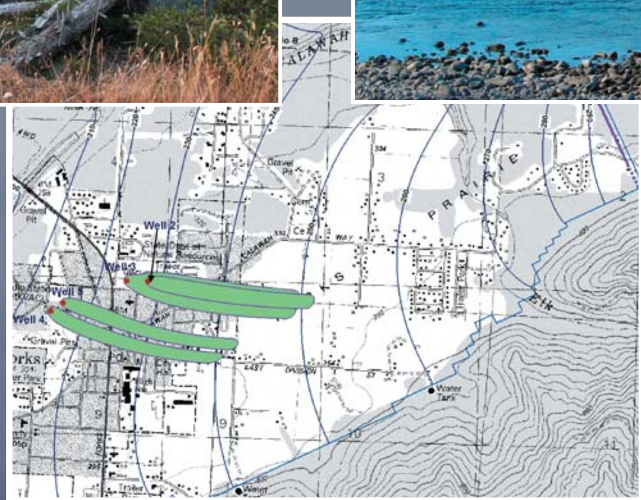
Prepared for Clallam County
and the WRIA 20 Planning Unit

Multi-Purpose Storage Assessment
Water Resources Inventory Area 20



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June 30, 2005

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June 30, 2005

Our Ref.: 043-1130-100.2400

Clallam County Environmental Health
223 E. 4th Street, Suite 14
Port Angeles, WA 98362

Attention: Val Streeter, WRIA 20 Watershed Coordinator

RE: WRIA 20 WATERSHED PLANNING
MULTI-PURPOSE STORAGE ASSESSMENT REPORT

Dear Val:

Enclosed is the WRIA 20 Multi-Purpose Storage Assessment Report. The subject matter covered by this assessment truly reflects the "Multi-Purpose" intent of the grant, including:

- Assessment of the geomorphology of the Big River drainage in its relationship to groundwater and wetlands storage;
- Groundwater and conventional infrastructure storage for the City of Forks; and,
- Reservoir storage for flow augmentation to sustain anadromous salmonid runs on the Hoh River.

It also addresses Washington State's "Water for Fish, Water for People" theme. Much work has been initiated by this study in a short period of time, and we hope that it will provide a good foundation for future work.

We very much appreciated the opportunity and enjoyed conducting this work on behalf of Clallam County and the stakeholders of the Planning Unit.

Sincerely,

GOLDER ASSOCIATES INC.

R. Anden for

Chris Pitre, P.G.
Associate, Water Resources

Draft WRIA 20 Storage Cover Letter

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REPORT ON

STORAGE ASSESSMENT FOR WRIA 20

Funded by Grant No. G0500029, provided by the Washington Department of Ecology under the Watershed Planning Act, RCW 90.82

Submitted to:

Clallam County
and
WRIA 20 Watershed Planning Unit

Submitted by:

Golder Associates Inc.
Redmond, Washington

Chris V. Pitre

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Distribution:

25 Hardcopies, 15 CDs - Clallam County
1 Copy - Golder Associates Inc.

June 30, 2005

043-1130-100

CE NEWS

EXECUTIVE SUMMARY

This supplemental storage assessment was undertaken at the direction of the WRIA 20 Planning Unit to support development of a watershed plan. Work was divided into two steps, with the first step focused on potential applications of Aquifer Storage and Recovery (ASR) and an identification of possible alternatives for more detailed assessment under the second step. The second step considered a range of storage alternatives, including effects of stream channel dynamics on floodplain groundwater storage, groundwater and conventional infrastructure storage related to municipal water supply, and groundwater and surface water reservoir storage to maintain adequate flows for fish habitat.

Aquifer Storage & Recovery

Water for enhanced groundwater recharge is available during the winter and spring runoff periods. The concept considered was to recharge a portion of this water to groundwater such that seepage back to streams would increase summer low flows. Recharge mechanisms considered included direct injection through wells, and infiltration from ground surface. Direct injection requires water quality equivalent to potable standards to minimize clogging of injection wells by suspended sediment and biological growth. Treatment of surface water to these standards has capital costs of approximately $1,000,000 per 1.5 cubic feet per second (cfs) capacity. Recharge to floodplains would require diversion structures on the river and conveyance channels to an appropriate infiltration site.

Increasing groundwater storage through artificial recharge was considered primarily for maintaining summer baseflows in streams. Available storage in the aquifers of WRIA 20 is practically excluded from bedrock areas, and limited to alluvial sediments in valleys. The storage capacity of the aquifers is restricted by the limited horizontal and vertical extents of the alluvial sediments. These aquifers are largely unconfined and well connected to streams. For these reasons, water recharged during the winter and spring runoff periods is expected to drain back to streams too quickly to realize the desired benefits of increased streamflows during critical low flow periods in the late summer and early fall.

Conventional ASR in WRIA 20 involving the direct injection of water into an aquifer is not considered feasible due to the cost of required treatment. Recharge to floodplains would require diversion structures on the river and conveyance channels to recharge sites.

Big River Geomorphology

The role of groundwater storage in maintaining summer low stream flows and floodplain wetlands is the focus of this portion of the storage assessment. The Big River stream channel has been modified by changes in land cover and land use, as well as the removal of large woody debris in the 1950s. This has resulted in down cutting of the stream channel relative to adjacent floodplains (channel degradation) by up to six feet in some reaches. Stream channel degradation has effectively enhanced the drainage of groundwater stored in the floodplain, possibly causing higher peak flows and lower summer flows. This also lowers the ambient water table, which can significantly alter the function of floodplain wetlands.

The approach taken in the assessment of the geomorphology of Big River was to delineate reaches and identify controlling factors within each reach. The Big River was delineated into six reaches of different characteristics, for which actions have been identified for consideration in a watershed plan:

- **Headwaters Reach:** Steep slopes, heavily forested. The primary influence is expected to be erosion.

Primary Recommended Action: Implementation of Road Maintenance and Abandonment Plans (RMAPs).

- **Falls Reach:** Dynamic, transitional/response reach. Site of possible recharge to the alluvial floodplain sediments.

  Primary Recommended Action: None. The dynamic nature of this reach precludes effective control. This reach will be more responsive to actions undertaken in upstream and downstream reaches as opposed to actions within this reach.

- **Boe Creek Reach:** Reach of highest residential density. Riparian zones cleared in parts for agricultural use, resulting in removal of recruitment material for large woody debris (LWD).

  Primary Recommended Action: Restore riparian vegetation through voluntary enrollment by agricultural land owners into the United States Department of Agriculture's Conservation Reserve and Enhancement Program (CREP) and Conservation Reserve Program (typically administered through the local conservation district).

- **Solberg Creek Reach:** Transitional/response reach.

  *Primary Recommended Action***:** None. Maintenance of stream channel function will be achieved by restoration of riparian vegetation and associated LWD recruitment material in the upstream reach (Boe Creek reach), and accelerated reintroduction LWD in the downstream reach (Highway reach).

- **Highway Reach:** Constrained in parts by Hoko-Ozette Road. Reach of most intense historical removal of large woody debris.

  Primary Recommended Action: Accelerate natural recovery by installation of large woody debris to control and possibly reverse channel down cutting.

- **Lake Reach:** Low gradient influenced by backwater from Lake Ozette.

  Primary Recommended Action: Survey the reach for candidate sites for re-establishment of side-channel habitat.

More detailed descriptions of these actions are provided in the text, along with additional actions. Actions to modify streams result in changes at the reach scale (as opposed to the restoration site alone). The analysis of streams at the reach scale and identification of controlling factors will better ensure successful implementation of remediative actions. Without considering reach scale effects, remediation efforts may simply transfer the target problem elsewhere in the channel, or create unintended effects. The approach taken in this analysis (i.e., delineate reaches and identify controlling factors within each reach) may be applied to other streams in WRIA 20.

City of Forks Municipal Water Supply

The City of Forks relies on groundwater storage for 100% of its municipal water supply. A range of management tools are available to ensure the reliability and security of that supply, including protection of groundwater, and diversification of sources. Wellhead protection areas were delineated using a three-dimensional steady state groundwater model.

Installing a new well will diversify the existing array of municipal water supply wells to improve system redundancy and reliability. It will also allow the City to more fully exercise existing water rights. Such a well could be permitted with water rights by adding it as an additional point of withdrawal to existing water rights.

Current demand estimates (Polaris, 1999) indicate that new water rights will be needed in the near future (e.g., within five years). These estimates may be conservative, and new water rights may not be needed for an extended period of time, depending on water demand growth rates (e.g., new industrial demand). Applications should be submitted now for future water rights.

In order to prevent contamination of groundwater north of the river, we recommend that the Grafstrom well in the Forks Industrial Park be abandoned in accordance with WAC 173-160-381. If other unused wells are identified within the City's service area, they should be properly abandoned as well.

The current operation of the wells consists of pumps whose flow is maintained significantly below their designed rates by valves. This creates an unnecessarily high energy bill. Simple energy cost auditing may indicate significant cost savings through the purpose of appropriately sized submersible pumps.

Given the age of the wells, a video inspection should be conducted on any of the City wells in which pumps are pulled for maintenance. A video inspection of Well 2 from 2004 indicated that the screen was in fairly good shape. However, there appeared to be staining around a casing joint, perhaps indicating that one of the welds might be compromised. Unfortunately the camera could only record downhole views (not sideways) and no depth information was provided on the video in order to determine the depth of the casing joint.

Before groundwater development occurs at the Quillayute Airport, a hydrogeologic investigation should be conducted. In order to do this, a close working relationship with the citizens living near the airport should be established to facilitate access to private wells. This work could be conducted in conjunction with the Army Corps of Engineers.

A hydrogeologic investigation of this area would entail gathering well logs, collecting water level measurements, collecting samples for water quality analysis, perhaps limited pumping tests could be conducted on existing wells.

Water Supply for Hoh River Fish

The Hoh Indian Tribe relies almost exclusively on salmon runs of the Hoh River for cultural and economic purposes. There have been several years (e.g., 1987 and 2002) in which river flows have dropped to levels that impaired the upstream passage of returning adult Chinook at River Mile 3.0 (G&L Shake Road crossing) of salmon returning for spawning. The impact of a single year's significant reduction of fish spawning is compounded by reduced production in subsequent return years. The frequency of such low flows is anticipated to increase under predicted global warming conditions, and may present a significant challenge to the continuing viability of salmonid runs. Options considered for maintaining the viability of salmon runs were hatchery supplementation, streamflow augmentation and channel modification.

Hatcheries offer the capacity to directly support salmonid runs in the Hoh River. Fall Chinook are the species currently most affected by low flows. In the event of frequent recurrence of low flows, natural salmonid runs may not be self-sustaining.

Management actions to maintain salmon production on the Hoh River include periodic augmentation of streamflow during critical low flow periods, and/or operating a fish hatchery. Four sites were evaluated with respect to the quantities of water that could be impounded and released, based on topography, precipitation, and assumed release schedules.

Channel modification has been effectively used in WRIA 20 in recent years. However, it requires a significant response effort, and typically only addresses known points of passage barriers. New points may appear due to natural dynamic channel migration in the future in locations that are not accessible. Therefore, channel modification offers limited reliability as an option for maintaining salmon runs in the longer term.

Limiting factors to salmonid habitat other than low flows were not addressed in this assessment.

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1.0 INTRODUCTION

The WRIA 20 Planning Unit received a supplemental multi-purpose storage grant to assess groundwater resources and groundwater supply potential, and to evaluate the use of artificial recharge and Aquifer Storage and Recovery (ASR) to supplement existing water supplies for drinking water, habitat, and/or recreation. In WRIA 20, groundwater development is geographically constrained, and is concentrated in the lower portions of the major river valleys such as the Quillayute, Calawah, and Hoh Rivers, along major transportation corridors such as Highway 101, or near lakes such as Lake Pleasant or Lake Ozette. These areas are also the areas where future growth and water demand will likely be concentrated. Many of the aquifers used for groundwater supply are shallow, susceptible to contamination, or are potentially under the influence of surface water. In some areas, the likelihood of drilling a dry or low-producing well that could be seasonally dry is high. In addition, little is known concerning the general hydrogeologic conditions in most areas of WRIA 20 where population and groundwater withdrawals are concentrated.

1.1 Scope of Assessment

This first step of assessment is focused primarily on evaluating ASR. The WRIA 20 Planning Unit selected seven areas for detailed assessment of groundwater storage (Figure 1-1):

- Forks Prairie;
- Quillayute Prairie;
- Lower and Upper Hoh (two separate areas);
- Three Rivers;
- Beaver/Lake Pleasant; and,
- Ozette/Trout Creek.

These areas were selected based on the following criteria:

- Existing groundwater development and anticipated future groundwater development; and,
- Aquatic habitat needs.

The findings of the first step are reported in Chapter 2. Given the limited potential for ASR in WRIA 20, additional concepts were developed in Planning Unit meetings for evaluation in Step 2. Consensus was obtained through several Planning Unit meetings and discussions with individual Planning Unit members to refocus the storage assessment effort into the following options, which are individually covered in their own chapters in this report:

- Geomorphological Assessment of Big River (Chapter 3);
- Municipal Water Supply for the City of Forks (Chapter 4); and,
- Water Supply for Hoh River Fish (Chapter 5).

1.2 Authorization, Acknowledgements and Limitations

This work was authorized by Val Streeter of Clallam County on behalf of the WRIA 20 Planning Unit. The contract between Clallam County and Golder Associates Inc. (Golder) was signed on May 18, 2004. Amendments to this contract were signed on November 9, 2004 and April 12, 2005 commissioning this Multi-Purpose Storage Assessment.

This work was funded by Grant No.G0500029 provided by the Washington Department of Ecology (Ecology) under the Watershed Planning Act, RCW 90.82.

Val Streeter is the Project Manager on behalf of Clallam County and the WRIA 20 Planning Unit. Bob Duffy is the Ecology Watershed Lead. The principal Golder staff involved in this project are Chris Pitre (project manager), Andreas Kammereck (geomorphology) and Tim White (hydrogeologist).

This work was conducted according to generally accepted professional practices within the limitations of readily available information, budget and schedule. This preliminary report has been prepared exclusively for the use of WRIA 20 for specific application to this project. Our conclusions and recommendations are based on observations made from review of the available existing information. New information may warrant revision of the findings.

2.0 AQUIFER STORAGE AND RECOVERY

This section contains a general overview of the hydrogeology of WRIA 20 and findings related to Aquifer Storage and Recovery potential in the watershed.

2.1 Brief Geologic History of WRIA 20

The Olympic Peninsula contains a variety of notable geologic features. Among the features are a thick sequence of Tertiary basalt (Crescent Formation – erupted between 60 and 50 million years ago [mya]) thrust over younger Tertiary marine sedimentary rocks (sandstones, siltstones and shales deposited between approximately 50 and 24 mya). The uplift of the Olympic Mountains (which thrust the marine sedimentary rocks beneath the basalt) caused regional streams to become incised, creating an erosional landscape of steep, rugged valleys. During the Pleistocene epoch (beginning approximately two million years ago), ice from British Columbia (Cordilleran Ice Sheet) flowed southward into western Washington numerous times. One lobe of the Cordilleran Ice Sheet advanced into the Straight of Juan de Fuca and wrapped around the northern portion of the Olympic Peninsula to the western slope of the peninsula. Alpine glaciers originating in the interior mountains of the Peninsula also advanced during the Pleistocene, further eroding the valleys, and creating much of the landscape characterizing the region today.

2.2 Principal Hydrogeologic Units

The sediments (silts, sands and gravels) deposited in meltwater streams draining alpine glaciers comprise the most important hydrogeologic units in WRIA 20. These overlie bedrock that has little potential for groundwater development.

2.2.1 Unlithified Deposits

The unlithified materials (sedimentary material that has not been converted into coherent, solid rock) present in WRIA 20 include glacially deposited materials (drift [fine and coarse-grained undifferentiated deposits], outwash, and till) and non-glacial deposits (alluvial and fluvial sediments; Figure 1-1). These materials were deposited on top of the lithified marine sedimentary rocks and basalt, primarily in valleys. Till and fine-grained drift generally do not form productive aquifers. Till is a highly heterogeneous, often highly compacted mixture of clay, silt, sand, and gravel that was deposited directly beneath the glacier and generally does not produce a significant amount of water.

