TECHNICAL BRIEFING DOCUMENT
ON

HYDROGEOLOGIC INVESTIGATIONS
IN THE
UPPER SNOQUALMIE BASIN

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On behalf of:

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Permit Application G1-27834

January 17, 1996

933-1306.012
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1. INTRODUCTION

This briefing document has been prepared as a supplement to a presentation to the Washington Department of Ecology on hydrogeologic investigations in the Upper Snoqualmie Basin. These investigations have been conducted by Golder Associates Inc. on behalf of the East King County Regional Water Association since 1993. The objectives of the investigations have been focused on identifying hydrogeologic conditions and evaluating the potential for a regional groundwater supply from the Upper Snoqualmie Basin.

Hydrogeologic and geologic studies have been conducted in the upper Snoqualmie Basin for many years by academic, private, and government interests. Recent notable studies include a USGS study of the East King County Groundwater Management Area (USGS, 1995), a Draft Initial Watershed Assessment for Water Resources Inventory Area 7 (Ecology Open-file Technical Report 95-06, 1995) and consultant studies in the area around Snoqualmie and Snoqualmie Falls.

The Upper Snoqualmie Basin occupies a drainage basing of approximately 375 square miles above Snoqualmie Falls. And constitutes a sub-basin of the Snohomish drainage basin, which occupies approximately 1,250 square miles. The Upper Snoqualmie Basin is further sub-divided into three sub-basins - North Fork, Middle Fork and South Fork.

The potential for a groundwater supply in the Snoqualmie Basin has been recognized for many years, and recent studies by the USGS and the Ecology Watershed Assessment recognize that only a very small portion of the predicted groundwater in the Snohomish Basin is utilized for water supply.

The remainder of this document summarizes the basic hydrogeologic data collected and analyzed as part of the regional groundwater investigation of the Upper Snoqualmie Basin. For the purpose of this briefing, an attempt has been made to concisely summarize the key data and hydrogeologic controls. Additionally, a basin-scale perspective is pursued, supported by detailed site specific analyses as appropriate. The magnitude of the proposed groundwater withdrawal is recognized to be significant. The intent of this briefing is to provide data, analyses, and interpretations from which Ecology technical and regulatory staff can actively participate in developing the needed information to process a water right.

2. MIDDLE FORK BASIN - DEEP AQUIFER

The principal aquifer identified as a possible regional groundwater supply is referred to as the Middle Fork Deep Aquifer. The presence of the aquifer was confirmed by a test well installed in 1994. This section summarizes geologic conditions based on existing and newly collected data.

2.1 1994 Test well TW-1

A test well was installed in 1994 to confirm the presence of a productive aquifer in the upper reaches of the Snoqualmie Basin. The location of the well was selected based on an extensive geophysical survey which suggested regionally continuous deposits of sediments having favorable water-supply potential. The location of the well is shown on Figure 1. The well was drilled to a depth of 360 feet and encountered an upper aquifer to a depth of 109 feet, a very dense silty gravel between 109 and 207, a highly productive, very coarse, confined aquifer between 207 and 350, and a fine sand and silt at the base of the aquifer. The well log for the well is included in Appendix A. The geologic interpretation of this sequence is:

1. Upper Aquifer: Vashon Recessional deposits
2. Confining layer: Vashon Till, assumed to be regionally continuous,
3. Deep Aquifer : pre-Vashon, (Olympian) gravels, consistent with the Q(A)c aquifer described by the USGS.
4. Basal Silt : pre-Vashon Lacustrine material

The well was completed at 6-inch diameter with 60 feet of screen placed at intervals between 246 and 340 feet. An observation well was installed in a shallow water-bearing zone adjacent to the test well. A 72-hour pumping test was conducted at a rate of 1,500 gpm and stabilization of water-levels was observed. The pumping test hydrograph is presented in Appendix A. The production from the well is excellent, particularly since it is only a 6-inch diameter well. A high capacity production well yielding up to 3,500 gpm is possible at this location. The transmissivity of the aquifer is estimated at 21,400 ft^2/day (160,000 gpd/ft). No leakage through the till was observed in the pumping test response, but two boundary effects were observed:

- A barrier boundary caused by bedrock along the valley margin; and
- A recharge boundary caused by one or more of the following:
    1. Gravity drainage/leakage from an unconfined aquifer beneath the Middle Fork Embankment.
    2. Leakage from underlying sediments.
    3. Direct infiltration from the Middle Fork Snoqualmie River, upstream of the wellsite

Water quality from the well is excellent and suitable for municipal purposes.
The results of the test well and aquifer test formed the basis for further investigations in the area during 1995.

