eastern portions of East King County. 	<ul style="list-style-type: none"> • Provides information regarding methods to update map (groundwater quality concerns). • Presents metadata for development of criteria and maps.
Bauer, H. H. and M. C. Mastin .1997. <i>Recharge From Precipitation in Three Small Glacial-Till-Mantled Catchments in the Puget Sound Lowland, Washington</i>	None Presented	None Presented	<ul style="list-style-type: none"> • Water budgets computed for southern portion of Puget Sound to estimate groundwater recharge from precipitation through till. • Use of tritium for recharge rate estimation.

Notes:

***Main Geologic Units for King County**

Qb	bogs
Qal	alluvium
Vashon Stade	
Qvr	Vashon recessional outwash
Qvt	Vashon till
Qva	Vashon advance outwash
Qtb	Vashon transitional beds
Qvi	Vashon ice-contact deposits
Older Glacial and Nonglacial Deposits	
Qpf	pre-Fraser deposits pre-Vashon deposits
Qob	Olympia gravels
Qaf	pre-Vashon deposits upper fine grained unit
Qac	pre-Vashon deposits upper coarse grained unit
Qbf	pre-Vashon deposits lower fine grained unit
Qbc	pre-Vashon deposits lower coarse grained unit
Qc	pre-Vashon deposits deep undifferentiated unit
Bedrock	Tukwila Formation, Rattlesnake Mountain Formation

Abbreviations and Symbols

bgs	below ground surface
ft	feet
DTW	depth to water
GWMA	groundwater management area
MSL	mean sea level
<	less than
+	plus or more than

Appendix B

Additional References



EAST KING COUNTY

- Adolfson Associates, Inc. and GAIA Northwest, Inc. 1990. *Fall City Wastewater Facilities Plan: Draft Environmental Impact Statement*. November 1.
- AGI. 1996. *Production Well 11.1 Construction and Testing Report, Sammamish Plateau Water and Sewer District*. February.
- Aspect Consulting. 2002. *Beneficial Use of Ground Water Survey: Duvall Custodial Landfill, Duvall, Washington*. Prepared for King County Department of Natural Resources and Parks, Solid Waste Division. November 7.
- Associated Earth Sciences, Inc. 1990. *Hydrogeology and Pump Test Data: Proposed Snoqualmie Ridge North Valley Well Field, King County, Washington*. Prepared for Snoqualmie Ridge Associates. January 23.
- Carr/Associates. 1988. *Preston Industrial Park Water System: Wells 1 and 2 Pumping Test Report*. December 20.
- Carr/Associates. 1990. *Preston Industrial Park Water System: Wells Report on the Completion and Testing of Well 1R and Well 3*. January 15.
- CH2M Hill. 1992. *Snoqualmie and Issaquah Valley Aquifers Evaluation (Draft Report)*. Prepared for East King County Regional Water Association. December.
- CH2M Hill (In association with Carr/Associates). 1993. *Snoqualmie and Issaquah Valley Aquifers Evaluation (Final Report)*. Prepared for East King County Regional Water Association. February.
- CH2M Hill. 1994. *Final Report, Highline Well Field Aquifer Storage and Recovery Project*. August.
- Dragovich, J.D., Anderson, M.L., Walsh, T.J., Johnson, B.L., and T. L. Adams. 2007. *Geologic Map of the Fall City 7.5-minute Quadrangle, King County, Washington*. Washington Division of Geology and Earth Resources, GM-67. Scale 1:24,000. p 16.
- Eastside Consultants, Inc. 1983. *Carnation Research Farm: Water System Analysis*. January 16.
- Geoengineers. 1995. *Report of Hydrogeologic Services, South Well Field Characterization, Snoqualmie, Washington*. November.
- Golder Associates. 1993. *Snoqualmie Basin Groundwater Supply Evaluation: Geophysical Survey*. Prepared for East King County Regional Water Association. September 3.
- Hart Crowser. 1989. *Groundwater Explorations: Tolt Dam and Regulating Basin Area. Tolt Wellfield Project, King County, Washington*. Prepared for Seattle Water Department and CH2M Hill Northwest. February 21.
- King County Planning and Community Development Division. 1989. *Snoqualmie Valley Community Plan: Draft Environmental Impact Statement*. January 6.
- King County Planning and Community Development Division. 1989. *Snoqualmie Valley Community Plan*. September 15.