A yield of between 10 and 50 gpm is typically sufficient for domestic or small group wells, while the yield of a larger group well is typically much higher (75 to 500 gpm in WRIA 20). The most significant unlithified sediments for water production in WRIA 20 are sand and gravel deposited on top of the marine sedimentary rock and basalt. Sand and gravel can be deposited by present day streams or by meltwater streams draining from glaciers. The most productive glacially-derived deposits are advance outwash sand and gravel, which were deposited as the glacier advanced.

The thickness of the unlithified materials in WRIA 20 ranges from a few feet thick up to about 370 feet thick, but is generally less than 100 feet thick. The transmissivity of the primary water-bearing unlithified materials (coarse sand and gravel) were estimated based on specific capacity information (pumping rate and drawdown) presented on well logs (Golder, 2005a). The transmissivity of the sand and gravel materials was estimated to range from about 10 ft^2/d to over 45,000 ft^2/d. Well yields in the unlithified materials range from dry wells (no water) completed in fine-grained drift or till materials, to 100 gpm to 300 gpm for larger diameter, properly constructed wells completed in sand and gravel, such as those operated by the City of Forks and the Quileute Indian Tribe.

2.2.2 Lithified Deposits

Lithified deposits in WRIA 20 include marine sedimentary rocks (sandstone, siltstone and shale) and lesser amounts of igneous bedrock (primarily comprised of basalt). The lithified deposits in WRIA 20 are generally of low permeability, and the yield of water is primarily through fractures. In WRIA 20, wells completed in the lithified deposits generally yield small quantities of water (less than five gallons per minute; gpm). Some wells completed in the lithified sediments in WRIA are dry (Golder 2005). The low permeability of these materials limits their ability to transmit large quantities of water and they are not considered further for significant groundwater development or artificial recharge and storage.

2.3 Recharge Methods

Conventional aquifer storage and recovery (ASR) involves the use of wells to inject water into an aquifer, where it is storage and later pumped out for use. Several other methods of recharging water have also been used to augment groundwater supply. This section describes methods of recharging groundwater, including surface methods in the unsaturated zone such as spreading basins or dry wells, and underground methods in the saturated zone (wells). Recharge methods are summarized on Table 2-1.

2.3.1 Spreading Basins

Spreading basins are topographically controlled features (e.g., depressions or shallow valleys) underlain by permeable, unsaturated materials such as sand and gravel that can be used to recharge unconfined (water table) aquifers. Recharge water is conveyed to the basin, where it infiltrates and travels through the unsaturated zone to the water table. The recharge water source could be peak streamflows, stormwater runoff, or highly-treated wastewater. Spreading basins are relatively inexpensive to construct and operate, and can be constructed in existing or abandoned gravel pits or other excavations in favorable areas. The recharge water is filtered through the unsaturated zone before reaching the water table.

Some form of pre-treatment system such as oil-water separators or sediment traps may be incorporated into spreading basins to provide some treatment prior to infiltration. Spreading basins may require periodic cleaning or maintenance to remove trapped sediment to prevent clogging of the basin, or service oil-water separators or other treatment facilities.

Spreading basins are currently being evaluated to recharge shallow groundwater in unconfined aquifers that are in direct continuity with surface water as a means to augment flows using groundwater discharge during low-flow periods in the Walla Walla watershed. Peak flows are conveyed using irrigation ditches to spreading basins.

2.3.2 Augmentation of Streamflow with Bank Storage

Bank storage involves infiltration of recharge water, typically peak flows or stormwater, using spreading basins or infiltration canals. The recharge water infiltrates to the groundwater flow system, where it is stored. The recharge water flows under the hydraulic gradient to the aquifer discharge location (rivers or streams). The recharge water discharges to surface water, augmenting the flow.

The volume of water that could potentially be available for augmentation over a three month period is estimated using the following idealized assumptions:

- **Aquifer width** equal to the average valley width, and a representative length;
- **The workable unsaturated zone** (thickness). This is assumed to be 5 feet. The term "workable" refers to the minimum unsaturated zone. When the water table is raised, topographic lows such as ancestral stream channels that define topographic swales will drain any additional rise in the water table effectively limit additional groundwater storage. Because the period of recharge is during the rainy season, this estimate may be high if the unsaturated zone is already fully recharged.
- **Aquifer porosity.** This is the pore space within the aquifer, and is assumed to be 20%;
- Water is recharged until the start of the streamflow augmentation period; and,
- Bank storage is released and augments flow over a three month period (90 days).

Example Theoretical Calculations of Streamflow Augmentation by Artificial Bank Storage

	Hoh River	**Big River**
Aquifer area (A)	1 mile wide; 10 miles long (from Highway 101 bridge to the confluence of the North and South Forks); = 10 square miles	½ mile wide; 5 miles long; = 2.5 square miles
Workable unsaturated zone thickness (T)	5 feet	
Aquifer porosity (n)	20%	
Theoretically available storage (cubic feet; V=A*T*n)	278,784,000 cubic feet	69,696,000 cubic feet
Average streamflow augmentation assuming stored water is released over a 3-month period (cfs; Q=V/90 days)	36 cfs	9 cfs

The assumption that groundwater is released from bank storage at a constant rate over 90 days is a highly idealized representation. Actual augmentation discharge will be highest at the start of the augmentation period, immediately after recharge is stopped, and will decline over the duration of the augmentation period. This decay in streamflow augmentation will result in the lowest augmentation occurring late in the summer season, during natural low flows, just when it is most needed.

This method of estimating streamflow augmentation provides a theoretical maximum to frame the range that may be attained. The assumption assumes flooding of the complete floodplain, and values that might actually be realized will probably be significantly less.

2.3.3 Wetlands

Generally, wetlands exist at groundwater discharge points or in locations where recharge rates are very low. Such conditions are not conducive to aquifer recharge. However, under certain conditions, wetlands can be used to infiltrate recharge water similar to spreading basins if the wetland area is above the water table. Wetlands can also be used to filter or "polish" recharge water (such as treated wastewater) prior to infiltration to improve water quality. The Cities of Yelm and Sequim use wetlands as part of reclaimed water treatment and groundwater recharge.

2.3.4 Dry Wells

Dry wells are small, shallow excavations in permeable materials above the water table that are constructed with a liner or casing. The liner or casing is perforated or has sections of screen that allow recharge water to pass from the drywell to the surrounding unsaturated materials. The recharge water infiltrates through the unsaturated materials to the water table. Dry wells are typically used to infiltrate stormwater. Some form of pre-treatment system such as oil-water separators or sediment traps may be incorporated into dry wells to provide some treatment prior to infiltration, depending on the quality of the stormwater which is dependent upon the nature of the contributing area. Dry wells require periodic cleaning and service to remove trapped sediment and maintain oil-water separators or other treatment systems. Such infiltration may have to comply with Ecology stormwater management rules, and/or regulations protecting groundwater quality.

2.3.5 Wells

Wells can be used to directly recharge groundwater through injection. Wells are particularly suitable for recharging deep, confined aquifers or unconfined aquifers where the unsaturated zone is thick. Recharge wells could be dual-purpose aquifer storage and recovery (ASR) wells that are used for both recharge and pumping, or wells that are used only for recharge in conjunction with other wells that are used for pumping only. Wells are used to recharge groundwater in Walla Walla, Portland, and Salem, and several other cities in the Northwest are evaluating artificial recharge.

Because recharge wells introduce the recharge water directly into the aquifer, no filtration through the unsaturated zone occurs. The recharge water must effectively meet drinking water quality and anti-degradation standards unless a waiver can be obtained, and should have low turbidity (less than one NTU) and low suspended solids concentrations (less than 1 mg/L) to limit clogging of the recharge well and aquifer. The water quality criteria for direct recharge using wells generally require that the recharge water be treated. There are no water treatment plants in WRIA 20. The cost to construct a treatment plant is on the order of $1,000,000 per 1 million gallons per day (mgd) capacity.

2.4 Water Sources for Recharge

Three sources of water for recharge are considered: diversion from stream channel during high flow conditions, stormwater (i.e., overland flow), and reclaimed wastewater.

2.4.1 Peak Flows

Peak flows are a common source of recharge water for artificial recharge projects. Peak flows are used by the Cities of Walla Walla, Salem, and Portland for artificial recharge of drinking water. Peak flows are also being evaluated in the Walla Walla watershed as a means to recharge shallow aquifers to store water that is used to augment streamflow as the groundwater discharges to the streams during low-flow periods of the year.

In WRIA 20, peak flows occur in the late fall and winter, coincident with increased precipitation. Peak flows continue into the early to mid-spring as snowmelt in the higher elevation portions of the WRIA occur. Streamflow hydrographs for the Hoh, Dickey, Sol Duc, Bogachiel, and Calawah Rivers are included in Appendix 2-A.

Water used for direct artificial recharge (such as with injection wells or ASR wells) must meet anti-degradation criteria (WAC 173-200) summarized on Table 2-2. Temporary variances from these regulations may be obtained for periods of up to five years, but must be renewed. Criteria for the issuance of a variance include:

- Benefit to the environment;
- In the interest of human health and the environment; and,
- Impacts will be minimized.

Water used for recharge should also have low turbidity and low suspended solids to limit clogging of recharge wells or infiltration basins. Water quality data for selected constituents are available from the Hoh River. The available water quality criteria are compared to the anti-degradation criteria on. During peak flow periods, the Hoh River contains concentrations of fecal bacteria, turbidity, and high suspended solids that exceed water quality standards for the protection of groundwater. The water quality of other rivers in WRIA 20 is likely similar to the Hoh River, and thus would require treatment to reduce suspended solids and turbidity, and eliminate bacteria prior to direct recharge unless a variance could be obtained. No surface water treatment plants currently exist in WRIA 20 that could treat surface water for direct recharge.

Instream flows have not been set in WRIA 20 at this time. However, several Surface Water Source Limitation (SWSL) letters were written by the Department of Fish and Wildlife in the early 1990's in response to eight surface water right applications for the Sol Duc River and its tributaries (Beaver Creek, Lake Pleasant, and Snider Creek) and the Bogachiel River (Table 2-3). The SWSL letters recommended low-flow provisions for specific periods (e.g., summer) for three of the surface water bodies. Detailed examination of recommendations of water right denials without defined periods and/or discussions with agency personnel may reveal whether the effective instream flow restriction is year round or seasonal. Although no SWSLs have been written in response to groundwater applications, future groundwater applications could be conditioned on instream flow or recommended for denial because of hydraulic continuity and streamflow concerns or fisheries concerns.

The seasonal availability of peak flows to use as recharge water would have to be determined by Ecology in consultation with the Washington Department of Fish and Wildlife (WDFW), tribes, and other stakeholders as part of the water right application process.

2.4.2 Stormwater Runoff

Stormwater runoff can be used to recharge groundwater using infiltration basins or dry wells. Stormwater is typically recharged to the unsaturated zone and allowed to infiltrate to the water table. Because stormwater is typically untreated or minimally treated, water quality may be a concern. Typical constituents in stormwater from urban areas include fecal bacteria, metals, pesticides and herbicides, and hydrocarbons. Stormwater would likely require some form of pretreatment prior to infiltration.

The availability of stormwater as a source of recharge requires further evaluation. It is possible that stormwater runoff may be available in some of the more populated areas of the watershed, such as Forks, where stormwater collection systems are developed or planned. However, the total volume of managed stormwater is not anticipated to be significant because the watershed is largely rural, undeveloped and forested.

2.4.3 Reclaimed Water

Reclaimed water (water collected and treated after use) may be beneficially used for surface infiltration provided the reclaimed water meets the groundwater recharge criteria as measured in the groundwater beneath or down gradient of the recharge site. Reclaimed water used for groundwater recharge shall be at all times of a quality that fully protects public health and the water quality of waters of the state. Reclaimed water that does not meet the groundwater recharge criteria may be beneficially used for surface percolation where the Departments of Health and Ecology have specifically authorized such a use at a lower standard. Reclaimed water may also be used to directly augment streamflow.

Reclaimed water that is used to recharge groundwater using surface infiltration methods must be treated to Class A standards, with an additional step to reduce nitrogen concentrations in oxidized reclaimed water. Reclaimed water can also be used for direct aquifer recharge. The standards for direct aquifer recharge are more stringent than for surface infiltration and include:

- Treatment by reverse osmosis;
- Turbidity less than 0.1 NTU, total nitrogen less than 10 mg/L, and total organic carbon less than 1 mg/L;
- The recharge location must be greater than 2,000 feet from other wells;
- The recharged water must remain in the aquifer for at least 12 months; and,
- The reclaimed water must meet drinking water criteria and state groundwater standards.

Reclaimed water intended for beneficial reuse may be discharged for streamflow augmentation provided the reclaimed water meets the requirements of the federal water pollution control act, (Chapter 90.48 RCW) and is incorporated within a sewer or water comprehensive plan as applicable, adopted by the applicable local government, and approved by the Departments of Health and Ecology.

Reclaimed water is presently used to recharge groundwater in the Forks Prairie area. The City of Forks operates the only wastewater treatment plant in WRIA 20. Reclaimed water from the City's wastewater treatment plant is currently infiltrated to groundwater using several infiltration basins. The depth to water near the wastewater treatment plant is about 80 to 90 feet below ground. Therefore, the reclaimed water passes through a thick section of unsaturated sand and gravel before reaching the water table. The infiltration ponds are down gradient of the City's wellfield.

2.5 Evaluation of Aquifer Storage and Recovery Potential in WRIA 20

ASR potential was evaluated for selected areas of WRIA 20. Hydrogeologic characteristics of the seven areas selected for the assessment in the first step were evaluated in relation to ASR applications. A preliminary assessment of groundwater development and storage alternatives were developed and are summarized in this section.

2.5.1 General Findings

Conventional Aquifer Storage and Recovery (ASR) – involving the direct injection of water into an aquifer – has limited potential in WRIA 20. The findings of the evaluation are summarized in Table 2-4. ASR is not considered highly feasible in the area because the high cost of treatment required for operational considerations and to meet state groundwater antidegradation rules. A suitable source typically involves surface water that has been treated to potable standards. Capital costs of such a plant are usually on the order of one million dollars per 1 million gallons per day (mgd) capacity.

In addition to the cost of water treatment, ASR studies would require detailed hydrogeological evaluations to fully evaluate the technical feasibility of recharge and storage, including:

- Recharge water availability;
- Recharge water quality and compatibility with the native groundwater and aquifer mass;
- Aquifer boundaries;
- Hydraulic continuity with surface water;
- Recharge and storage capacity of the aquifer; and,
- Potential effects on other groundwater users.

Theoretical maximum estimates of streamflow augmentation based on the maximum capacity of alluvial floodplain aquifers and idealized release of that water during low flow periods results in streamflow augmentation of 11-29 cfs on the Big River, and 61-127 cfs on the Upper Hoh. Actual augmentation results are expected to significantly lower than these estimates. Recharge to floodplains would require diversion structures on the river and conveyance channels to recharge sites.

Individual sites evaluated are:

- Forks Prairie;
- Quillayute Prairie;
- Three Rivers;
- Lower and Upper Hoh (two separate areas);
- Beaver/Lake Pleasant; and,
- Ozette/Trout Creek.

General information related to ASR considerations is presented in separate sections below. More detailed and broader ranging hydrogeologic information on the Forks and Quillayute Prairies and Three Rivers areas is contained in Chapter 4. Considerations related to the Upper Hoh are not presented in this chapter, but are fully contained in Chapter 4.

2.5.2 Forks Prairie

Forks Prairie is a flat to gently sloping terrace that is located between the Calawah and Bogachiel Rivers, and an upland area south of the City of Forks. It extends from the confluence of the Bogachiel and Calawah Rivers, east to the confluence of the North and South Forks of the Calawah River. Portions of the Forks Prairie area extend into the Calawah and Bogachiel Subbasins. Drinking water for much of the Forks Prairie area is supplied by the City of Forks by operation of a wellfield on the northeast side of Forks. The geologic units in the Forks Prairie area include alluvial materials in the channels of the rivers, glacial outwash, and marine sedimentary rocks and undifferentiated glacial drift in the upland areas adjacent to the prairie.