2.2 Test Well TW-2 (Middle Fork Embankment)

This well is located on the flanks of the Middle Fork Embankment (elevation 1,080). The location of the well is shown on Figure 1. The Middle Fork Embankment is a glacial delta-moraine, deposited during the maximum extent of the Vashon glaciation. The Middle Fork embankment is one of several embankments in the Snoqualmie and Skykomish basins that mark the maximum extent of the Puget Lobe. The surface of the Embankment consists of very coarse sand and gravel with virtually no surface drainage. Even during heavy precipitation there is little ponding or surface flow of water on the Embankment. Thus, these Embankments represent very significant recharge areas to aquifers. Following from the observed recharge boundary in the pumping test of TW-1, the principal objective of the test well was to determine the extent and properties of the deep aquifer beneath this major recharge area.

The well encountered three distinct water-bearing intervals, separated by less permeable materials:

1. An upper most perched aquifer is present at a depth of 140 feet. Silty gravel, cobbles, fine sand, and clayey silt are present beneath the perched aquifer.

2. An upper unconfined aquifer exists between 280 and 400 feet below ground. Water-levels during drilling remained relatively constant at about 280 feet. Between 400 and 480 feet, layers of compact silty gravel, laminated silt and clay, and stiff organic clay are present. No water was encountered during drilling in these materials.

3. A deeper confined aquifer is present between depths of 480 and 700 feet. Water-levels in this aquifer remained stable at about 328 feet below ground, indicating a downward hydraulic gradient from the upper unconfined aquifer to the confined aquifer. Thus the confined aquifer is recharged by leakage from the unconfined aquifer. Aquifer materials become more fine-grained with depth, grading to a uniform fine to medium sand between 520 and 665 feet. Below 665 feet, the aquifer materials grade to a silty sand and become predominantly silt at a depth of 700 feet.

A wood sample was obtained at a depth of 477 feet (just above the deep aquifer) and submitted for Carbon-14 dating. A date of 38,630 years BP was determined. This age date clearly places the deep aquifer as a pre-Vashon deposit, consistent with Q(A)c materials described by the USGS and the “Olympia Gravel Aquifer” described in the Snohomish Basin Assessment (Ecology, 1995).

The well log for the well is included in Appendix A. The well was completed with 10 feet of 100-slot well screen between 502 and 512 feet. A 24-hour pumping test was performed on TW-2 at a pumping rate of 360 gpm. The pumping test hydrograph is presented in Appendix A. Neglecting partial penetration effects, a transmissivity of about 5,000 ft2/day is estimated. This is lower than the transmissivity observed at well TW-1, but is a lower bound because of limitation in the interpretation of the test (e.g. partial penetration). Based on grain size, however, the transmissivity of the aquifer does appear to decrease up-valley of well TW-1. A higher capacity well could be installed at this location by screening the entire aquifer and installing a larger diameter well.

2.3 Observation Well OB-3

Observation well OB-3 is located upstream of the Middle Fork Embankment. The location of the well is shown on Figure 1. The objective of this well was to identify sources of recharge up-valley of the Middle Fork Embankment. The well was drilled to a total depth of 400 feet without encountering bedrock. Flowing artesian conditions were encountered at a depth of 180 feet in a fine to medium sand. Alternating layers of fine sand, silt and clay were encountered to the final depth of the borehole. The well was completed with a 2-inch piezometer at a depth of 190 feet. Water-level upon completion of the well was approximately 42 feet above ground surface. The well log for the well is included in Appendix A.

A pressure recovery test on the well indicates a permeability of between 2 and 5 feet per day. The recovery test hydrograph is presented in Appendix A. Analyses were carried out using a Theis recovery method, and a slug test analysis.