EAST KING COUNTY (continued)

- King County Department of Natural Resources and Parks, Water and Land Resources Division. 2004. *An Overview of the Geology and Geomorphology of the Snoqualmie River Watershed*. April
- Northwest Hydrogeo. 1995. *Additional field investigations, Ames Lake Water Association*. October.
- Northwest Hydrogeo. 1995. *Aquifer Test Report for Well No. 2 24-hour Pumping Test for Robert Smallwood, Blue Sky R.V. Park*. September.
- Northwest Hydrogeo. 1996. *Addendum to Aquifer Test Report for Well No. 2 24-hour Pumping Test*. Prepared for Robert Smallwood, Blue Sky R.V. Park. July.
- R. W. Beck and Associates. 1990. *Fall City: Draft Wastewater Facilities Plan*. August.
- R. W. Beck and Associates. 1990. *City of Carnation: Draft Wastewater Facilities Plan*. November.
- Robinson and Noble. 1979. *King County Water District #82, Construction and Testing, Well 5*. January.

EASTSIDE AND SAMMAMISH

- AGI. 1994. *Herzel Memorial Park Irrigation Well, Construction and Testing Report*. August.
- Booth, D.B. and J.P. Minard. 1992. *Geologic Map of the Issaquah 7.5' Quadrangle, King County, Washington*. U.S. Geological Survey, Miscellaneous Field Studies Map MF-2206. Scale 1:24000.
- Booth, D.B. and K. G. Troost. in preparation. *Geologic Map of the Kirkland and Redmond 7.5-minute Quadrangles, Washington*. U.S. Geological Survey Scientific Investigations Map.
- Booth, D.B., and K. G. Troost. in preparation. *Geologic Map of the Mercer Island and Issaquah 7.5-minute Quadrangles, Washington*. U.S. Geological Survey Scientific Investigations Map.
- Carr Associates. 1992. *Background and Update on Use and Performance of Sammamish Plateau Water and Sewer District Well 1R*. December.
- Carr Associates. 1992. *Production Well 9 Drilling and Completion Report, Sammamish Plateau Water and Sewer District*. November.
- Carr Associates. 1992. *Test Well PT-3 Completion and Testing Report, prepared for Sammamish Plateau Water and Sewer District*. September.
- Carr Associates. 1992. *Valley Test Well 7 (VT-7) Drilling and Completion report, Sammamish Plateau Water and Sewer District*. November.
- Carr Associates. 1992. *Valley Test Well 8 (VT-8) Drilling and Completion report, Sammamish Plateau Water and Sewer District*. November.
- Hart Crowser. 1993. *Groundwater Explorations, Woodinville Water District, Woodinville, Washington*. February.
- Hart Crowser. 1994. *District Production Well Report, Woodinville Water District, Woodinville*. June.

EASTSIDE AND SAMMAMISH (continued)

- Hart Crowser. 1994. *Wellington Production Well Report, Woodinville Water District, King County, Washington*. May.
- Jones Associates, Inc. 1978. *Issaquah Plateau Groundwater Study*. Prepared for Puget Sound Power and Light Company. July 14.
- King County Department of Natural Resources and Parks. 2007. *Exempt Wells in the Issaquah Creek Valley Groundwater Management Area*. Prepared by Ken Johnson. Water and Land Resources Division. Seattle, Washington. Final. November.
- Minard, J.P. 1983. *Geologic Map of the Kirkland Quadrangle, Washington*. U.S. Geological Survey Miscellaneous Field Studies Map MF-1543. Scale 1:24000.
- Minard, J.P. 1985. *Geologic Map of the Bothell Quadrangle, Snohomish and King Counties, Washington*. U.S. Geological Survey Miscellaneous Field Studies Map MF-1747. Scale 1:24000.
- Minard, J.P. and D. B. Booth. 1988. *Geologic Map of the Redmond Quadrangle, King County, Washington*. U.S. Geological Survey Miscellaneous Field Studies Map MF-2016. Scale 1:24000.
- RH2 Engineering, P. S. 1987. *Amendment to Comprehensive Wastewater Plan*. Prepared for Sammamish Plateau Water and Sewer District. October.
- RH2 Engineering, P. S. 1987. *Comprehensive Wastewater Plan: Pre-Design Report*. Prepared for Sammamish Plateau Water and Sewer District. September.
- Robinson and Noble. 1979. *King County Water District #82, Construction and Testing, Well 5*. January.
- Rongey/Associates Hydrogeology. 1990. *Hydrogeological Investigations for Water District No. 119 of King County*. Washington State Department of Ecology. 1991. *Snoqualmie River Low Flow Water quality Assessment: July – September 1989*. April.
- Rongey Associates. 1991. *Completion, Well No. 4, Tam-O-Shanter Golf and Country Club, Bellevue*. September.
- Rongey Associates. 1993. *Hydrogeological Investigation for the Echo Falls Country Club*. October.
- Troost, K.G. and Booth, D.B. in preparation, *Geologic Map of the Bothell 7.5' Quadrangle, Washington*. U.S. Geological Survey Miscellaneous Field Studies. Scale 1:24,000.
- SEATTLE AND NORTH**
- Booth, D. B., Troost, K. G, and S. A. Shimel, 2005, *Geologic Map of Northwestern Seattle (part of the Seattle North 7.5' X 15' Quadrangle), King County, Washington*. U.S. Geological Survey Scientific Investigations Map 2903, 1:12,000 [<http://pubs.usgs.gov/sim/2005/2903/>].
- Troost, K.G. and Booth, D.B. in preparation, *Geologic Map of the Seattle NE 7.5-minute Quadrangle, Washington*. U.S. Geological Survey Miscellaneous Field Studies. Scale 1:12,000.
- Troost, K.G. and Booth, D.B. in preparation, *Geologic Map of the Seattle NW 7.5-minute Quadrangle, Washington*. U.S. Geological Survey, Miscellaneous Field Studies Map. Scale 1:12,000.