Most of the groundwater for municipal and domestic use in WRIA 20 is obtained from the Forks Prairie area. The City of Forks obtains its water supply from five wells located in Sec. 9, T28N, R13W. Information is also available from two of the water supply wells and two monitoring wells installed at the City of Forks wastewater treatment plant in Sec. 9, T28N, R13W, about one mile west of the water supply wells. The total thickness of unlithified sediments in the Forks Prairie area is estimated to range between 100-200 feet. The wells are completed in confined, coarse sand and gravel aquifer that is about 10 to 15 feet thick, at a depth of about 110 feet below ground. The aquifer appears to be moderately to highly permeable, and well yields are between 100 and 400 gpm. The coarse sand and gravel aquifer is overlain by glacial till with lenses of sand and gravel. The extent of the aquifer is uncertain because few well logs are available in the Forks Prairie area. The wells are terminated in clayey sand and gravel.

Aquifer testing using the City of Forks wells suggest that the range of influence of pumping is limited (i.e., less than 2,000 feet) due to the high aquifer transmissivity and the leaky nature of the aquifer (see Chapter 4). (Transmissivity is the ability of geologic materials to transmit water. It is the product of hydraulic conductivity [K; ft/day] of the material, times the thickness of the formation [feet; Freeze and Cherry, 1979].)

The groundwater elevation in the sand and gravel aquifer is about 200 feet msl, or about 80 to 90 feet below ground, based on water levels in the City wells. The groundwater elevation in the wells is about 10 to 30 feet higher than the elevation of the Calawah River.

Artificial recharge and storage in the confined aquifer is considered limited because available information indicates that the aquifer does not hold water through the summer for effective seasonal storage (see Chapter 4).

2.5.3 Quillayute Prairie

Quillayute Prairie and Little Quillayute Prairie are flat to gently sloping terraces that are located between the Dickey and Sol Duc Rivers on the upland north of Quillayute Road. Quillayute Prairie extends from the confluence of the Dickey and Quillayute Rivers east to about the east side of Sec. 9, T28N, R13W. The Quillayute Prairie area extends into the Sol Duc and Dickey subbasins. Drinking water in the Quillayute Prairie area is supplied by individual exempt wells and several Group B water systems that rely on wells.

The geologic units in the Quillayute Prairie area include alluvial materials in the channels of the rivers, and glacial till and drift and marine sedimentary rocks in the upland areas adjacent to the prairie. Alluvium, and permeable glacial materials (outwash) underlying till, are the principal aquifers in the area. The Quillayute Prairie is capped by till and underlain by higher permeability aquifer materials that may be older alluvium and/or glacial outwash materials.

The principal water-bearing zones in the Quillayute Prairie area are five to 20 foot thick lenses of sand and gravel that form confined aquifers or water-bearing zones within till and fine-grained glacial drift materials. The lateral extent and continuity of these zones is unknown. Groundwater elevations range between about sea level and 175 feet msl. Well yields range from about four to 70 gpm. The transmissivity of the aquifer materials ranges from about 30 to 7,600 ft^2/d, with a median transmissivity of 760 ft^2/d, indicating the aquifer materials are low to moderately permeability. No information on water quality for the sand and gravel aquifers is available, except for comments on a few well logs, such as “soft” water and “irony” water.

Some wells in the Quillayute Prairie area are completed in marine sedimentary rocks. Well yields from the marine sedimentary rock are low, ranging from about one gpm to five gpm, while some wells were dry. This is typical for wells completed in lithified materials in WRIA 20.

Artificial recharge and storage in the confined aquifer(s) may be technically feasible if a suitable source of recharge is available. However, the potential for ASR in the Quillayute Prairie area is estimated to be moderate due to the limited storage capacity of the aquifers and high degree of hydraulic continuity with streams (Table 2-4). Geotechnical considerations related to overpressurizing the aquifer and associated ground stability where the aquifer may discharge at the bottom of slopes surrounding the prairie may also be a concern.

2.5.4 Three Rivers Area

The Three Rivers area is in the vicinity of the confluence of the Bogachiel and Sol Duc Rivers that form the Quillayute River. Drinking water in this area is supplied by several Group A and B water systems and individual exempt wells. The Quileute Tribe also operates two wells in this area that supply water via a pipeline to the Quileute Reservation.

The geologic units in the Three Rivers area include unconsolidated alluvial materials (sand and gravel, glacial outwash and drift) overlying lithified marine sedimentary rock (shale and sandstone). The alluvial sand and gravel forms productive unconfined aquifers in the Three Rivers area. The underlying marine sedimentary rocks form a poor aquifer, with low well yields (less than 1 gpm) or dry wells.

The Quileute Tribe has drilled numerous test wells from Thunder Field, to the area east of the confluence of the Sol Duc and Bogachiel Rivers as part of their development of a reliable water supply for their Reservation, which is located west of the Three Rivers area. The test well information, along with other water well logs in the area, indicate the presence of moderately to highly productive sand and gravel aquifers(s), that are alluvial materials deposited by the rivers or glacial outwash. Observations near the Quileute Tribe's wells in Sec. 20, T28N, R14W indicate that a portion of the aquifer discharges to springs along the bank of the Bogachiel River.

The sand and gravel deposits occur between about 20 to 70 feet below ground, with a saturated thickness of about 10 to 30 feet. The sand and gravel deposits do not extend below sea level, and appear to pinch out to the east in Sec. 22, T28N, R14W.

Aquifer test data presented on the well logs indicate the transmissivity of the sand and gravel aquifer is about 600 to 72,000 ft^2/d, with a median transmissivity of about 3,800 ft^2/d, indicating the aquifer is generally moderately to highly permeable. The transmissivity of the sand and gravel aquifer is confirmed by pumping tests conducted on two wells drilled for the Quileute reservation in Sec. 20, T28N, R14W. The transmissivity estimated from the pumping tests was about 65,000 to 80,000 ft^2/d, and the storativity was estimated to be about 0.02. (The specific storage [S_s; ft^{-1}] of an aquifer is the unit volume of water released from storage under a unit decline in hydraulic head [Freeze and Cherry, 1979]. Storativity [S] is defined as the specific storage times the thickness of the aquifer, and is unitless.)

Interferences between pumping wells in the Three Rivers and the Quillayute Prairie are not expected to exist because of the high storativity (which may reflect a leaky aquifer characteristic, or not being well-confined), and high transmissivity. The aquifers of these two areas are also interpreted to be different (i.e., younger alluvium in the Three Rivers area, and older alluvium and/or glacial outwash in the Quillayute Prairie). These aquifers may also have a relatively high degree of continuity with streams, in which case the Sol Duc River that separates the Three Rivers and Quillayute Prairie areas would further attenuate the transmission of pressure pulses between the two areas.

Groundwater level observations made during pumping tests conducted on two test wells drilled at Thunder Field indicate that the sand and gravel aquifer is tidally influenced at least to this area (about River Mile 2 on the Quillayute River). Tidally-influenced groundwater level fluctuations of 0.5 to 2.5 feet were observed during testing of the wells, which occurred during a period of extreme tidal flux. The tidal fluctuation in the Quillayute River was about 3 to 4 feet. The upstream limit of tidally-influenced groundwater and surface water is not known, but groundwater levels in Sec. 20, T28N, R14W, near the confluence of the Sol Duc and Bogachiel Rivers, do not appear to be tidally influenced.

Water quality in the sand and gravel aquifer appears to be good based on existing information. Manganese and iron concentrations were below the secondary water quality standard in all of the Quileute Tribe test wells. Several well logs from the Three Rivers area contained comments on high iron concentrations. Chloride concentrations were measured during testing of wells located at Thunder Field near the Quillayute River, where the aquifer is tidally influenced. The testing indicated chloride concentrations were between about 6 mg/L and 50 mg/L, well below the secondary standard of 250 mg/L. It is not clear whether this salinity is related to marine saline influences. However, the lower reaches of valleys are commonly discharge locations for deep seated regional groundwater flow paths, and such salinity may be related to mineralize groundwater discharging from bedrock.

The sand and gravel outwash materials in the Three Rivers area appear to be suitable for development of additional groundwater. The marine sedimentary rocks are not favorable for groundwater development.

Artificial recharge for storage of drinking water may not be feasible because of the unconfined aquifer(s) and the high degree of hydraulic continuity with surface water. Additional evaluation is needed to confirm whether artificial recharge is feasible (Table 2-4).

2.5.5 Lower Hoh

The Lower Hoh area considered in this evaluation is the south side of the river, extending upstream from the mouth of the river to the Highway 101 Bridge. The Lower Hoh area is in the Hoh subbasin. Drinking water is supplied by individual exempt wells and one Group B system at a campground. Groundwater is the source of drinking water at the Hoh Reservation at the mouth of the river.

The geologic units in the Lower Hoh area include unlithified alluvial and glacial outwash sediments overlying marine sedimentary rocks. Information on the hydrogeologic conditions in the area was obtained from well logs, the USGS and consultant reports on groundwater development for the Hoh Reservation.

The principal aquifer in the Lower Hoh area is glacial outwash deposits. The glacial outwash is about 5 to 20 feet thick. The outwash is overlain by fine-grained terrace deposits and by fine-grained glacial drift, and underlain by low-permeability marine sedimentary rocks. In the vicinity of the Hoh Reservation, several large springs discharge from the glacial outwash where the Hoh River has eroded terrace deposits and exposed the outwash. These springs discharge up to about 250 gpm to 500 gpm. Well yields in the outwash range from about 5 to 75 gallons per minute. The highest well yields were from wells installed upgradient of the springs. Well yields are limited by the low saturated thickness and discontinuity of permeable lenses in the outwash materials in the Lower Hoh area.

In some areas (particularly in the vicinity of River Miles 3 and 4), the outwash is confined below fine-grained glacial drift materials, with groundwater levels ranging from about 10 feet below ground to flowing artesian, or about 50 to 90 feet above the water bearing zones intersected in the wells. The glacial outwash is discontinuous. Several wells drilled in Sec. 4, T26N, R12W did not intersect outwash or other water-bearing materials and were abandoned. The marine sedimentary rocks underlying the outwash material are fine-grained and no wells in the Lower Hoh area were completed in the marine sedimentary rock. It is likely that well yields in the marine sedimentary rock would be in the range of less than one gpm to three gpm, based on observations from wells completed in similar materials in other areas of WRIA 20.

Limited groundwater quality sampling from test wells drilled on the Hoh Reservation indicate groundwater from the outwash aquifer has low pH of about 5.5 to 6.0, which is below the secondary standard of 6.5, and may have iron concentrations greater than the secondary standard of 0.3 mg/L. Low pH water increases the potential to leach lead and copper from distribution systems. Water quality samples from a Group B well (Hoh campground) indicated iron and manganese concentrations below the secondary water quality standard of 0.3 mg/L and 0.05 mg/L, respectively.

Storage of water in the Lower Hoh area does not appear to be feasible because of the limited aquifer capacity and continuity of the aquifer with the Hoh River (Table 2-4). Storage concepts for the Upper Hoh are presented in Chapter 5.

2.5.6 Beaver/Lake Pleasant

The Beaver/Lake Pleasant area is located in the Sol Duc subbasin between Tyee Hill and the Sol Duc River (Figures 2-1). Conditions of this area also probably characterize the hydrogeology of the Sappho area immediately upstream. Lake Pleasant is located between Upper Lake Creek and Lower Lake Creek, which flows into the Sol Duc River. The area includes the town of Beaver (Tyee). Drinking water in the area is supplied by individual exempt wells, and several Group A and B groundwater systems. Information on wells was obtained from Ecology’s well log database and the Washington Department of Health, as filed by well drillers and water system owners, respectively (Figure 2-1; plotted to the resolution of the available data). Some of the data is duplicated in the two systems and may therefore be represented in duplicate in figure 2-1.

The geologic units exposed at the surface in the Beaver/Lake Pleasant area include unconsolidated alluvial materials, glacial outwash, and glacial till in the Sol Duc valley (Tyee Prairie and Beaver Prairie), and lithified fine-grained marine sedimentary rock and glacial till in the upland areas (Tyee, Shuwah and Beaver Hills.

Glacial outwash is the principal water bearing material in the area. Well logs indicate several lenses of confined water-bearing sand and gravel that occur between about 20 feet and 180 feet below ground, that are overlain by glacial till and separated by glacial till or other fine-grained glacial drift materials (Figure 2-2). The sand and gravel lenses are commonly about 5 to 40 feet thick. Groundwater elevations in the sand and gravel range between about 228 and 526 feet msl. A small amount of groundwater also occurs in the fine-grained marine sedimentary rock, however most wells completed in the marine sedimentary rock were dry, and were abandoned.

Wells in the Beaver/Lake Pleasant area produce between about 1 and 60 gpm (Figure 2-3). There is an area of dry or low-yielding wells on the south east side of the lake, in Sections 25, 35, and 36 (T30N, R13W). In this area, glacial outwash sediments are thin or absent, and clay and sedimentary rocks are at or near the ground surface. The transmissivity of the sand and gravel ranges between about 60 to 10,400 ft^2/d, with a median transmissivity of about 800 ft^2/d, indicating the sand and gravel aquifer has low to moderate permeability. The continuity of groundwater and surface water near Lake Pleasant is unknown. There is potential for Groundwater Under the Influence of surface water (GUI) to occur if wells are located in close proximity to surface water, such as Lake Pleasant, and pumping induces recharge from surface water.

Groundwater in the Beaver/Lake Pleasant Area meets the secondary water quality standards for iron and manganese based on sampling conducted at two Group A water systems.

Surface Water Source Limitation letters were filed by WDFW over concerns for Coho salmon for three surface water right applications for water from Lake Pleasant (Table 2-3). Since the letters were filed, most of the applications have been processed and are either in the permit stage or have been certificated.

The sand and gravel outwash materials in the Beaver/Lake Pleasant area host the only developable aquifer zones. However, Planning Unit members report that several attempts are commonly required before successfully installing productive wells (e.g., several dry wells are installed before a productive aquifer zone is encountered). This is a costly process for the individual commissioning the well. The marine sedimentary rocks are not favorable for groundwater development. Therefore, the potential for implementing groundwater storage in the area is estimated to be low (Table 2-4).

The difficulty in siting wells that intersect productive portions of the aquifer system is a result of the dominance of finer-grained sediments. The inability to correlate strata between well logs may also be an effect of the discontinuous nature of the more transmissive layers. A geophysical survey using multiple parameters may provide a better characterization of the stratigraphy and improve the probability of success in installing productive wells. Geophysical parameters that could be considered include seismic and electromagnetic surveys. A survey grid involving several cross-valley sections along with a section extending along the axis of the valley to tie the cross-valley surveys may be most productive. Site accessibility will exert a significant control on the survey orientation. Some electromagnetic survey methods are subject to interference from cultural influences, such as buried pipelines and power lines. Survey lines should be oriented to intersect existing well logs where possible for calibration purposes.

2.5.7 Ozette and Trout Creek Area

The Ozette area is located on the east shore of Lake Ozette in the Ozette subbasin. Planning Unit concerns in this area are related to drinking water and maintenance of summer low streamflows. The Trout Creek area is located on the northeast side of Lake Ozette, northeast of Umbrella Creek. This area is relatively undeveloped. The shallow depth and limited extent of unconsolidated sediments limits easily developable groundwater supplies. Because of this, some residents rely on water taken directly from the lake without treatment or disinfection, which presents a health risk from naturally occurring pathogens (e.g., *Giardia*). Drinking water is also supplied by individual exempt wells, and a Group A water system and a Group B water system that rely on wells at the north end of the lake.

Hydrogeologic information in the Ozette area is limited to a few well logs and existing geologic maps. No well logs are available for the Trout creek area. The geologic units exposed at the surface include unlithified alluvial materials (silt, sand, and gravel) near Ozette and Swan Bay, and fine-grained glacial drift over most of the east shore of Lake Ozette. The glacial drift overlies lithified fine-grained marine sedimentary rock. Information presented on well logs indicates the unlithified materials range in thickness from less than five feet to over 100 feet.