The flowing artesian conditions encountered in OB-3 indicate that the source of recharge to the aquifer zone is at a significantly higher elevation. Elevated terraces exist along the flanks of the valley near the well. Recharge to the aquifer zone is interpreted to originate in these upland areas. This is supported by subsequent water-level monitoring which shows direct correlation between precipitation events and water-level changes. The permeability of the aquifer zone is significantly lower than aquifer materials farther downvalley. This allows a gradual build-up of hydraulic head, rather than rapid decay of hydraulic head as observed in the Embankment materials.

2.4 Other Deep Wells

Deep wells in the lower portions of the valley, near Snoqualmie Falls, have been described by others. These wells are characterized as pre-Vashon Q(A)c by the USGS and have similar geologic characteristics to the Middle Fork test wells. Thus, the confined aquifer in the upper portions of the basin appears to be continuous with the deep wells located near Snoqualmie Falls, though the permeability of the aquifer is significantly higher in the upper portions of the basin.

Although no pre-Vashon, Q(A)c, well completions were identified in the upper portions of the basin in the USGS study, further review of well logs suggests that there are potentially two wells that may have penetrated into the very upper portions of the confined aquifer. These two wells are the Camp Waskowitz well and the Rogers Well (Ken’s Truck Stop). Further monitoring of water-levels is required to confirm this interpretation, but a maximum of 7 wells are completed in the deep confined aquifer of the upper Snoqualmie Basin, five in the lower reaches and two in the upper reaches.

Figures 2 and 3 show generalized geologic cross-sections through the Middle Fork Embankment (Figure 2) and along the entire axis of the Upper Snoqualmie valley (Figure 3). Table 2 summarizes aquifer properties of the deep aquifer in the Upper Snoqualmie basin.

2.5 Hydraulic Continuity - Geologic Perspective

From a geologic standpoint, the deep aquifer of the Middle Fork Aquifer system can be considered to have a relatively low degree of hydraulic continuity with surface water because of:

1. The presence of a regionally extensive overlying aquitard (Vashon Till).

2. The Pre-Vashon (Olympian) age of the aquifer, which would indicate that discharge from the aquifer will tend to remain in the deeper portions of the geologic section, separated by overlying stratified deposits and till, and hydraulically separate from stream/aquifer interactions.

3. Water-levels in the deep aquifer near Snoqualmie Falls are more than 100 feet below the elevation of the falls, indicating that the deep aquifer does not discharge to the Snoqualmie River above Snoqualmie Falls.

This interpretation of low hydraulic continuity is consistent with recent Snohomish Basin Assessment (Ecology, 1995) which recognizes that “hydraulic continuity between the Olympia Gravel aquifer and local surface water is likely low to moderate due to its depth and the presence of overlying aquitards”.

3. MIDDLE FORK BASIN - SHALLOW AQUIFER

There are a number of community and domestic water systems registered with Washington Department of Health (WDOH) in the Upper Snoqualmie Basin which obtain groundwater from shallow aquifers and springs. There are also a number of domestic or other wells not registered as community water systems. The upper aquifer is variable in composition and is on the order of 60 to 100 feet thick. Wells in the upper aquifer encounter a variety of glacial materials and have a wide range of estimated hydraulic properties.

A program of monitoring of the upper aquifer has not yet been undertaken, but based on well log information, a map of the shallow groundwater table has been constructed. A fairly uniform hydraulic gradient is observed from the Embankment areas to the North Bend/Tanner area. The gradient then flattens considerably through the North Bend/Snoqualmie area and then steepens again in the vicinity of Snoqualmie Falls. The flattening of the hydraulic gradient in the North Bend/Snoqualmie area is interpreted to be caused by a the presence of coarse grained aquifer materials associated with the confluence of the North Fork Snoqualmie valley and additional groundwater flux from this area.

Water-levels in the shallow aquifer are generally consistent with river elevations and suggest shallow groundwater discharge (e.g. direct hydraulic continuity) to the surface water. The magnitude of shallow groundwater discharge to surface water in the upper reaches of the basin (up-valley of North Bend) is, however, quite low, based on seepage runs conducted by the USGS. The magnitude of groundwater discharge to the main stem of the Snoqualmie River in the lower portions of the basin (downstream of North Bend) appear to be greater, but, as a proportion of flow over Snoqualmie Falls, is also quite low. This is discussed in the following sections.