SEATTLE AND NORTH (continued)

- Troost, K.G., and Booth, D.B. in preparation, *Geologic Map of the Seattle SE Quadrangle*. U.S. Geological Survey Miscellaneous Field Studies Map. Scale 1:12,000.
- Troost, K.G., Booth, D. B., Wisher, A.P., and S. A. Shimel, 2005, *The Geologic Map of Seattle - a progress report*. U.S. Geological Survey Open-File Report 2005-1252 [http://pubs.usgs.gov/of/2005/1252/]
- Troost, K.G., Booth, D.B., Shimel, S.A., and R. J. Blakely. in preparation. *Geologic Map of the Seattle SW 7.5-minute Quadrangle, Washington*. U.S. Geological Survey Miscellaneous Field Studies Map. Scale 1:12,000.)

SOUTH KING COUNTY

- Booth, Derek B. 1995. *Surficial Geologic Map of the Maple Valley Quadrangle, King County, Washington*. U.S. Geological Survey, Miscellaneous Field Studies Map MF-2297. Scale 1:24000.
- Booth, Derek B. and H. H. Waldron. 2004. *Geologic Map of the Des Moines 7.5' Quadrangle, King County, Washington*. U.S. Geological Survey Scientific Investigations Map 2855. Scale 1:24,000. [http://pubs.usgs.gov/sim/2004/2855).
- Brown and Caldwell, Municipality of Metropolitan Seattle, and TCW Associates, Inc. 1989. *Geohydrology Studies of the Metro Section 16 Silvigrow Project*. March.
- CH2M Hill. 1988. *Construction and Testing Report, Renton Well 5A*. May.
- City of Auburn Department of Public Works. 2000. *Draft Comprehensive Water System Plan: City of Auburn*.
- City of Black Diamond. ????. *Draft Comprehensive Water System Plan: City of Black Diamond*. Prepared by Penhallegon Associates Consulting Engineers, Inc.
- City of Black Diamond. 2000. *Final Comprehensive Water System Plan: City of Black Diamond*.
- City of Enumclaw. 1994. *1993 Comprehensive Water System Plan: City of Black Diamond*. Prepared by Hedges and Roth Engineering, Inc. May.
- City of Kent Department of Public Works. 1988. *Water System Plan for the City of Kent, Washington*. May.
- Covington Water District 1994. *Covington Water District Comprehensive Water System Plan*. Prepared by Hammond, Collier and Wade-Livingstone Associates, Inc. February.
- Geoengineers. 1986. *Report of Phase I Hydrogeologic Services, Test Well Installation, Maplewood Golf Course*. Prepared for the City of Renton. October.
- Geoengineers. 1994. *Production of Hydrogeologic Services, Production Well Testing, Webster Lakes Estates, Maple Valley, Washington*. October.
- Golder. 1990. *Installation and Testing of Water-Supply Wells, The Lakes, Kent Washington*. Prepared for Centron. April.