Wells completed in both the glacial drift and marine sedimentary rock yield small quantities of water to wells (less than five to 10 gpm), or are dry. The estimated transmissivity from three wells that had aquifer test information indicates a transmissivity of about 25 to 800 ft^2/d, indicating low to moderate permeability. Groundwater quality data from the Ozette Campground well indicates iron and manganese concentrations are above the secondary water quality standards of 0.3 and 0.05 mg/L, respectively.

Siting of wells could consider large scale (e.g., mile-scale) geomorphic (topographic) features that may indicate the presence of sediment-filled bedrock valleys. Siting of wells close to surface water could inadvertently induce infiltration of surface water and possible associated pathogens. The Washington Department of Health considers wells that are closer than 200 feet from surface water and shallower than 50 feet in depth to be susceptible to the influence of surface water, and recommends evaluation of such sources for health concerns.

Because bedrock is relatively shallow in this area, conventional aquifer storage is not considered feasible. Two alternatives methods of storage considered in the Ozette area are bank storage for streamflow augmentation, and the use of forest roads along the river valleys to impound water, creating wetlands that could be used for storage or habitat enhancement.

One approach for using bank storage involves the infiltration of recharge water, typically peak flows or stormwater, using spreading basins or infiltration canals, as described in Section 2.3.2 (Augmentation of Streamflow with Bank Storage). The recharge water infiltrates to the groundwater flow system, where it is stored. The recharge water flows under the hydraulic gradient to the aquifer discharge location (rivers or streams). The recharge water discharges to surface water, augmenting the flow.

The theoretical volume of water that could potentially be available for augmentation over a three month period is estimated using the following assumptions:

- A valley (aquifer) width of half a mile and a length of five miles;
- Aquifer porosity of 20%;
- A workable unsaturated zone of five feet;
- Water is recharged until the start of the augmentation period; and
- Flow is augmented over a three month period.

Using these assumptions, the average augmentation discharge is estimated to be about 9 cfs. The actual augmentation discharge will be highest at the start of the augmentation period, immediately after recharge is stopped, and will decline over the duration of the augmentation period. The estimate of streamflow augmentation should be considered as a theoretical maximum to frame the range that may be attained. The assumption assumes flooding of the complete floodplain, and values that might actually be realized will probably be significantly less.

Development of groundwater storage in the Ozette/Trout Creek area may be technically feasible. However, the potential for implementing more conventional methods of groundwater storage in the area is estimated to be low (Table 2-4).

An alternative approach to increasing bank storage is to maintain the existing groundwater storage through control of downcutting of the stream channel (degradation). Big River is the largest stream in the Ozette Subbasin. A geomorphological assessment of this river was selected by the Planning Unit for detailed analysis in Step 2 of this storage assessment, which is presented in the next chapter.

3.0 BIG RIVER GEOMORPHOLOGY

Big River geomorphology and stream habitat have changed significantly during the last one hundred years due to human modifications including: channel spanning log jam removal (Kramer, 1953), permanent riparian clearing for agriculture, channel relocation for agriculture, riparian conifer timber harvest and resultant loss of wood recruitment, and floodplain road construction. Subsequently, down-cutting and incisement of the channel have reduced proper floodplain function and a reduction in floodplain connectivity in some reaches, and in other reaches lateral migration has been accelerated. As the channel has incised and the profile lowered in elevation, the ambient groundwater table has also been lowered, resulting in reduced wetland areas and reduced connection to floodplain areas. The compounded effect has been to reduce floodplain storage and seasonally low stream flows in a system used by sockeye salmon that are listed as threatened under the Endangered Species Act.

Theoretical estimates of the degree to which streamflow baseflows might be supported by the drainage of ambient groundwater stored in the unconsolidated sediments of the floodplain were presented in Section 2.3.2. Assumptions used were:

- Aquifer area: 2.5 square miles;
- Workable unsaturated zone: 5 feet;
- Period of release of stored water: Continuous over three months; and,
- Amount of streamflow augmentation: 9 cfs.

The assumption that groundwater is released from bank storage at a constant rate over 90 days is a highly idealized representation. Actual augmentation discharge will be highest at the start of the augmentation period, immediately after recharge is stopped, and will decline over the duration of the augmentation period. This decay in streamflow augmentation will result in the lowest augmentation occurring late in the summer season, during natural low flows, just when it is most needed.

This method of estimating streamflow augmentation provides a theoretical maximum to frame the range that may be attained. The amount of streamflow augmentation that may be achieved by seasonally increasing floodplain storage can also be used as a surrogate to represent the amount of baseflow that is lost as a result of lost floodplain storage. Downcutting of the stream channel accelerates drainage of the floodplain and exacerbates late summer low flows. With this in mind, grade control of the stream channel where it has downcut may result in the restoration of higher summer baseflows.

This assessment reviews and discusses geomorphic channel characteristics within the project area to gain a better understanding for how conceptual in-channel changes may perform and/or mitigate for losses in habitat quality. The assessment focuses on defining geomorphic characteristics on a *reach scale*, recognizing that changes at one location may have effects up- or downstream of a given site. By understanding the behavior of the Big River at the reach scale, we hope to better evaluate and discuss potential improvements that minimize detrimental impacts to up- and downstream properties.

The project area is defined as including the Big River channel from the confluence with Lake Ozette at River Mile (RM) 0 and extending upstream approximately 15 miles to the headwaters. Reach breaks within the study area were defined based on geomorphic channel characteristics (Figure 3-1):

Big River Reaches

Reach Name	River Mile (RM)
Headwaters	~15 to ~11
Falls	~11 to ~10
Boe Creek	~10 to ~6.5
Solberg Creek	~6.5 to ~5
Highway	~5 to ~2
Lake	~2 to 0

The goal of this assessment is to develop a framework for continued planning efforts in the Big River basin that looks at the issues at a reach scale. The existing information was reviewed and organized to define and explain reach scale riverine processes and geomorphic characteristics, and thereby support continued efforts to improve water storage and/or plan, design, and implement habitat enhancement projects. This assessment was completed based on existing available information, studies, mapping, or data. No new additional information was developed or new data acquired through field investigations or site specific analyses. As such, a secondary goal of this assessment is to identify gaps in the existing data and outline approaches for addressing future data needs. This effort may be used as a model for assessing additional drainages throughout WRIA 20.

3.1 Background Information/Data

Existing background data and information was acquired and reviewed to develop an understanding for channel dynamics and basin characteristics in the Big River basin. The following is a summary of the available information.

- **Literature Addressing Bank Storage.** Various papers addressing storage of flows in overbank and wetland areas, as well as channel dynamics relative to in-stream flows are listed in the bibliography section of this report. These papers were reviewed and the concepts incorporated where applicable (Bunn and Arthington, 2002; Hatten, 1996; Naiman and others, 2002; Poff and others, 1997; Poff and others, 2003; Richter and others, 1996; Richter and others, 1997; Richter and others, 2002; and, Silk and others, 2000)]. The bibliography is intended to provide a resource list for continued future efforts to plan, design, and implement projects in the Big River and other drainages. As such, we view the bibliography as a "living document" that will continue to expand as more information is acquired and incorporated into the database.
- **Big River Flow Discharge Data.** The Makah Tribe installed a continuously recording stream flow and water quality (i.e., turbidity) gaging station in November of 2003. The station period of record extends from November 4, 2003 to the present. The gage is located upstream of the Trout and Dunham Creek tributaries at the Big River Bridge (Coordinates: 124 degrees, 33', 56.38" W, 48 degrees, 8' 53.25"N). The station is comprised of an Ott Nimbus Pressure Bubbler/Level Sensor. Periodic discharge measurements are made for maintenance of the rating curve.
- **Aerial Photographs and Mapping Coverages**. The following is a summary of available historical photo and mapping resources:

- Log jam locations that were removed in the 1950's were digitized from maps contained in (Kramer, 1953; Figure 3-1, Appendix 3-B).

- Partial 2003 LiDAR coverage of the Big River drainage was received from the Makah Tribe (approximately RM 0 through RM 8; Figure 3-2).

- Orthophoto coverage, including:
  - Partial coverage of the drainage in 2003 (Figure 3-3);
  - Complete coverage of the drainage in 2000 (Figure 3-4); and,
  - Complete coverage of the drainage in 1994 (Figure 3-5).

- River mile markers at one mile increments were generated using Big River stream channel topographic data from the Department of Natural Resources.

- Big River Drainage boundary is based on USGS fifth field Hydrologic Unit Codes (HUC) and modified to reflect the Big River drainage area.

- Channel Migration Zone (CMZ) boundaries were obtained from Clallam County

- Wetlands boundaries received from Clallam County

- Historical stream channel locations of Big River, including:
  - 1996 – GIS coverage from the Department of Natural Resources accurate to +/- 40 ft.
  - 1956/1957 – Digitized and rectified from historic Lake Ozette and Lake Pleasant USGS topographic maps (1:62,500).
  - 1942/1935 – Digitized and rectified from historic Lake Ozette and Lake Pleasant USGS topographic maps (1:62,500).

- Makah Tribe Stream Gauge locations received from the Makah Tribe.

- Toe Width Station location received from the Washington Department of Fish and Wildlife (WDFW).

- Property Ownership boundaries received from Clallam County.

- Lakes coverage received from the Washington State Department of Ecology.

- Federal Emergency Management Agency (FEMA) Floodplain boundaries received through the U.S. Department of Agriculture; data originates with FEMA, and is derived from Flood Insurance Rate Maps (FIRM) maps.

- Base topography from USGS 1:24,000 quadrangles.

- Hill shade overlying topography derived from USGS 10-meter Digital Elevation Model (DEM) coverage.

• **Mid-Project Meeting**. A mid-project review meeting was held on April 25, 2005 to consolidate information and discuss basin and channel specific issues. In attendance were Ed Bowen (local resident), Jeff Shellberg (Makah Tribe), Chris Pitre (Golder), and Andreas

Kammereck (Golder). The purpose of the meeting was to gain insights on Big River geomorphology from local resources, review the definition of channel reach designations, and discuss how channel features and dynamics interacted within the project area. Jeff Shellberg provided photographs of the Big River. Selected photographs are shown in Appendix 3-A for locations at approximately RM 0, 1.8, 2.5, 4.7, and 7.9.

- **Relevant Background Documents.** Several background documents were reviewed and the information incorporated into this assessment. The following lists of some of the more relevant documents. Additional resources are provided in the bibliography section of this report.
    - "Survey Reports of Major Rivers and Streams of Northwestern Washington with reference to a Stream Improvement Expenditure Program, Part 1 (Clallam County), Compiled by the Division of Stream Improvement, State of Washington, Department of Fisheries", completed by Robert Kramer (Cartographer and Field Technician) in June 1, 1951 (Kramer, 1951). This document focuses on the approach and costs for removing accumulated woody debris from rivers and streams in the Ozette Basin area, including the Big River. The copy of this report obtained is incomplete, and the pages (specifically pages 14 and 15) addressing the Big River are not included in our copy. The report offers insights into how the stream clearing work was scoped and implemented. Further details specific to the Big River can be found in the subsequent follow-up report completed in 1953 that summarizes the work completed under the stream clearing program.
    - "Completion Report by Stream Clearing Unit on Ozette and Big Rivers", completed by Robert Kramer, Supervisor or Stream Clearance Projects, Stream Improvement Division of the Department of Fisheries (April, 1953). This report is the follow-up summary of work completed by the Stream Clearing Unit and offers specific information about work done on the Big River between 1951 and 1953 (Kramer, 1953). The report and applicable maps for the Big River are provided in Appendix 3-B, and includes maps showing the location of woody debris jams that were removed from the Big River as well as some historical photos of the river.
    - "A Catalog of Washington Streams and Salmon Utilization, Volume 2, Coastal, Washington State Department of Fisheries, 1975." (Phinney and Bucknell, 1975). This document provides some insights on salmon utilization (dated) and offers a map of the Big River and some known woody debris locations upstream of Solberg Creek. A copy of the section relevant to Big River is provided in Appendix 3-C.
    - "Lake Ozette Tributary Habitat Conditions", completed by Mike Haggerty and Andy Ritchie for the Makah Tribe (June 2004 final draft version). These documents provide a summary assessment of habitat conditions in the Lake Ozette basin, including information specific to the Big River and some of its tributaries (Haggerty and Ritchie, 2004).

This information is incorporated into the following sections.

3.2 Description of Reach Dynamics

The Lake Ozette basin is located on the northwestern edge of the Olympic Peninsula in Washington State. Lake Ozette is approximately 7,300 acres in size, making it the third largest natural lake in Washington State with a drainage basin area of approximately 77 square miles (Haggerty and Ritchie, 2004). Several significant tributaries drain into Lake Ozette including: Big River, Umbrella Creek, Crooked Creek, Siwash Creek, and South Creek. The Big River is the largest tributary to Lake Ozette (Haggerty and Ritchie, 2004).

The Big River enters the lake at the north end of Swan Bay. The main channel of the Big River is approximately 15 miles long, and the basin area is approximately 22.8 square miles in size (Figure 3-1). The major tributaries to the Big River are (in order of largest to smallest):

- Trout Creek;
- Dunham Creek;
- Solberg Creek;
- Boe Creek;
- Stony Creek;
- An un-named tributary; and,
- Brown Creek (located upstream of the Falls).

A naturally occurring falls at approximately RM 11 is a barrier to anadromous fish passage. The Headwaters Reach above these falls is rugged and steep. The valley below the falls becomes broader and the stream gradient flattens downstream to the confluence with Lake Ozette (Figure 3-6).

The Headwaters Reach above the falls is underlain by Pleistocene age glacial drift and alluvial deposits (Figure 3-7). The northeast side of the valley is bound by topographically steep Eocene age volcanic flows and breccias (of the Crescent Formation). The southwest side of the valley is bounded by slightly less steep Oligocene-Eocene age marine sedimentary rock types. The river drops over the Falls into the lower basin area and meanders across a wide (~0.5 mile wide) valley composed of Pleistocene age glacial till and drift deposits for the reach extending downstream to where it enters Lake Ozette (USGS, 1988; Haggerty and Ritchie, 2004).

The river was broken into several reaches that define changes in geomorphic characteristics. The following is a summary of the location and characteristics of each reach. Reaches are named to reference local features or otherwise designate the governing issues in each reach.

- **Headwaters Reach** (RM 15 – 11). The Headwaters Reach extends from the upper extent of the river channel at approximately RM 15 to the falls at approximately RM 11. The Headwaters is vegetated with conifer tree species, and held in limited land ownership. The Headwaters area has been historically logged, and has existing logging road networks.

- **Falls Reach** (RM 11 - 10). The Falls Reach is a short transition reach and is generally confined with stream gradients ranging up to approximately 3 percent. The upper portion of the reach is defined by a series of naturally occurring waterfalls. The falls define the transition from the Headwaters to the lower basin. Substrate is dominated by gravel, cobbles, and boulders (Haggerty and Ritchie, 2004).

- **Boe Creek Reach** (RM 10 – 6.5). The Boe Creek Reach extends from approximately above the confluence of Boe Creek with Big River to approximately RM 6.5. This reach has experienced the majority of land use changes in the Big River system, and has the greatest concentration of residential and agriculturally developed areas. Riparian vegetation along the river banks has been historically cleared for logging and agricultural purposes. The resulting reduction in near bank large vegetative cover has increased lateral erosion of the river banks. The Boe Creek Reach is defined as a response reach due to the increased potential for lateral and/or vertical changes in channel configuration as a result of changes in flow regime, sediment regime, bank armoring, or other modifications to floodplain features. The channel gradient is generally <1 percent, with occasional sections approaching 2 percent. Sand and pebble materials are common in the lower portions of the reach, while gravel substrate dominates most of the pool tails and riffles (Haggerty and Ritchie, 2004). The lower Boe Creek Reach is one area that experienced the greatest amount of woody debris removal during stream clearance activities in the 1950's (Kramer, 1953; Figure 3-1, Appendix 3-B). Example photos of lateral bank erosion are shown in Appendix 3-A (Photos A-5 through A-7). Photo A-8 shows an example of existing bank armoring in the reach.