4. UPPER SNOQUALMIE BASIN - HYDROLOGIC ANALYSIS

4.1 Precipitation Monitoring - Grouse Ridge

Isohyetal maps of precipitation in the Upper Snoqualmie Basin (Ecology, 1995) indicate substantial amounts of precipitation in the basin. In the Middle Fork sub-basin, the maps indicate up to 180 inches of precipitation annually.

A precipitation gage has been established on Grouse Ridge (elevation 1,600 feet) to monitor precipitation at a similar elevation and geographic location to the recharge areas of the Middle Fork aquifer system. Precipitation at Snoqualmie Falls (elevation 400 feet) is sufficiently lower than the recharge embankments of the aquifer, and data from higher elevations is considered more appropriate for estimating recharge. The results of this monitoring have been used to correlate with precipitation records at Cedar Lake (elevation 1,200) dating back to 1931. Figure 4 shows annual precipitation at Cedar Lake since 1931. Mean annual precipitation at Cedar Lake over the period of record is 102 inches. Figure 5 shows mean monthly precipitation based on the period of record, ranging from over 14 inches in December to less than 3 inches in July.

Based on one year of monitoring at Grouse Ridge, precipitation is about 80% of the precipitation at Cedar Lake, for a mean annual precipitation of about 80 inches. This is somewhat surprising, given the elevation difference, but illustrates the variability in the distribution of precipitation along the flanks of the Cascade range. In analyses requiring precipitation input (e.g. groundwater modeling), a value of 80% of the precipitation at Cedar Lake has been used. This is considered conservative in terms of water availability. The correlation between precipitation at Grouse Ridge and Cedar Lake is presented in Appendix A.

Assuming an average evapotranspiration of 23 inches per year (Ecology, 1995), mean annual available recharge to the Upper Snoqualmie Embankments (assuming no run-off) could be as high as 58 inches annually. This amount is in excess of 35 cfs total direct recharge to the permeable deposits in the Middle Fork sub-basin alone. A more conservative estimate of 50 inches annually has been used in quantitative analyses.

4.2 Stream Gaging (USGS)

A series of four seepage runs were conducted during the summer of 1995 on the Middle Fork Snoqualmie by the USGS. Five stations were established on the Middle Fork Snoqualmie between the upstream bridge at Granite Creek and the downstream bridge at Tanner. Measurements were taken on July 25, August 28, September 7, and September 26. Flows in the river were less than 400 cfs. Manual gaging could not be conducted at higher flows. The change in flow between stations is, in general, within the range of uncertainty associated with manual stream gaging. Although a definitive interpretation of the data is not strictly valid, the results indicate that no significant inflows or outflows to the river are present. The river reach adjacent to the Middle Fork Embankment appears to show a consistent increase in flow of approximately 7 cfs (Figure 6). This represents less than 4% of the observed flow in the river. Thus, groundwater baseflow is not a significant source of streamflow in the Middle Fork Snoqualmie, nor is streamflow a significant source of recharge to the aquifer.

4.3 Streamflow Analysis

Streamflows in the Upper Snoqualmie River and its tributary forks show a distinct responses to climatic and hydrologic conditions in the basin. Mean monthly streamflows show two distinct peaks - one during the winter (November-January) and a second during the spring (April - June). The winter peak is the result of high rainfall and the spring peak is the result of melting of the Cascade snowpack. Low flows are observed during August and September. Figure 7 shows the mean monthly streamflow on the Middle Fork Snoqualmie for 1995, and for a ten year period between 1961 and 1971. Figure 8 shows the mean monthly flow at Snoqualmie Falls over the period of record, along with the minimum instream flow requirement for each month. Instream flows are set at two-week intervals and the lower of the two is shown on the figure. Additionally, Figure 8 shows the 90-percentile mean monthly flow, which is a mean monthly flow that would occur once in ten years, based on the period of record.