SOUTH KING COUNTY (continued)

- Grimstad, Peder. 1972. *A Geohydrologic Reconnaissance of North Fork Green River Area, King County, Washington*.
- Hart Crowser. 1990. *Lake Sawyer Hydrogeologic Study, Black Diamond, Washington*. October.
- Hong West. 1993. *Ravensdale Park Irrigation Well, Well Design and Testing Report*. September.
- King County Department of Natural Resources and Parks, Water and Land Resources Division and Washington State Conservation Commission. 2000. *Habitat Limiting Factors and Reconnaissance Assessment Report: Green/Duwamish and Central Puget Sound Watershed (Water Resource Inventory Area 9 and Vashon Island)*. December.
- King County Department of Natural Resources and Parks, Water and Land Resources Division. 2002. *Green – Duwamish Watershed Water Quality Assessment Comprehensive Monitoring Program, Sampling and Analysis Plan*. May 30.
- King County Department of Natural Resources and Parks, Water and Land Resources Division. 2004. *Green-Duwamish Watershed Water Temperature Report: An Assessment of Surface Water Temperature Conditions*. Prepared by Taylor Associates, Inc. and King County Water and Land Resources Division. June.
- Kleinfelder. 1995. *Phase I Water Resources Feasibility Investigations, City of Enumclaw, Washington*. July.
- Liesch, B. A. 1955. *Records of Wells, Water Levels, and Quality of Ground Water in the Sammamish Lake Area, King County, Washington*. Open File Report. Prepared by United States Geological Survey - Water Resources Division, Ground Water Branch p 241. February.
- Luzier, J. E. 1969. *Geology and Ground-Water Resources of Southwestern King County, Washington*. Water Supply Bulletin No. 28. Prepared by State of Washington Department of Water Resources in cooperation with United States Geological Survey Ground-Water Division. p 51.
- Mullineaux, D.R. 1965. *Geologic Map of the Auburn Quadrangle, King and Pierce Counties, Washington*. U.S. Geological Survey Geologic Quadrangle Map GQ-406. Scale 1:24000.
- Mullineaux, D.R. 1965. *Geologic Map of the Black Diamond Quadrangle, King County, Washington*. U.S. Geological Survey Geologic Quadrangle Map GQ-407. Scale 1:24000.
- Mullineaux, D.R. 1965. *Geologic Map of the Renton Quadrangle, King County, Washington*. U.S. Geological Survey Geologic Quadrangle Map GQ-405. Scale 1:24000.
- Northwest Hydraulics Consultants, Inc. 2005. *Assessment of Current Water Quantity Conditions in the Green River Basin*. Prepared for the WRIA 9 Steering Committee. September.
- Pacific Groundwater Group. 1990. *Final Hydrogeologic Report, Maplewood Production Wells PW-11 and PW-17, City of Renton*. January.
- Pacific Groundwater Group. 1992. *Well 25 Pilot Recharge Study, Results of Baseline Monitoring and Short-Term Injection Testing: A Technical Reference Document*. September.

SOUTH KING COUNTY (continued)

- Pacific Groundwater Group. 1999. *1999 Hydrogeologic Characterization Report: City of Auburn: Volume I*. October.
- Robinson and Noble. 1979. *Preliminary Groundwater Study for King County Water District 105*. May.
- Robinson and Noble. 1979. *Well 20 and 20A Construction and Testing for the King County Water District 124*. June.
- Robinson and Noble. 1984. *Construction of Well 4 (Deep) for King County Water District 124*. July.
- Robinson and Noble. 1984. *Construction of Well 4A for King County Water District 124*. September.
- Robinson and Noble. 1987. *Construction Report for Site 19 Well Field, Federal Way Water and Sewer District*. June.
- Robinson and Noble. 1989. *Federal Way Water and Sewer, Well 25, Construction Report*. February.
- Robinson and Noble. 1990. *Federal Way Water and Sewer District Report of Test Drilling, Well 17T*. June.
- Robinson and Noble. 1991. *Federal Way Water and Sewer District, Production Well 17B Construction Report*. May.
- Robinson and Noble. 1991. *Lake Sawyer Well Field Well F, Covington Water District*. June.
- Robinson and Noble. 1992. *Hydrogeologic Analysis of the Federal Way Area, Washington. Volume 1*. December.
- Robinson, Roberts and Associates. 1969. *Geohydrologic Investigation of the North Fork of Green River Valley*. March.
- Robinson, Roberts and Associates. 1970. *Results of Additional Studies on the Groundwater Underflow of the North Fork of the Green River*. April.
- Shamir, Uri. 1981. *The South Tacoma Aquifer as a Supplementary Water Source*. October.
- Smith, Mackey. 1977. *Geologic Map of the City of Tacoma, Pierce County, Washington*. Washington Division of Geology and Earth Resources Open File Report 77-9. Scale 1:24000.
- Soos Creek Water and Sewer District. 1996. *1996 Soos Creek Water Comprehensive Plan*. Prepared by Hedges and Roth Engineering, Inc. May 28.
- Tacoma Water/Tacoma Public Utilities. 2001. *Tacoma Water Habitat Conservation Plan: Green River Water Supply Operations and Watershed Protection-Final: Volume 1 of 2*. July.
- Tacoma Water/Tacoma Public Utilities. 2001. *Tacoma Water Habitat Conservation Plan: Green River Water Supply Operations and Watershed Protection-Final: Volume 2 of 2*. July.
- Troost, K.G. in preparation. *Geologic Map of the Puyallup 7.5-minute Quadrangle, Washington*. U.S. Geological Survey Open-File Report. Scale 1:24,000. (submitted).