- **Solberg Creek Reach** (RM 6.5 – 5). The Solberg Creek reach extends from River Mile 6.5 to approximately River Mile 5, just below the confluence with Solberg Creek. A large majority of the reach is in limited ownership. This reach is a transition reach between the more dynamic upstream Boe Creek Reach and the lower gradient downstream located Highway Reach. The banks of the river are vegetated with large conifers tree species and overbank riparian areas have had limited modifications (e.g., very little logging, agricultural, or other land-use changes). The riparian areas provide sources for woody debris to the river system, as evidenced by the increase of log jams (Haggerty and Ritchie, 2004). The increased woody debris and existing riparian vegetation along the banks of the river have acted to stabilize this reach and limit lateral movement. The channel gradient is generally <1 percent, with occasional sections approaching 2 percent. Sand and pebble materials are common in the lower portions of the reach, while gravel substrate dominates most of the pool tails and riffles (Haggerty and Ritchie, 2004). The Solberg Creek Reach is one area that experienced the greatest amount of woody debris removal during stream clearance activities in the 1950's (Kramer, 1953; Figure 3-1).

- **Highway Reach** (RM 5 – 2). The Highway Reach extends from approximately River Mile 5, just below the confluence with Solberg Creek, to River Mile 2 at the confluence with Trout Creek. This reach is named as such because the highway (Hoko-Ozette Road) located along the rightbank (north side) is perceived to significantly limit channel movement (Golder, 2005b). The river gradient is similar to the Lake Reach (i.e. < 1 percent) due to influence from the lake during winter high water levels. Sediments in this reach include mostly sand and pebbles with occasional gravel patches in the lower half. Gravel becomes more common in locally higher gradient pool tails and glides in the upper half of the reach. This reach lacks developed side channel complexes and sand or gravel bars (Haggerty and Ritchie, 2004). The channel is incised where sands and silts are accumulating, making it relatively stable in its current alignment (Appendix 3-A, Photo A-2). Measured width:depth ratios are low throughout the reach (Haggerty and Ritchie, 2004), which reflects a high degree of channel downcutting (also referred to as incisement and degradation). The Highway reach is one area that experienced the greatest amount of woody debris removal during stream clearance activities in the 1950's (Kramer, 1953; Figure 3-1). The reduction in woody debris complexes accounts for the apparent channel incision. Estimates of vertical drop in channel elevation due to incision range up to approximately 6 feet (Golder, 2005b).

- **Lake Reach** (RM2 – 0). The Lake reach extends over the lowermost two miles of the Big River to its confluence with Lake Ozette (Figure 3-1). The lower reach of the Big River is influenced by backwater from Lake Ozette (Appendix 3-A, Photo A-1). Dunham Creek enters the Big River at approximately RM 1.5. The channel has a low gradient (< 0.2%; Haggerty and Ritchie, 2004). The substrate is mostly fine-grained sediments including silts, sand, and small pebbles. The banks are vegetated, high and steep. The upper portions of this reach are incised (Appendix 3-A, Photo A-2). Woody debris buried in the channel is prevalent throughout the reach. Removal of debris in this reach during clearance efforts in the 1950's was difficult due to limited accessibility, fine grained sediments and backwater from the lake (Kramer, 1953; Figure 3-1).

3.3 Interpretation of Reach Dynamics

Floodplain connectivity is complex and dynamic. A functioning connected channel and floodplain may have one or more of the following components: balance in sediment regime, varied flow regime, overbank riparian areas, relic channels, swales, eroding banks, woody debris, and varied vegetative land covers. Healthy floodplain connectivity requires multiple levels of each of these pieces to work, and may take many years to develop. An understanding for the long-term geomorphic processes in a given system is required to make decisions about proposed projects. Long-term goals can be achieved if the baseline processes for the system are understood and the basic rules governing the system are considered in each management decision step.

The benefits of enhanced floodplain connectivity are well-documented. Increasing the distribution of flood waters into overbank areas or inter-connected off-channel systems reduces site-specific erosion problems, distributes sediment into more varied and long-term storage scenarios, balances sediment transport/deposition further reducing erosion issues, encourages the replenishment of fine grained topsoil sediments into riparian areas thereby encouraging healthy riparian vegetation systems, dissipates floodwaters and floodwater energy by storing peak volumes in overbank areas, and encourages more long-term groundwater recharge of overbank areas and wetlands thereby improving longer term returns to the main channel to sustain low flows. Improvements in floodplain storage cannot be gained by implementing only one project at an isolated location. Doing so often results in relaying the problem being addressed to a different location in the stream. Desired benefits are more likely to be realized if the approach is applied and measured over longer time frames and at the reach scale.

Natural channel development follows a cycle of incision and widening. The channel cuts down into accumulated sediments leading to subsequent erosion of the channel banks. Continued down-cutting leads to the gradual widening of the active channel as the toe of the banks are eroded and more sediment is contributed to the system. As the channel widens the hydraulic geometry changes, and the sediment transport capacity of the channel is exceeded in relation to available flow, causing sediment to accumulate in complex layers across the developing floodplain. As sediment accumulations re-shape the floodplain landscape, the hydraulic geometries are again re-defined and the process of incision may again initiate, starting the cycle over again across a more complex floodplain surface (Simon and Hupp, 1986). The introduction of vegetative materials (i.e., large woody debris) adds additional complexity to the model as it acts to re-direct flows and sediment materials across the floodplain.

The longer-term effect of the large quantities of mobilized woody debris (i.e., eroded from the banks) and riparian colonies throughout floodplain areas is to trap and store sediments in islands or rafts with complex horizontal and vertical geometries. Localized problems with erosion can occur around accumulations of large woody debris and log jams, but the net reach scale effect is to provide a naturally structured (but not necessarily linear) matrix that holds the sediment in place and slows the movement of the sediment laterally or downstream. This matrix works over long periods of time, corresponding to the colonization of vegetation around accumulations of sediment materials at log jams and peak flow histories. For instance, a log jam may form at a given location causing the development of a gravel bar downstream in the hydraulic shadow of the jam. As the gravel bar builds in volume (i.e., length, width, and height) it may start to gain a vegetative cover of trees, shrubs, and/or grasses. The sediment that continues to accumulate within and around the island is "temporarily" stored there until the jam releases or the island erodes in response to some flood event.

This cycle may occur on the scale of take 10’s of years or more, and is strongly influenced by peak flow events.

A series or larger network of large woody debris within a riverine system can act essentially as a large collective grade-control structure(s) that can hold and/or release sediment to downstream reaches. A large system of woody debris distributed over many miles of stream can trap and hold an large volume of material. The same concept applies to traditional dam structures in river systems. Removing a dam from a stream or river can result in mobilization of the upstream accumulated sediment into downstream reaches. The large scale removal of large woody debris from a riverine system can also result in the large scale mobilization of the “accumulated” or stored sediments into downstream areas. Although this can occur naturally in response to peak flows or other events, it can also occur in response to historical land and channel management practices, thereby speeding up the timeline of individual components of the channel evolutionary process.

This is essentially what has happened on the Big River with the implementation of the stream clearance work by the Washington State Department of Fisheries in the 1950’s. The large scale removal of woody debris in the Highway, Solberg Creek, and lower Boe Creek Reaches has resulted in a reduction in storage of sediments and a loss in complexity of woody debris structure throughout the main channel and floodplain. This has lead to gradual incision of the channel, and a corresponding drop in the channel profile elevation. In areas where riparian corridors are not in place, this has lead to increased bank erosion. In areas where riparian vegetation is in place, the channel has continued to incise. The overall effect in some places has lowered the channel as much as 6-feet (Golder, 2005b).

Where the main channel has dropped in elevation, the tributary stream channels will also drop in elevation. The effect therefore spreads to tributary basin areas where networked wetlands may exist. Long-term lowering of the main channel and corresponding tributary channels can have the effect of lowering the adjacent floodplain groundwater table, and essentially developing a better drained floodplain. This has the greatest impact on wetland areas connected to the main channel and/or its tributaries.

The following outlines specific recommendations for future actions within each of the project reaches incorporating the information and data reviewed as apart of this assessment and as outlined in the discussion above.

3.4 Discussion of Potential Actions

The following discussion incorporates the data and information outlined in previous sections and develops the ideas for potential future actions in each reach of Big River. The discussion is generally organized around improving and/or enhancing floodplain connectivity, increasing and/or maintaining floodplain groundwater storage, and wetland storage in each reach. These two issues were identified through review of the existing information and other literature on riverine and floodplain systems as key to restoring long-term natural fluvial geomorphic processes.

3.4.1 Headwaters Reach

Floodplains in the Headwaters reach are limited in size due to the narrow, steep, and rugged terrain. The scales at which improvements in floodplain connectivity can be achieved are varied, but generally correspond to the predominately small stream networks throughout the reach. Although the scales are different from the broad floodplains of the lower valley, the basic concepts of channel process and function remain the same. Changes in stream function are primarily influenced by changes in land use and by patterns of natural disturbance. Changes in basin vegetation cover caused either by changes in land use, vegetation cover or natural disturbance can result in increases in peak stream flow and run-off volumes. The increase in road networks can increase the delivery of fine grained sediments to streams.

Recent trends in restoration and improvement of floodplain connectivity in contributing basin areas are moving toward abandonment of un-used forest roads and restoration of stream crossings where large fills and/or culverts were installed. The USFS abandonment of forest roads policy is to restore the road section to pre-disturbed contour and graded condition. For instance, where roads were cut into side slopes, the cuts are filled. Where roads are constructed of fill, sections the material are removed/regraded to match the original grades. Road abandonment policies accepted by DNR for RMAP work typically focuses on restoration of forest roads to undisturbed conditions where unstable fill exists or where there is a clear environmental hazard. Large fills at culverted road crossings can be removed and the original stream gradient restored through the crossing. Fish passage issues may addressed where road crossings limit upstream access. There are also situations where road embankments have created wetland areas where ponded water accumulates on the upstream side. These areas should be identified and preserved where they exist, and enhanced to the extent necessary to maintain the created wetland resource.

These types of projects require a comprehensive look at the location, quality, and conditions at individual sites. Because there are typically a large number of candidate sites, an inventory is required to identify, evaluate, and prioritize the sites so that resources can be effectively applied to the project area.

Therefore consideration may be given to the development of an inventory of the existing road network, tributary streams, and historical land use practices in the Headwaters reach. The inventory would provide a basis for assessing the feasibility of proposed enhancement opportunities. The inventory would focus on gaining a better understanding of the extent of the road network, streams, wetlands, fish passage, etc., and how they may be connected to within the Headwaters area. This type of site specific data can support development of road abandonment and maintenance plans, as well as develop a better understanding for land owners on how to manage road networks over the long-term.

The Road Maintenance and Abandonment Plan (RMAP) program focuses on improving existing road networks on private commercial forest and state forest land. Priorities for work include the following:

- Removing fish passage blockages, on roads affecting most habitat first, usually from the bottom of basin and working upstream.
- Preventing or limiting sediment delivery/mass wasting.
- Correcting drainage or unstable sidecast where mass wasting "could deliver to public resources or threaten public safety.
- Preventing road drainage to typed waters.
- Repairing or maintaining stream parallel roads, emphasis on minimizing/eliminating water and sediment delivery.
- Minimizing the interruption of surface and subsurface water.
- Repair/maintenance work that can be done with maximum operational efficiency.

Much of the Headwaters Reach has been mapped as susceptible to landslides under Clallam County's Critical Areas Ordinances (CAOs; Figure 3-7). However, the Clallam County Critical Areas ordinance does not apply to forest practice lands that are being used for Class I, II, or III forest practices, as these are under jurisdiction of the Forest Practices Act. The Forest Practice Rules provides protection of areas within Riparian Management Zones and protected buffers along streams.

Any lands that are cut for harvest and are not intended to be reforested because they will be used for urban or residential development are classified as Class IV general forest practices (WAC 222-16-050(2)). When this forest conversion occurs, there is a transfer of jurisdiction from the state (forest practice rules) to the county (comprehensive plan and zoning) that occurs at the time when the land is no longer used for forest practices. To complete a Class IV conversion, an application is filed with the Forest Practice Board, the SEPA lead agency is determined, SEPA is conducted, and then, if approved the county or city changes the land use designation of the property. Once a forest conversion has been completed, local regulatory protections to apply to the land, including Critical Areas Ordinances and zoning regulations. However, there are gaps in the protection of these parcels. The Forest Practices Act exempts land clearing on lots smaller than two acres with less than 5,000 board feet of timber removed.

It is assumed that the lands in the Headwaters Reach of Big River are Class I, II, or III forest lands, are not subject to county ordinances, and are governed by the Forest Practices Act.

3.4.2 Falls Reach

The Falls Reach is a transition reach between the Upper and Lower Basin areas. The falls act as a natural fish barrier and as a natural grade control for upstream versus downstream channel dynamics. The reach is very dynamic and responsive to in-channel changes (i.e. woody debris, sediment loading, etc.). Aside from maintaining the function of the falls reach, no additional in-channel work is proposed in this reach. Continued monitoring of the reach for physical changes in channel morphology is recommended to provide a comprehensive record of the Big River system and to support work in other reaches.

3.4.3 Boe Creek Reach

The Boe Creek Reach is one of the more dynamic river reaches within the project area. The long-term reduction in riparian vegetation through development of agricultural land uses has lead to incision and increased bank erosion. Channel migration studies document areas where lateral erosion problems exist (Figure 3-1). The bank erosion issues are contributing fine grained sediments into the river system, and leading to continued damage of agricultural properties. Any future planning efforts should recognize this reach has the highest density of residential and agriculturally developed areas within the project area. As such, any proposed enhancement work in this reach should fully incorporate land owner concerns and balance enhancement efforts with existing land uses.

Enhancement opportunities in the Boe Creek Reach should recognize the highly dynamic response mechanisms that are at work in the river channel. The propensity for lateral erosion in the reach makes it a candidate for possible bank stabilization projects. Proposed bank stabilization work should consider both up- and downstream impacts and incorporate the reach geomorphic characteristics specific to this reach. For instance, increased roughness (i.e. installation of woody debris) in active channel areas may lead to increased lateral bank erosion due to the lack of available riparian vegetation and generally unstable banks. Therefore, restoration efforts should focus stabilizing banks through soft-engineering approaches or improving riparian vegetation cover in overbank areas along the river channel through conservation programs such as the Conservation Reserve and Enhancement

Program (CREP), Conservation Reserve Program (CRP), and other programs of the United States Department of Agriculture and/or conservation easements (Appendix 3-D). These are typically administered and facilitated through the local conservation district.

- **Conservation Reserve Enhancement Program**. Unique state and federal partnerships allow landowners to receive incentive payments for installing specific conservation practices. Through the CREP program, farmers can receive annual rental payments and cost-share assistance to establish long-term, resource conserving covers on eligible land. This program is designed to re-establish riparian buffers along streams, especially those with ESA-listed salmon species. Compensation to the landowner consists of several components including:
  - Annual rental rate (typically $135-$423 per acre, but varies widely);
  - Signing incentive ($10/acre/full contract year. e.g., 100 acres for 10 years would generate a signing incentive payment of $10,000); and,
  - Other incentives and cost sharing such as for fencing costs, re-establishment of riparian vegetative cover, and others.
- **Conservation Reserve Program -** The Conservation Reserve Program is a voluntary program for agricultural land owners. Landowners receive annual payments by planting vegetation on idle, highly erodible agricultural lands. The land must be highly erodible and have a history of non-irrigated cropland tracts for at least four of the most recent six years. Since the payout per acre is low (annual rental rates typically run $160-$220 per acre), landowners must have many acres to make this program worthwhile. Enrollment is highly competitive, and landowners would be bidding against each other across the country.

Wherever possible, enhancement projects should be initiated where landowners are interested in supporting and maintaining such projects. Recruiting cooperative landowners and establishing a sponsor for the project is the key to the long-term viability of enhancement projects. Continued education and outreach programs that explain the benefits and long-term returns from enhancement work will help to encourage landowners to participate in continued enhancement efforts.