Hydrologic assessments of streamflow in the Snohomish/Upper Snoqualmie Basins have been conducted by Ecology in the recent Basin Assessment (Ecology, 1995). It was concluded that total annual streamflow in the Snoqualmie was declining, possibly reflecting changes in land-use or water withdrawals. Inherent limitations in the data were recognized, emphasizing that conclusions should be drawn with caution. A subsequent analysis by Dr. Stephen J. Burgess, professor of hydrology at the University of Washington, suggests that limitations in the data do not support a conclusion of declining flows in the basin. This is primarily because the approach was highly dependent on the available precipitation record, which is both limited and extremely variable in the Basin. Dr. Burgess' analysis is presented in Appendix B. Dr. Burgess concludes that measured annual run-off (e.g. streamflow) in unregulated parts of the Basin reflects natural climatically-driven variability and that a recognition of the high degree of natural variability in the Basin is necessary in hydrologic assessments.

Further analysis of streamflow records in the Upper Snoqualmie basin has been carried out on a mean monthly basis, using data from USGS stream gages on the North Fork Snoqualmie (121430), Middle Fork Snoqualmie (121413), South Fork Snoqualmie (12144) and Snoqualmie Falls (12145). Each gage has a different period of record, but there is a period between 1961 and 1971 when all gages were operational. Observations and interpretations from these data are summarized below:

1. Since 1968, 18 mean monthly flows of less than 700 cfs have been observed at Snoqualmie Falls. Each of these observed low flow events has also been observed on the Middle Fork Snoqualmie gage, in the far upper reaches of the Basin, as a flow of less than 300 cfs (Figure 9). Thus, even at low flows, climatic and other hydrologic factors in the upper reaches of the Basin are the principal factors controlling historical streamflow at Snoqualmie Falls.

2. Minimum instream flow requirements at Snoqualmie Falls are set lower than the average naturally-occurring mean monthly flow for all months, being close to the mean August flow.

3. Minimum instream flow requirements at Snoqualmie Falls are set higher than a naturally-occurring mean monthly flow that would occur 1 in every 10 years during July, August, September or October.

4. For the period 1961 to 1971, the sum of mean monthly streamflows from the Forks of the Snoqualmie are consistently lower than the observed flow over Snoqualmie Falls (Figure 10). This suggests that groundwater discharge provides a portion of the flow over the falls. The magnitude of this mean monthly baseflow is estimated at about 50 to 60 cfs, based on the difference between observed mean monthly flows on the three forks versus flows over Snoqualmie Falls and in August and September. Higher baseflows are predicted during other months of the year, but variability in surface run-off and the sensitivity of gaging measurements during high flows likely account for much of the observed difference.

5. The percentage of observed mean monthly flow over Snoqualmie Falls attributed to groundwater baseflow can be plotted (Figure 11) and shows that, at all times, groundwater baseflow is less than 10 percent of the observed mean monthly streamflow over Snoqualmie Falls. During the summer/fall low flow months (July - October) groundwater baseflow accounts for less than 6 percent of the observed mean monthly flow over Snoqualmie Falls.

4.4 Groundwater-Level Monitoring

Observation of groundwater levels provides further insight into hydrogeologic conditions of the deep confined aquifer.

Water-levels in test well TW-1 has been monitored continuously using pressure transducers since January 31, 1995. Water-levels peaked during the first month of March and declined steadily throughout the spring, summer, and fall. Water-levels began to increase slowly in late October, and increased sharply during the high precipitation events in early November, 1995. A comparison of water-levels versus cumulative precipitation (Figure 12) clearly shows that the decay of water-levels is associated with a change in the rate of cumulative precipitation increase. The response of the aquifer does not correlate well with the observed streamflows in the Middle Fork Snoqualmie (Figure 13). There is a secondary correlation only because streamflow is correlated to precipitation. The lack of a response to spring melt streamflow in the Snoqualmie is an indication that the Middle Fork Snoqualmie is not a significant source of recharge to the deep aquifer.

Water level monitoring of well TW-2 on the Middle Fork Embankment indicates that precipitation recharge is transmitted rapidly downward to the water table (Figure 14). Similarly, water-levels up-valley of the Embankment in well OB-3 (Figure 15) also respond to precipitation.
Water-level monitoring in the deep aquifer near Snoqualmie Falls is summarized on Figures 16 and 17, and show that water levels are more than 100 feet lower than the elevation of the Falls. Therefore, the deep aquifer does not provide recharge to the Snoqualmie River at this location. Fluctuations in the deep aquifer near Snoqualmie Falls are similar to those observed in the upper portion of the aquifer at TW-1. Water-levels peak in March and reach a minimum in September or October. This response further indicates the continuity of the aquifer and its lack of a hydraulic connection with surface waters and associated spring run-off. The magnitude of the fluctuation is on the order of 4 feet in the lower portion of the aquifer, compared with 20 feet in the upper portion of the aquifer. This type of relationship would be expected in a confined system driven by upstream recharge, where the driving “pulse” of winter recharge decays with distance downgradient.