SOUTH KING COUNTY (continued)

- Troost, K.G. in preparation, *Geologic Map of the Tacoma South 7.5-minute Quadrangle, Washington*. U.S. Geological Survey Open-File Report. Scale 1:24,000.
- Troost, K.G., and D. B. Booth. in preparation, *Geologic Map of the Tacoma North 7.5-minute Quadrangle, Washington*. U.S. Geological Survey, Open-File Report. Scale 1:24,000.
- U. S. Fish and Wildlife Service National Marine Fisheries Service. 2000. *Final Environmental Impact Statement: For the Proposed Issuance of a Multiple Species Incidental Take Permit for the Tacoma Water Habitat Conservation Plan, Green River Water Supply Operators and Watershed Protection, King County, Washington: Volume I*. Prepared for U. S. Department of Interior Fish and Wildlife Service and the U. S. Department of Commerce National Marine Fisheries Services. Prepared by Tacoma Water/Tacoma Public Utilities and Adolfson Associates, Inc. December.
- U. S. Fish and Wildlife Service National Marine Fisheries Service. 2000. *Final Environmental Impact Statement: For the Proposed Issuance of a Multiple Species Incidental Take Permit for the Tacoma Water Habitat Conservation Plan, Green River Water Supply Operators and Watershed Protection, King County, Washington: Volume II*. Prepared for U. S. Department of Interior Fish and Wildlife Service and the U. S. Department of Commerce National Marine Fisheries Services. Prepared by Tacoma Water/Tacoma Public Utilities and Adolfson Associates, Inc. December.
- Waldron, H.H. 1962., *Geology of the Des Moines Quadrangle, Washington*. U.S. Geological Survey, Geologic Quadrangle Map GQ-159. Scale 1:24000.
- Walsh, T.J., 1987, *Geologic Map of the South Half of the Tacoma Quadrangle, Washington*. Washington Division of Geology and Earth Resources, Open File Report 87-3. Scale 1:100000.
- Washington State Department of Ecology. 1989. *Green River Fish Habitat Analysis using the Instream Flow Incremental Methodology: IFIM Technical Bulletin*. July.
- Washington State Department of Ecology. 1995. *Final Amended: Initial Watershed Assessment, Water Resources Inventory Area 9, Green-Duwamish Watershed*. Prepared by Ecology Northwest Regional Office (Water Resources Program), Science Applications International Corporation, Shapiro and Associates, Taylor Associates, and Environmental Systems Research Institute. November 22.
- Washington State Department of Ecology. 1995. *Draft Initial Watershed Assessment: Water Resources Inventory Areas 10: Puyallup-White Watershed. Open-File Technical Report 95-08*. Prepared by Washington State Department of Ecology Southwest Regional Office Water Resources Program; Science Applications International Corporation, Shapiro and Associates, Taylor Associates, and Environmental Systems Research Institute. March 15.
- Washington State Department of Ecology. 1995. *Final Amended Initial Watershed Assessment: Water Resources Inventory Area 9: Green-Duwamish Watershed. Open-File Technical Report 95-01*. Prepared by Washington State Department of Ecology Northwest Regional Office Water Resources Program; Science Applications International Corporation, Shapiro and Associates, Taylor Associates, and Environmental Systems Research Institute. January 22.
- Water District No. 111 of King County. 1998. *1997 Water System Comprehensive Plan*. Prepared by Hedges and Roth Engineering, Inc. May 8.