3.4.4 Solberg Creek Reach

The Solberg Creek Reach is a transition reach between the upstream dynamic and laterally erosion prone Boe Creek Reach, and the downstream Highway Reach. The Solberg Creek Reach most likely represents a template for what the Boe Creek reach used to look like before the riparian vegetation was removed. This reach is relatively sparsely inhabited with few residential homes. Property ownership is widely held. This reach offers excellent potential for development of woody debris enhancement structures, with a reduced risk of impacting up- or downstream developed properties.

The morphology of the Solberg Creek Reach allows for installation of in-channel structures. Enhancement efforts should incorporate complex woody debris structures with off-channel and back-channel habitat areas where possible. Existing riparian vegetation in overbank areas will provide excellent cover and enhance the rapid return on investment in project development, design, and installation in the form of habitat value. Development of increased woody debris complexes through this reach over the long-term should improve connectivity between the main channel and overbank areas. In particular, there is the opportunity to expand wetland areas in the lower portion of the Boe Creek Reach (Figure 3-1) and further downstream into the Solberg Creek reach through development of increased roughness (i.e., installation of woody debris).

3.4.5 Highway Reach

The Highway reach is influenced by the presence of the Hoko-Ozette Road running along the rightbank (north) side of the main river channel. The channel through this reach experienced some of the greatest extent of removal of large woody debris during the 1950's (Figure 3-1), resulting is a net loss of in-channel diversity and subsequent down-cutting and incision of the stream profile. The channel has slowly lost connectivity to the adjacent floodplain as it has cut down and incised into the finer grained material prevalent throughout the reach. Additionally, the net cumulative effect of armoring the road embankment throughout this reach will encourage the river to remain along the toe of the road embankment and further reduce connectivity with the rest of the active floodplain.

The primary goal for this reach is therefore to slow the incision process and possibly, over the long-term, restore connectivity between the channel and floodplain. One approach for increasing roughness in the channel and floodplain is through the introduction of large woody debris, in essence reversing the work completed by the stream clearance efforts in the 1950's. This approach would work best if implemented at a reach scale. Development of more woody debris structures throughout the reach would have a net increase in roughness and develop a matrix of material that could trap sediments in the form of bars and islands. The diversity of flows around individual structures would also increase resulting in more complex and higher quality habitat areas. Increasing roughness in the channel and floodplain would force flows to interact with woody debris, thereby developing more varied flow regimes around individual structures. The long-term effect of this at a reach scale would create varied thalweg profiles (i.e., scour pools, runs, pool/riffles sequences, etc.) around roughness features. This increased complexity in flow regime especially at low-flows would enhance habitat diversity and quality.

An individual woody debris structure would over time establish a corresponding depositional area/bar/island located in its downstream shadow. This depositional area will slowly establish a vegetative cover and stabilize as the vegetation matures and take hold. Localized scour and erosion should be anticipated around individual woody debris structures as the channel responds to the initial placements. The sediment and other woody debris material stored in this "structure" may change/move downstream in response to peak flow, but the net effect distributed over the entire reach will diversify the storage of sediments across the floodplain and reduce continued degradation of the channel.

Numerous wetland complexes are evident in this reach throughout the north floodplain of the river and along Trout Creek (Figure 3-1). Restoring, or at least stabilizing the channel against continued down-cutting can only improve the viability of these existing wetland areas and possibly develop, enhance, and expand them in the future.

3.4.6 Lake Reach

The Lake reach has remained essentially unchanged in recent history and continues to be influenced by back-water from the lake. Numerous log jams were identified during the stream clearance work completed in the 1950's, but little was actually removed due to the difficult access and equipment limitations of the day. The conditions are largely un-changed today, making implementation of project in the Lake reach still difficult. Habitat may be enhanced by connecting the main channel to off-channel areas or possibly to historical channel networks. The back-water effect from the lake may provide inundation of developed off-channel areas and also encourage rapid development of riparian cover. Review of the LiDAR data will support identification of project sites (e.g., old channel alignments, swales, relic channels, or sloughs). The focus in this reach is to use the back-water condition of the lake environment to develop corresponding habitat enhancement opportunities.

3.5 Data Gaps

Much useful data exists and was reviewed in the execution of this assessment. A limited but useful record of historical photographs was obtained from Kramer (1953) and recent photographs provided by the Makah Tribe. The collection of additional photographs is currently being undertaken by Mr. Ed Bowen. Recommendations relating to data gaps include: the continuation of on-going continuous data collection (e.g., stream gaging); periodic synoptic data collection (e.g., air photos); and, detailed surveys (e.g., channel profiles).

3.5.1 Stream Gaging

The initiation of a stream flow gaging station (Figure 3-1) by the Makah Tribe is the first and one of the most important efforts in developing an understanding of flow regime in the Big River basin. Continued stream flow monitoring should be a priority for the future. Maintenance of the current continuous stream gaging should be the priority. Additional stream gaging stations located on tributaries to the Big River would further develop a better understanding for contributing flows in Trout Creek, Solberg Creek, and Boe Creek to the main river channel. Additional stream gaging stations should provide continuous data collection, so that a corresponding continuous flow record can be developed. In the absence of continuous stream gaging stations, spot measurements of streamflow are very useful.

3.5.2 LiDAR (Light Detection and Ranging)

LiDAR aerial flights completed in 2003 only extended approximately 8 to 9 miles upstream of the mouth of the Big River (Figure 3-2). Extending the existing 2003 LiDAR database upstream to incorporate the entire Big River basin through approximately RM 15 would provide a useful dataset in the design of remediative actions (e.g., locating large woody debris installations). Additionally, we understand that the algorithms for the previously completed LiDAR data require re-calibration to rectify inaccuracies in the data. We recommend these accuracy issues be addressed and the data updated as needed.

3.5.3 Aerial photos

Aerial photographs are most valuable in the historical context when efforts are initiated to look at long-term changes in basin characteristics, or to look at changes over time at a particular location. We recommend the existing database of historical aerial photos including 1994, 2000, and 2003 (Figures 3-3 through 3-5, respectively) be expanded to include updates at regular time intervals (e.g., every 10 years). Where possible these photos should be in color and provide stereo-pair sets for future analysis and photo interpretation efforts.

3.5.4 In-channel elevation data/bathymetry

The availability of LiDAR and aerial photos provides a resource for viewing and assessing surface features throughout the basin. Photo interpretation can also be used for rough assessments of vertical channel and floodplain changes through stereo pair evaluations and analysis of geomorphic characteristics. But, the highest quality source of data for quantification of vertical channel changes is through recording of historical elevations at known locations over time. This report talks about changes in channel morphology that relate to vertical channel movement and/or changes in channel section geometry. An effective way to track changes in channel geometry is to record those changes over time through site surveys. Surveys can consist of (in order of increasing cost and usefulness):

- Cross section surveying of cross-sections at fixed reference locations;

- Surveying of channel profiles along thalweg alignments or other channel alignments (i.e. relic channels, swales, back-channel areas, etc); and,

- Full bathymetric scanning/mapping of channel bottom areas.

Development of a database of channel survey information will help explain or support geomorphic characterizations and track trends in channel behavior.

A likely start for the database is at the flow gaging station location (Figure 3-1). We recommend that a survey benchmark be established so that continued stream gaging measurements can be tied to a known elevation datum. This will allow for the long-term comparison of channel geometries relative to flow histories at this location. Channel survey data will also provide a basis for completing hydraulic assessments and engineering analysis.

Additional channel surveys are recommended for the extent of the project area. Priorities should be given to the reaches below the Falls in developed areas and areas/reaches where projects are proposed. Survey should be coordinated to the elevation datum used in the LiDAR flights. Surveys can consist of detailed channel bottom contouring, channel profiles measured along the thalweg, or cross-sections taken at known locations throughout the project area. The latter is most common. Successive channel surveys would readily show possible trends in channel change (either degradation or aggradation) at those locations, and a network of channel cross-sections throughout the project area would provide a reach based comparison of channel characteristics.

3.6 Summary

The following offers a bulleted summary of key enhancement opportunities in each reach. Recommendations common to all reaches include:

- A reach scale approach to analysis and projects.

- Monitoring (aerial photos, surveys, stream flow data gathering, etc).

- Appropriate implementation of riparian zone Critical Areas Ordinances, as applicable.

3.6.1 Headwaters Reach

Opportunities for enhancement in the Headwaters Reach are focused on evaluating the existing resource and developing plans for best long-term management of diverse relationship between existing road networks, small tributary streams, and corresponding wetland areas. The following summarizes the key actions in this reach:

- Comprehensive road/drainage inventory and implementation of Road Maintenance and Abandonment Plans (RMAPs) in accordance with the Forest Practices Act.

3.6.2 Falls Reach

The Falls Reach is a transition reach between the Upper and Lower Basin areas. No specific enhancement activities are proposed but the reach should be monitored in conjunction with the other work completed in the basin to track possible changes in the morphology of this reach.

3.6.3 Boe Creek Reach

The Boe Creek Reach is one of the most altered and more dynamic river reaches within the project area, and has the heaviest developed residential community. Any efforts to implement restoration activities in this reach should recognize the importance of the local residents and find the balance between habitat enhancement and existing land use. Long-term enhancement opportunities in this reach are summarized as follows:

- Soft-engineered bank stabilization (e.g., anchored large woody debris and strategic riparian plantings, versus rip rap rock).
- Conservation programs such as CREP and/or conservation easements (Appendix 3—D).
- Recruitment of landowners for implementation of enhancement projects.
- Appropriate implementation of riparian zone Critical Areas Ordinances.

3.6.4 Solberg Creek Reach

The Solberg Creek reach is a transition reach between the upstream located dynamic and laterally erosion prone Boe Creek reach and downstream located Highway reach. This reach offers excellent potential for development of woody debris enhancement structures, with a reduced risk of impacting up- or downstream properties. Additional benefits include enhancement of wetlands function in overbank areas. Long-term enhancement opportunities in this reach are summarized as follows:

- Soft-engineered bank stabilization .
- Increase large woody debris/roughness features in channel and floodplain.
- Appropriate implementation of riparian zone Critical Areas Ordinances.

3.6.5 Highway Reach

Enhancement efforts in the Highway reach should focus on increasing roughness in the main channel corridor and overbank floodplain areas, and incorporate considerations into planning and design to minimize the potential for the channel to relocate along the Hoko-Ozette Road. Long-term increases in channel and floodplain roughness will slow or reverse historical down-cutting trends (channel incisement/degradation), improve connectivity between the main channel and the floodplain, and enhance wetlands function in overbank areas. Long-term enhancement opportunities in this reach are summarized as follows:

- Increase large woody debris/roughness features in channel and floodplain.

3.6.6 Lake Reach

Habitat enhancement opportunities in the Lake reach should look for connecting the main channel to off-channel areas and historical channel networks. The back-water effect from the lake may provide inundation of developed off-channel areas and also encourage rapid development of riparian cover. Long-term enhancement opportunities in this reach are summarized as follows:

- Install large woody debris/roughness features in channel and floodplain in conjunction with development of off-channel habitat areas.

4.0 CITY OF FORKS MUNICIPAL WATER SUPPLY

The City of Forks (City) is located in western Clallam County, near the confluence of the Sol Duc, Calawah and Bogachiel Rivers on the Olympic Peninsula of western Washington (Figures 1-1 and 4-1). Forks is the largest community in WRIA 20 with a water service population of approximately 5,000, including the incorporated city limits and surrounding unincorporated area. The City serves water to over half of the population of the watershed with groundwater from their municipal water supply.

Information on the City's water system was reviewed as a component of the WRIA 20 Storage Assessment in order to assist the City in providing a safe and reliable source of drinking water. The information contained in this chapter will help in the planning of the City's municipal water supply needs, which is one objective of the watershed planning.

4.1 Hydrogeology

Groundwater in the Forks Prairie area is mainly found in glacial sediments, therefore understanding the glacial geology of the region is important for determining many factors, including groundwater recharge, discharge and movement, as well as any hydraulic connection between groundwater and surface water. The extent of glaciation is important to the hydrogeology of an area because the presence of till (deposited at the base of a glacier) often results in confining units which can control the recharge and flow of water in an aquifer. There are reports that the ice may have been up to 2,000 feet thick in the Quillayute-Forks area (Booth and Goldstein, 1994).

4.1.1 Glacial Deposition

Two main types of glaciers are alpine (valley) and continental (ice sheet). Alpine glaciers are bodies of ice originating in mountainous areas and flowing downvalley to their terminus. A typical alpine glacier might cover several square miles and reach thicknesses of several hundred feet. Ice sheets are much larger, covering hundreds to thousands of square miles with ice thickness up to thousands of feet. While alpine glaciers are usually restricted to alpine valleys, ice sheets are thick enough to move over existing terrain.

The continental glacier which flowed into the western United States during the last ice age is called the Cordilleran Ice Sheet. The Cordilleran Ice Sheet advanced from Canada into western Washington between 1 million years ago and retreated approximately 12,000 years ago. The Puget Lobe of the ice sheet occupied Puget Sound between the Cascade Range and Olympic Mountains. West of the Puget Sound, the Cordilleran Ice Sheet advanced into the Straight of Juan de Fuca, along the northern edge of the Olympic Mountains, wrapping slightly southward around the western tip of the Olympic Peninsula to near the present-day location of the City of Forks. Geologic mapping indicates the north and west sides of the Olympic Peninsula are covered with a blanket of glacial deposits derived from the last major advance of the Cordilleran Ice Sheet (Tabor and Cady, 1978).

In addition to the continental glaciers, smaller alpine glaciers also strongly influenced this region of WRIA 20. Today the Olympic Mountains harbor 266 active alpine glaciers. Most are cirque glaciers, but several small valley glaciers extend beyond the cirques (Spicer, 1986). Despite the relatively small size of most of the alpine glaciers in the Olympic Mountains today, the sedimentary record of many valleys of the Peninsula indicate a history of much more extensive glacial activity. Geologic mapping indicates that some valleys in the western Olympics repeatedly hosted large Pleistocene valley glaciers, whereas other valleys had only limited glacial activity in their headwaters, or glaciers were absent altogether (Montgomery, 2002). Glaciation, sea level fluctuation and tectonic deformation were the main governing forces in the Quaternary history of Olympic Peninsula, but glaciogenic deposition has exerted the dominant influence on geomorphic and stratigraphic evolution of the river valleys (Thackray, 1996). In the western Olympic Peninsula, for instance glaciated valleys are thought to have had between two and four times as much rock mass removed from them as fluvial valleys (Montgomery 2002).

The hydrogeology of the Forks Prairie area is complicated by fact that there were numerous glacial advances into the western Olympic Peninsula. The glacial record of the western Olympic Peninsula is unique because it records a time of limited alpine ice extent during the last maximum extent of continental glaciers. The Queets and Hoh river valleys contain morphologic and stratigraphic evidence of at least six ice advances during the last (Wisconsin) glacial cycle (Thackray, 2001). It has been assumed that mountain glaciers fluctuate synchronously with continental ice sheets. However, the glacial sediment record indicates that the maximum advance of the alpine glaciers of the Olympic Peninsula preceded the maximum advance of the Cordilleran Ice Sheet by as much as 8,000 years (Thackray 2001). The smaller mass of alpine glaciers typically allows more rapid response to short-lived regional climatic fluctuations than continental ice sheets. However this has been difficult to document because many mountain glacier records in the western United States are incomplete due to a lack of datable material, poor stratigraphic exposure and/or erosion or concealment as a result of the extensive advances during the last glacial maximum (Thackray, 2001). Alpine glaciation in the Olympic Mountains appears to have been driven mainly by moisture supply from the Pacific Ocean and not necessarily by periods of coldest temperatures. Moisture supply to the Olympic mountains during the last glacial maximum was hindered by changes in regional weather patterns (e.g., a southern shift in the winter jet stream) thought to have been caused by the presence of the Cordilleran Ice Sheet (Thackray, 2001). The apparent differences in the timing of alpine and continental glacier fluctuations may also be the result of the contrasting preservation of sedimentological record.

We speculate that alpine glaciation in the Calawah River basin may not have been as extensive as other areas in the western Olympics (e.g., Queets and Hoh) because the elevation in the catchment is generally below 4,000 feet. The topography of the South Fork of the Calawah River and the Sitkum River do not indicate the strong "U-shaped" topography typically present in glaciated valleys. The North Fork of the Calawah River may have had a much stronger influence.