4.5 Hydraulic Continuity - Hydrologic Perspective

From a hydrologic perspective, the deep aquifer of the Middle Fork Aquifer system can be considered to have a relatively low degree of hydraulic continuity because:

1. The Middle Fork Snoqualmie is not a source of recharge to the Middle Fork aquifer. If it were, a water-level response would be expected during spring run-off and streamflow losses would be observed in the seepage runs.

2. Water-level fluctuations in the deep aquifer near Snoqualmie Falls show a similar pattern to those in the upper reaches of the basin, suggesting continuity of the aquifer and effective downgradient transmission of the recharge pulse that occurs during the winter months.

3. The Middle Fork Snoqualmie receives a very small amount of groundwater baseflow in reaches above Tanner, estimated at 7 cfs or 4% of the summer low flow. Thus, groundwater baseflow is not a significant source of streamflow in the Middle Fork Snoqualmie.

4. Total baseflow discharge to Snoqualmie Falls is estimated to be, on average, less than 6% of the observed mean monthly low flows over the Falls. Thus, groundwater baseflow is not a significant source of streamflow to Snoqualmie Falls. Given the high degree of natural variability in run-off in the basin, groundwater is not a significant control on the observed flows at Snoqualmie Falls.

5. GROUNDWATER MODELING

A MODFLOW model has been constructed that extends from the Middle Fork Embankment to Snoqualmie Falls. Significant new data from the City of North Bend's recent well and Puget Western/City of Snoqualmie groundwater model have not yet been incorporated and model results are not presented in this briefing. The model simulates shallow and deep aquifer systems, is transient with variable recharge occurring on a monthly time step; and accounts for groundwater discharge to streams. At this stage, the model is not intended to be used to support a final water-rights application nor to predict specific impacts. It is a tool that we are using to evaluate aquifer behavior under a range of conditions, a means to test and support our conceptual understanding of the system, and a tool to evaluate possible operation scenarios for a wellfield and to describe possible impacts to the aquifer system resulting from wellfield operation.

Preliminary runs of the model have been used to determine groundwater availability, estimate wellfield yield, and to evaluate potential impacts and possible mitigation strategies. The model correctly predicts water-levels in well TW-1 and simulates the observed discharge to the Middle Fork Snoqualmie, and uses recharge and aquifer properties that are consistent with the available data.

The preliminary modeling indicates the following:

1. The Middle Fork aquifer above North Bend is capable of supporting a year-round 20 MGD groundwater withdrawal using 4 to 6 high-capacity wells. An additional 5 to 10 MGD could possibly be developed by using more wells, lower pumping rates, and varied well locations. The most efficient configuration of wells has not yet been determined.

2. The source of water to the wells is a combination of direct recharge to the deep aquifer on the Embankment, leakage from the overlying shallow aquifer, and naturally occurring aquifer storage which results from the variable recharge. All of the water pumped from the deep aquifer originates from the subsurface and no direct infiltration of surface water results from pumpage. Lowering of water-levels in the upper aquifer causes a minor reduction in groundwater baseflow to the Middle Fork Snoqualmie.

3. Mitigation strategies such as artificial recharge and direct augmentation of streamflows will be considered in the final design of a wellfield. Preliminary simulations of an artificial storage and recovery (ASR) concept on the Middle Fork Embankment, suggest that ASR has a marginal effectiveness in storing spring peak streamflows for enhanced production of a wellfield. Further simulations of ASR configurations may be useful, particularly in downstream locations, but ASR does not appear to be a viable method to enhance production at this time. Its effectiveness as a mitigation strategy has not been evaluated in detail.

FIGURES

APPENDIX A

WELL LOGS AND SUPPLEMENTAL DATA

APPENDIX B

HYDROLOGIC EVALUATION
OF SNOHOMISH BASIN