REGION-WIDE DOCUMENTS

- Alexander, D., and R.N. Palmer (Alexander et al.). 2007. Technical Memorandum #8: *Impacts of Climate Change on Groundwater Resources- A Literature Review*. Prepared by the Climate Change Technical Subcommittee of the Regional Water Supply Planning Process, Seattle, WA. December 13. [[http://www.govlink.org/regional-water-planning/tech-committees/climate-change/UWreports/TechMemo8\(12-13-07\).pdf](http://www.govlink.org/regional-water-planning/tech-committees/climate-change/UWreports/TechMemo8(12-13-07).pdf)]
- Boland, J. J. and B. K. Boland (Boland et al.). 2008. *Central Puget Sound Water Suppliers' Forum Independent Review of Water Demand Forecast Model: Final Report*. June 9. [<http://www.govlink.org/regional-water-planning/docs/FinalReport.pdf>]
- Booth, D. B. and K. G. Troost. 2005. *Geologic Map of the Olalla 7.5' Quadrangle, King, Kitsap, and Pierce Counties, Washington*. U.S. Geological Survey Scientific Investigations Map 2902. 1:24,000. [<http://pubs.usgs.gov/sim/2005/2902/>].
- Booth, Derek B. and A. P. Wisher. 2006. *Geologic Map of King County, Washington*. Scale 1:100,000. [http://geomapnw.ess.washington.edu/services/publications/map/data/KingCo_composite.pdf].
- CDM. 2008. *Central Puget Sound Regional Water Supply Outlook: Water Demand Forecast*. Technical Appendix (Draft Report). April 7.
- Central Puget Sound Water Suppliers Forum and R. W. Beck (CPSWSF et al.). 2001. *2001 Central Puget Sound Regional Water Supply Outlook*. Prepared in association with Daily Environmental and Economic and Engineering Services, Inc. July. [<http://cpswatersuppliersforum.org/Outlook/outlookcomplete/title.pdf>]
- Keta Waters, Inc. 2006. *Phase II, Task 2 Hydrogeologic Investigation Feasibility Report for LOTT Alliance*. November 26.
- Keta Waters. 2008. *Improving The Quality and Quantity of In-stream Habitat by Resting Groundwater Extraction Wells*. Prepared in association with Aspect Consulting, RH2 Engineering, Inc., and A. Slavery. Prepared for King County Regional Water Supply Planning Process; Tributary Streamflow Technical Committee. May. [<http://www.govlink.org/regional-water-planning/docs/groundwater-extraction-well-report/RestingGWWellsFinalReport.pdf>]
- King County Conservation District. 1991. *Issue Paper: Agricultural Chemicals – BMPs and Ground Water Quality*. Prepared for King County Ground Water Management Areas. April.
- King County Department of Natural Resources and Parks. 2002. *Estimating the Impacts of Water Management Activities on Water Budgets within Sub-basins in King County, Washington*. Draft version, not finished. August.
- Konrad, Christopher P. and D. Booth. 2002. *Hydrologic Trends Associated with Urban Development for Selected Streams in the Puget Sound Basin, Western Washington*. U. S. Geological Survey Water-Resources Investigations Report 02-4040. Prepared in cooperation with the Washington State Department of Ecology.
- Minard, J.P. 1985. *Geologic Map of the Snohomish Quadrangle, Snohomish County, Washington*. US. Geological Survey Miscellaneous Field Studies Map MF-1745. Scale 1:24,000.

REGION-WIDE DOCUMENTS (continued)

Morgan, David S. and J. L. Jones. 1995. *Numerical Model Analysis of the Effects of Ground-Water Withdrawals on Discharge to Streams and Springs in Small Basins Typical of the Puget Sound Lowland, Washington*. U.S. Geological Survey Open-File Report 95-470

Richardson, Donald, J. W. Bingham and R. J. Madison. 1968. *Water Resources of King County, Washington: With a Section on Sediment in Streams by R. C. Williams*. U. S. Geological Survey Water-Supply Paper 1852. Prepared in cooperation with the Board of King County Commissioners. p 74.

Source Exchange Committee, King County. 2007. *Committee Report: Regional Water Supply Planning Process*. November 30.

Washington State Office of the Governor's Water Advisor. 2003. *Central Puget Sound Regional Water Initiative: Regional Water Resource Management*. Prepared from Jim Waldo. April.