4.1.2 Post-Glacial Processes and Contemporary Hydrogeology

This section includes discussion of the post-glacial processes that formed today's landscape, along with a relatively detailed discussion of groundwater flow in the Quillayute Prairie area. More detailed discussion of groundwater flow in the Forks area is contained within the section in which groundwater flow and wellhead protection areas are modeled.

According to the "hardpan" (as till is often referred to by well drillers) indicated in well logs for the City's wells, the continental ice sheet advanced into the Forks Prairie area (likely from the north along the present-day location of Highway 101). Till likely blanketed the entire area from Forks Prairie to Quillayute Prairie and locations further south and west. Water from the ancestral Calawah, Sol Duc and Bogachiel Rivers likely eroded and reworked the material deposited by the glacier, and may have deposited the sand and gravel unit in which the City's wells are completed. In the process of reworking the sediments deposited by the ice sheet, water draining from the Calawah River and other drainage basins likely eroded the till plain from its former position of occupying the valley into its current configuration (Figure 4-2).

Field visits were conducted to confirm previously mapped lithologies (Appendix 4-A). One cross section was developed along the east-west axis of the Quillayute System (Figure 4-3), along with three north-south cross sections (Figures 4-4 through 4-6).

The Quillayute Prairie is home to a few dozen residences and the Quillayute State Airport. The Airport was constructed in the early 1940s and used as a military airbase during World War II. While the military installation was active, it had a population of approximately 2,000 and was supplied with water from three wells. The Airport is now owned and operated by the City of Forks.

The Quillayute Prairie is a gently sloping terrace located between the Dickey and Sol Duc Rivers (Figures 4-4 and 4-5). The Prairie is comprised of till (compacted, poorly sorted clay, silt, sand, gravel and cobbles) which is over 80 to 100 feet thick, according to well logs for wells completed in the area and conditions observed in the field (Appendix 4-A). The southern edge of the prairie is abruptly truncated and forms a bluff overlooking the broad floodplain of the Sol Duc River.

The Quillayute Prairie is likely a remnant of the larger till layer, which was eroded by the Sol Duc and Dickey Rivers that left an "island" forming the prairie. The linear, northeast-southwest trending ridge located between the Calawah River and Quillayute Road (north of Forks; mapped as undifferentiated drift in Figure 4-1) is also capped by till (Figures 4-6). This linear hill is also likely a remnant of a continuous till sheet that was eroded leaving this island of till.

Using geologic and topographic maps and limited water level data, a conceptual model of groundwater flow was developed for the Quillayute Prairie area. Water levels were measured in several wells using an electronic water level sounder. Wellhead elevations were recorded with a handheld GPS unit. (The accuracy of GPS unit varied between ±18 and 23 feet and may produce inexact groundwater elevations). Groundwater elevations on Quillayute Prairie likely approximate topography and there appears to be a main groundwater divide along the axis of the prairie that might be coincident with the "east-west" runway of the Airport. Groundwater flow beneath the Airport is likely to the north and south off either side of the Prairie from this divide. Wetlands near Quillayute Road (SE ¼ SW ¼ Sec. 13, T 28 N, R 15 W) may be coincidental with groundwater discharge. On the north side of Quillayute Prairie, the small tributary streams of the Dickey River are incised into the Prairie and to which groundwater is draining (Secs. 7 & 13, T 28 N, R 15 W).

Most domestic wells on the Prairie are drilled to depths between 100 and 130 feet and are completed in a sand and gravel layer. The sand and gravel layer supplying water to domestic wells on Quillayute Prairie is likely a separate water bearing layer than the Quileute wells completed in the Three Rivers area (Figure 4-4 and 4-5). Well logs for wells completed in the Three Rivers areas indicate the presence of a clayey sand and gravel unit in the upper 20 to 30 feet of the borings. This unit is likely stratigraphically lower than the sand and gravel unit in which the wells on Quillayute Prairie are completed. Additionally, the water level in the wells on Quillayute Prairie are between 60 and 70 feet higher than the wells completed in the Three Rivers area. According to the conceptual model (Figure 4-2), wells in the Quillayute Prairie area tap older alluvium and outwash, whereas the Quileute wells tap younger alluvium. Hydraulic connection between wells on Quillayute Prairie and the Three Rivers area may be limited, if present at all. In addition to lack of a clear connecting unit between the areas, the Sol Duc River likely acts as a groundwater divide between the two locations.

4.2 Water Supply System

The municipal water system for the City of Forks is presented in this section. A review of water rights and use is first described, followed by a description of the sources of water, water quality considerations and finally conventional infrastructure storage.

4.2.1 Municipal Water Rights and Water Use

The City has three active groundwater rights. The City holds 1,100 gallons per minute (gpm) and 950 acre-feet/year in primary rights for Wells 1, 2, 4 and 5 (Table 4-1). The City's 1999 Comprehensive Water System Plan indicated a total water rights of 1,430 gpm and 950 acre-feet/year (Polaris, 1999). A review of the City's water right files indicated that some of the rights are supplemental (Table 4-1), however the designations are not clearly stated in the water rights files. Despite repeated mention in the water rights files of the portions of the total Qa (annual quantity) being supplemental, there is not an explicit mention regarding the amount of primary Qi (instantaneous quantity). It is assumed that 500 gpm under GWC 2108-A and 600 gpm under G2-24829C are primary, for a total primary Qi of 1,100 gpm. The relative size of these quantities is consistent with municipal water use patterns where the value for Qi (in gpm) is higher than the value for Qa (in acre-feet/year) calculated if the well were pumped continuously. In order to meet peak water demand, municipalities typically must pump at rates higher than those calculated for average Qa use.

In 2004, the City pumped approximately 655 acre-feet of water. Assuming a service population of 5,000, the average per capita water use is 119 gallons per day per person (gpcpd). This per capita use value is slightly higher than values reported for Clallam County by the USGS, where values of 100 gpcpd was reported for domestic use and 103 gpcpd was reported for all uses including domestic, irrigation and industrial uses (Lane, 2004). A full characterization of water use has not been conducted, and factors that may affect calculated per capita use patterns include industrial use.

Average monthly use is shown in Figure 4-7. The average monthly use from November to April is assumed to be representative of non-consumptive interior use and accounts for approximately 90% of the total water use. This water use is considered non-consumptive because it is returned to the groundwater through septic systems, including the treated effluent from the City of Forks wastewater treatment plant. The higher use from May to October is assumed to reflect exterior use (e.g., landscape irrigation). This use is considered to represent consumptive use due to evapotranspiration losses, although a portion of it may recharge to groundwater depending on irrigation patterns.

Total annual water use in 2004 has not changed significantly from 1999 (i.e., approximately 700 AF/yr). Therefore, annual and instantaneous water use projections from the 1999 Comprehensive Water System Plan are used and adjusted assuming no significant change between 1999 and 2005, and assuming future annual demand growth of 1% and 3% (Figures 4-8 and 4-9). This results in the need for additional water rights within the next few years as driven by the need to meet maximum daily demand estimates (e.g., instantaneous). This estimate is based on an assumed maximum daily demand peaking factor of 2.5 and an associated maximum average daily demand of slightly less than 1,100 gpm (Polaris, 1999). This factor may be conservatively large, given that the actual maximum installed pumping capacity is approximately 880 gpm. Conservative estimates are standard in water system planning to provide a safety margin. The City currently records water use on analog spiral chart recorders, which makes review of the data labor intensive. Replacement with digital recorders, as is planned in the near future, will facilitate data analysis.

The schedule for new water rights may be deferred if growth is slower than projected (as occurred between 1999 and 2005), or accelerated if demand increases above projected rates (e.g., new industrial demand develops). Given the rate that new water right applications are processed, it is recommended that the City submit applications for new water rights and pursue the processing of such applications.

4.2.2 Water Supply Sources

The City's water supply system relies exclusively on groundwater supplied by five wells ranging in capacity from approximately 140 gallons per minute (gpm) to 560 gpm. All of the City wells are completed in a sand and gravel aquifer. Bedrock was encountered during drilling of Wells 1 and 2, at 191 and 157 feet below ground surface (bgs) respectively. The City's wells are older (26 to 52 years) but have had very few problems during their operation. There are problems reported with low seasonal (summer) water levels and limited available drawdown. Butterfly valves were installed on the discharge line of several of the City's wells in the late 1990's in order to control drawdown in the wells during pumping. Therefore operation of the wells is not optimized with respect to their associated water rights.

City of Forks Municipal Water Supply Well Details

Well No.	**Township, Range, Section and ¼-¼ Section**	**Screened Interval** (ft bgs)	**Current Pumping Capacity** (gpm; valved back to control drawdown)	**Associated Water Right**	
				Qi (gpm)	**Qa** (AF/yr)
1	28/13-4 SW SE	125-135	(not used)	500	504
2	28/13-4 SW SE	110-115	180		
3	28/13-4 SW SE	101-109	140	290*	464
4	28/13-9 NE NW	118-128	350	600	446**
5	28/13-9 NE NW	117-128	560		
			Total:	**1,100**	**950**

* Supplemental to Wells 1 & 2.

** This right also has an additional 504 AF/yr volume that is supplemental to Wells 1 & 2, for a total Qa of 950 AF/yr.

The City has been considering installation of a new water supply well to replace the lost capacity of Well 1, to be able to fully exercise existing water rights, and to diversify the water sources supplying the City. Diversification of water supply sources also increases system reliability and redundancy. Because the existing wells do not fully exercise the existing water rights, a new well could be permitted as additional points of withdrawal under existing water rights. Well siting considerations are discussed later in this chapter.

4.2.3 Water Quality

The Washington State Department of Health (WDOH) water quality database (current as of November 2004 was queried to determine if the City's water system has documented any water quality problems. The quality of the City's water appears to be excellent and there are no concerns with the City's water quality, except:

- In 1985, there were several exceedances of iron and manganese (these are aesthetic concerns, not health concerns);

- In the late 1980s there were several detections of disinfection byproducts in the source water; and,
- Well 1 has experienced hydrogen sulfide concentrations in recent years and is currently not being pumped.

There have been anecdotal reports of saline water in isolated wells of the Forks Prairie area. This area is located too distant from the Pacific Ocean to have any reasonable concern related to saline intrusion. Such reports, along with the hydrogen sulfide in Well 1, is most likely related to deep-seated groundwater flow discharging from bedrock to the unconsolidated sand and gravel aquifers.

4.2.4 Existing and Future System Storage

The City has three above-ground storage tanks with nominal capacities of one million gallons, 750,000 gallons and 150,000 gallons. The 150,000 gallon tank is currently not in use and is being considered for replacement by a larger tank (e.g. one million gallons). The actual working storage capacity is approximately 1.55 million gallons (e.g., due to dead storage), which provides for 2.5 days of storage assuming at the current average daily demand of 0.6 MGD, based on assumptions in Polaris (1999). Although not explicitly stated in the Comprehensive Water System Plan, it is assumed that Polaris (1999) accounted for dead storage in the reservoirs.

Total annual water use in 2004 has not changed significantly from 1999. Therefore, current and projected future storage needs are taken from the 1999 Comprehensive Water System Plan and adjusted assuming no significant change between 1999 and 2005, and assuming future annual demand growth of 1% and 3% (Figure 4-10). The DOH Water System Design Manual has specific requirements and guidelines for storage, as summarized:

- Dead storage – storage needed to provide minimum water pressures; that is, the volume of water (in any reservoir) which is less than approximately 70 feet (30 pounds per square inch [psi]) above the highest service in that pressure zone.
- Standby storage – storage for reliability purposes (e.g., if one or more sources is out of service for a short time); required volume is calculated as follows:

  > 2 x average day demand minus daily supply capacity of all sources except the largest (but recommended not less than 200 gallons per day per Equivalent Residential Unit (ERU; an ERU is a unit of measure used to equate non-residential water usage to single family residences. For example, if a system has sufficient capacity to serve 100 Equivalent Residential units (ERUs), then it can serve 100 single family houses. Similarly the same system could serve 80 single family residences and one (or more) commercial services that has a water use equivalent to 20 ERUs. For example a school might be expected to use the same amount of water as 20 single family residences. Therefore, this school represents 20 ERUs.)

- Peak flow storage – storage to supply peak demands in excess of supply capacity. Required volume is calculated as follows:

  (Peak hour demand minus capacity of all sources) x 150 minutes

In some cases, peak flow and standby storage, the largest two components, are combined due to economic necessity on the assumption that the likelihood of a source outage and a major fire occurring on the same day is small. DOH requires the fire marshal to formally approve combining these two storages. Ten State Standards indicate only that storage is adequate to meet domestic and fire flow demands (Great Lakes - Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, 2003).

Based on Polaris (1999), the City of Forks will need new storage by the year 2012 at the earliest (i.e., assuming a 3% demand growth rate). New storage may be deferred significantly into the future based on lower historical annual growth rates (e.g., 1% or less).

4.3 Well Tests

Limited aquifer testing was conducted by Golder staff on May 24 and 25, 2005. The field visits performed by Golder staff are detailed in Appendix 4-A. In order to determine the specific capacity of the wells, each of the City wells was pumped for 30 minutes and the drawdown at the end of this time was measured. Well 5 was pumped for 1 hour in order to determine if there was an impact to the water level in other City wells as a result of pumping in Well 5. There was no drawdown observed in Wells 1, 2 or 3 as a result of pumping in Wells 4 or 5.

City of Forks Wells Specific Capacities

Well	**Pumping Rate** (gpm)	**30-Minute Specific Capacity** (gpm/ft)	**Comments**
1	-	-	Well was not tested. Used as observation well only. (2003-2004 data indicate a specific capacity of ~36 gpm/ft)
2	180	67	
3	140	89	
4	352	30	
5 *	565	-	Water level could not be sounded past 96 feet due to blockage in well.

Following the specific capacity tests, Well 3 was pumped at 140 gpm for approximately 18 hours and the water levels monitored in the other City wells in order to determine aquifer parameters (e.g., transmissivity and storativity; Figures 4-11 through 4-13). Analysis of the Well 3 aquifer test data indicated a leaky aquifer. This is likely the result of recharge being induced from layers above the screened sand and gravel layer. The pumping test analysis indicates that the sand and gravel aquifer unit is highly transmissive, which resulted in a shallow cone of drawdown. The data do not indicate that any hydraulic boundaries (e.g., low permeable or recharge boundaries) were encountered during pumping. The fact that no boundaries were encountered during the constant discharge test of Well 3 is consistent with the very shallow cone of depression observed, where approximately 1.9 feet of drawdown was observed in Well 3 and no drawdown was observed in Wells 5, located 1,600 feet away (Figure 4-14).

The constant rate pumping test data were analyzed using the commercial program *Aqtesolv for Windows* (version 2.12; Duffield, 1998). *Aqtesolv* is an interactive solver which enables the user to readily apply different analytical solutions to derive the key aquifer parameters, and has both manual and automatic curve matching functionality.

For the analysis, the applicability of the Theis confined aquifer method (1935), and the two leaky aquifer methods of Hantush (1955, 1960) were evaluated. The potential for aquifer boundaries to influence the test data were evaluated using both confined and leaky solutions.

The analysis using the Theis method resulted in reasonably good curve fits, with very high transmissivities (in the range of 28,000 to 42,000 ft^2/day). However, such a condition would yield an average hydraulic conductivity of between 1,100 and 1,700 ft/day (based on a saturated thickness of 25 feet). These results are not consistent with the lithologic description of the aquifer material, which are expected to have a lower conductivity.

One cause for the higher than expected transmissivity using the Theis method is the possibility that the overlying sediments contain and can release sufficient water when the well is pumped to effectively reduce the drawdown in the actual aquifer. This is often referred to as a leaky aquifer condition. The Hantush methods are, in essence, variations on the Theis approach, but account for the storage effect of the overlying formation. The two Hantush methods differ in that whereas one solution assumes that the piezometric level in the aquitard remains constant during pumping, the other assumes that drawdown occurs. Comparing the two approached for the test data, we decided that the latter was more appropriate, with the following results:

Assumed Aquifer Parameters

	Distance from pumped well (feet)	**Transmissivity** (ft^2/day)	**Hydraulic conductivity*** (ft/day)	**Storativity**	**β-value****
Well 1	**780**	**9,000**	**360**	**0.005**	**1.25**
Well 2	**330**	**11,700**	**470**	**0.01**	**0.5**
Well 3	**0**	**11,800**	**470**	**-**	**0.1**

* Based on a saturated thickness (b) of 25 feet

** For Hantush (1960), β-values were assumed based on a K':S' factor of between 2 and 2.5 (assuming b' = 50 feet).

Figures 4-11 through 4-13 show the final analytical curve matches for the field data. Following the brief well tests conducted in the City's wells, the pressure transducer used to measure water levels remained in Well 1 to record water level data between May 24 and June 2, 2005. The water level data were then compared to barometric pressure, precipitation and river stage in the Calawah River. Barometric pressure and precipitation data were measured at the Quillayute State Airport (www.ncdc.noaa.gov/oa/ncdc.html). River stage data for the Calawah was obtained from the USGS for a gage near the Highway 101 bridge in Forks (http://waterdata.usgs.gov/wa/nwis/uv?12043000).

There does not appear to be a strong and direct correlation between water level in Well 1 and barometric pressure (Figure 4-15). Such a correlation would indicate a confined aquifer. The pumping test indicated a leaky response, which is consistent with the absence of a discernible correlation of groundwater levels to fluctuations in barometric pressure. The relationship between groundwater levels on one hand, and stream stage and precipitation on the other hand is less clear (Figures 4-16 and 4-17). Groundwater levels dropped significantly over the period monitored. The water level in Well 1 are presumed to show a response to precipitation. Between May 13 and 23, approximately 4.5 inches of rain was recorded at the Quillayute State Airport (Figure 4-16). Between May 24 and May 30, not more than a trace of rain was recorded at the Quillayute State Airport and the water level in Well 1 declined approximately 0.5 feet. Unfortunately, water level data from Well 1 are not available before May 24, and therefore the aquifer's response to precipitation cannot be fully determined. However, it appears that the water level declines when precipitation is not recharging groundwater. The effect of Well 2 pumping is clearly seen on the water level in Well 1 (Figure 4-15). It is assumed that the drop in water level is related to environmental conditions (e.g., precipitation) and not to pumping of Well 2 because the dropping trend does not stabilize between the pumping cycles of Well 2.

The water level in Well 1 does not show a strong and direct correlation to stage in the Calawah River. between May 24 and June 2, 2005, the water level in Well 1 declined approximately 0.75 feet (Figure 4-17). During this same period, the Calawah River stage declined approximately 1.5 feet. There is insufficient data at this time to determine the exact hydraulic relationship between the Calawah River and the aquifer beneath Forks Prairie, but it appears that the aquifer does respond directly to changes in river stage. Instead both river stage and aquifer water level decline when precipitation is not occurring in the area.

4.4 Wellhead Protection

A Wellhead Protection Program consists of delineating capture zones of wells, conducting an inventory of possible contaminant sites in the general area, preparing a qualitative assessment of the potential impact of these to the water supply, and implementing appropriate ordinances for the adequate protection of drinking water supplies. In this report, a three dimensional steady state groundwater model is presented that simulates captures zones of the drinking water wells of the City of Forks, and a contaminant inventory was commissioned. (The contaminant inventory, Appendix 4-B, and is provided under separate cover to the City of Forks.)

4.4.1 Forks Prairie Groundwater Model

A numerical groundwater flow model of the area to assist with the wellhead protection evaluation. The model uses the USGS code *MODFLOW* to simulate groundwater flow in the alluvial and glacial outwash sediments. *MODFLOW* uses a finite-difference method to solve the complex groundwater flow equation in three dimensions. The particle tracking code *MODPATH* was used with the flow model to simulate the capture potential of the City's wells.

4.4.1.1 Model Construction

The numerical model was based on the current conceptual understanding of the hydrologic and hydrogeologic system. The main components of the system are:

- Aquifer properties;
- Surface water bodies;
- Recharge; and,
- Pumping.

Model Domain and Grid

The model grid consists of cells varying in size from 50 foot square (in the general vicinity of the wells) to 200 foot square at the model's perimeter (Figure 4-18). This grid system allows the model to predict flows, gradients and velocities with sufficient accuracy in the immediate wellfield areas. The aquifer system was divided into two discrete layers - an upper layer (representing the overlying, partially saturated material) and a lower layer (representing the true aquifer).

The top of the model was established as coinciding with land surface; Golder developed this surface from USGS DEM files (30-meter resolution) which were interpolated to the final model grid. The base of the model was set to coincide with the top of the bedrock, which for this project was assumed to be relatively impermeable.

Aquifer and Aquitard Properties

The model base was assumed to slope generally east to west at roughly the same gradient as the land surface (Figures 4-19 and 4-20). The depth also increases from the north and south edges to the center of the model. The hydraulic properties assigned to the aquifer and overlying aquitard based on the results of the aquifer testing performed in May 2005 (see Section 4-3). These parameter values were varied during model construction and calibration

- Upper layer: K_h = 20 ft/day; K_v = 10 ft/day
- Lower layer: K_h = 350 ft/day; b = 25 feet

For the purpose of performing transport runs for capture zone assessment, uniform effective porosities of 0.15 and 0.2 we assigned to layers 1 and 2, respectively. At this stage, the model was established to be used in steady-state mode; therefore, no specific storage parameters were assigned for these layers.

Recharge

Annual precipitation in the valley is typically over 100 inches. A uniform recharge rate of 54 inches per year (0.0123 ft/day) was applied to the top of the model to represent recharge derived from precipitation and run-off that enters the subsurface at the valley edges.

Subsurface Flow

As the model boundaries do not coincide with the true aquifer limits at the up and down-gradient extents, we used the Constant Head function in MODFLOW to allow groundwater to enter and exit. These boundaries were located at sufficient distances from the wellfield area that future pumping would not cause a significant change in the fluxes across these boundaries.

Surface Water

The Calawah River flows east to west through the valley, and includes a meandering reach just west of the wellfields. The river is suspected to receive considerable discharge from the aquifer system in the area. Although only one USGS river gage exists in the region, the baseflow component to the river flow is likely in the order of 50 cfs. Therefore, the river was considered to be a major sink for the groundwater in the model.

The river was incorporated into the model using the head-dependent *RIVER* module. The river stage (which remains unchanged in response to applied stresses) was set at the approximate land elevation based on the USGS topographic maps and DEM data. The river bed for each cell was assumed to be 5 feet below the stage level, and a river bed conductance value of 25 sq. ft/day per linear foot of river reach was assumed to be reasonable to represent the hydraulic effects of the relatively granular surficial soils.

Towards the southwest model boundary, the Fork Prairie terminates topographically; this feature is marked by a line of springs which discharge groundwater at an unknown rate. We represented this in the model using a line of *DRAIN* cells that allow water to flow out of the upper layer.

The net discharge from the river and springs in the calibrated model were 56 cfs and 6 cfs, respectively.

Pumping
The average pumping rates assigned the wells were equal to the average annual water right limits (assuming continuous, year-round pumping) distributed among the wells: 156 gpm (for Wells 2 & 3) and 138 gpm (for Wells 4 & 5). Well 1 is inactive and was not included in the model. For the baseline condition, we set pumping for these wells equal to zero; this was done because the best field-measured water levels for these wells were measured with all wells non-pumping. All pumping fluxes were assigned to model layer 2.

4.4.1.2 Model Results

Figure 4-2 shows the modeled baseline flow field in the aquifer (layer 2). Although groundwater is generally from the east to west through the valley, the piezometric contour pattern indicates the major sink effect of the river. The average potentiometric gradient in the wellfield vicinity is about 0.007.

Figure 4-21 also shows the calibration results for the target wells. The box-plots indicate the difference between the model-calculated and the field observed water levels. These residuals are between 0.2 and 3.5 feet at the wellfield wells, which is generally acceptable for a model of this magnitude. The calibration for the two, upgradient private wells are less close. However, some uncertainty exists regarding the reliability of the measured water level elevations.

The model was run to steady-state with the wellfield wells pumping at their average annual water right rates; Figure 4-22 shows the resulting groundwater flow field for the main aquifer. The piezometric contours differ from those for the calibration baseline set in the vicinity of the wells, but the difference is fairly minor. The maximum water level difference between the two conditions is about 2.5 feet. The actual drawdown in the wells will be greater than this because of the well inefficiency effects and the fact that the modeling method averages the water level in the cell containing the well across the cell width (50 feet).

Golder then used *MODPATH* to determine the time-based capture zones for the wells under the new flow field conditions. Figures 4-23 through 4-25 show these capture zones for 6 months, one year and 5 years, respectively. The capture zones have a distinctly long and narrow shape, which is typical for well pumping from a relatively highly transmissive aquifer at low rates.

The 10-year time-of-travel zone was not determined because it extended beyond the model boundary. The model did not extend further east because of lack of information on the aquifer thickness and properties, and recharge areas including points of connection with streams.

Some of the water intercepted by the wells will be derived locally from the overlying (aquitard) sediments. The model is unable to determine the relative contribution from each layer.

4.4.2 Contaminant Inventory

Golder contracted Environmental Data Resources, Inc. (EDR) to produce a contaminant inventory of the Forks area. This report uses available environmental databases and the data have not been verified. The Contaminant Inventory was centered on Section 13 of Township 28N, Range 13W, and has a coverage radius of three miles. The survey was dated May 15, 2005, and included in Appendix 4-B of this report.

Database Findings

The following summarizes the findings:

- Six facilities were found to be listed on the EPA's RCRAInfo database. This database includes sites that are known to generate, transport, store, treat and/or dispose of hazardous materials.
- One State Hazardous Waste (or priority) Site was identified. This designation indicates that the site has planned remedial action using state funds and potentially responsible parties.
- The report identified the presence of three (3) leaking underground storage tank (LUST) sites in the coverage area, and a further ten (10) underground storage tank (UST) sites in the survey area. USTs are regulated under RCRA, and the data are stored in Ecology's LUST and UST Site/Tank Reports.
- Two sites were identified as having entered into the Voluntary Cleanup Program (VCP), or as having some level of remedial action.
- The FINDS (Facility Index System) contains 21 sites in the survey area. This database lists sites which have activities that only could pose a risk to the environment, and provides sources for additional information.
- One mine site, listed in the Mines Master Index File, exists in the survey area.
- Two sites were found under the ICR list; these sites have undergone remedial action outside the regulatory oversight programs. (Both sites were also listed in the LUST and UST databases). Two sites were also listed in the Brownfields database, both of which were also in the UST list.

*Note - many of the sites were listed in more than one of the databases covered by the survey.

Potential Impact to Wellfield

The hazardous substances reported for all listed sites are petroleum products – gasoline, diesel and oil. These products contain chemical constituents (such as benzene) that are known to be detrimental to the environment and human health if released. Some of these chemicals are relatively mobile in the subsurface, and are readily dissolved in groundwater. Several of the listed sites are located upgradient from the City's wells.

Only one site should be considered for further assessment; this is the WADNR Headquarters facility. The WADNR facility is located between the well clusters, and also operated USTs which appear to have released gasoline products to the soil. The LUST database indicates that this site was cleaned up and some of the USTs have been removed.

None of the remaining sites have known chemical releases. If future releases do occur, the chemicals would need to travel vertically through as much as 75 feet of unsaturated zone before encountering the water table. The migration rate is difficult to estimate without field testing. Although upper soils are heterogeneous with lithologies ranging in texture from clay to sand, the infiltration rate is expected to be relatively high. During the migration, these chemicals typically degrade to less toxic products, thereby reducing their threat.

4.5 Future Well Siting

The most limiting factors in siting a new well are anticipated to be the existence of an aquifer at a particular site (versus encountering bedrock), and available drawdown (e.g., the water level in the well). Consideration should also be given to future zoning implications for wellhead protection purposes.

Bedrock irregularities may pose difficulty in siting wells. The marine sedimentary and igneous rocks that comprise the bedrock in the Forks area generally cannot support productive water wells (Golder, 2005). Depth to bedrock is a critical factor in siting future wells. If bedrock is encountered at a shallow depth, there may been insufficient drawdown to allow a municipal well to be installed. Cross-sections in hydrogeologic report contained in the most recent Comprehensive Water System Plan (Polaris, 1999) are highly speculative. A smooth U-shaped bedrock valley is unlikely given the degree of topographic relief present in the bedrock foothills adjacent to the valleys. The subsurface bedrock could have significant topographic relief.

Hydrogeologic cross-sections of the Quillayute Prairie/Three Rivers/Forks Prairie area were prepared using well logs on file with the Washington State Department of Ecology (Ecology). In addition to information provided by well logs, the Washington Department of Natural Resources (WDNR) 1:100,000 surficial geology was used to determine the location of geologic units (e.g., alluvium, till, outwash, bedrock etc). The hydrogeologic cross-sections indicate a basal gravel unit above the bedrock (Figures 4-3 through 4-6). Existing well logs on file at Ecology for wells installed north of the Calawah River indicate that bedrock is likely shallow in the area (40 to 100 feet). Department of Ecology's well log database indicates that at least four dry wells were installed north of City:

Dry Wells on North Side of Calawah River

Well Location (T/R-S ¼/¼)	**Total Depth of Borehole** (ft bgs)	**Material Encountered**
29/13-29 SW/SE	225	Shale
29/13-32	138	Shale
29/13-32 NE/NE	50	Clay
29/13-32 SW/SE	104	Shale

Our assessment is that there is more risk drilling a well north of the City. Therefore, we recommend well sites be considered near the middle of the Forks prairie, not too far from the location of Calawah Way. Moving north or south from the center of the prairie may encounter a shallower depth of aquifer material above the bedrock, thus limiting available drawdown. Areas east of town in T 28 N, R 13 W may be possible locations:

- SW Sec 3
- NW ¼ of the NW ¼ of Sec 10
- NE ¼ of the NE ¼, and the SE ¼ of the NE ¼ of Sec 9

The cost of a geophysical survey should be investigated for siting a new well to increase the probability of successfully installing a productive well. Potential methods include: time domain/seismic refraction to find depth to bedrock, resistivity to locate gravel layers.

The high transmissivity of the aquifer suggests that interference between wells should not be a major consideration in well siting. Figure 4-14 predicts drawdown interference from a well pumping 140 gpm on the order of half a foot at a distance of 100 feet.

4.6 Conclusions and General Recommendations

Installing a new well will diversify the existing array of municipal water supply wells and improve system redundancy and reliability. It will also allow the City to more fully exercise existing water rights. Such a well could be permitted with water rights by adding it as an additional point of withdrawal to existing water rights.

Current demand estimates (Polaris, 1999) indicates that new water rights will be needed in the near future (e.g., within five years). These estimates may be conservative, and new water rights may not be needed for an extended period of time, depending on water demand growth rates (e.g., new industrial demand). Applications should be submitted now for future water rights.

In order to prevent contamination of groundwater north of the river, it is recommended that the Grafstrom well in the Forks Industrial Park be abandoned in accordance with WAC 173-160-381. If other unused wells are identified within the City's service area, they should be properly abandoned as well.

The current operation of the wells consists of pumps whose flow is maintained significantly below their designed rates by valves. This is expected to create an unnecessary energy bill. Simple energy cost auditing may indicate significant cost savings through the purpose of appropriately sized submersible pumps.

Given the age of the wells, a video inspection should be conducted on any of the City wells in which pumps are pulled for maintenance. A video inspection of Well 2 from 2004 indicated that the screen was in fairly good shape. However, there appeared to be staining around a casing joint, perhaps indicating that one of the welds might be compromised. Unfortunately the camera could only recorded downhole views (not sideways) and no depth information was provided on the video in order to determine the depth of the casing joint.

Before groundwater development occurs at the Quillayute Airport, a hydrogeologic investigation should be conducted. In order to do this, a close working relationship with the citizens living near the airport should be established to facilitate access to private wells. This work could be conducted in conjunction with the Army Corps of Engineers, who are currently conducting contamination cleanup efforts in the area. A hydrogeologic investigation of this area would entail gathering well logs, collecting water level measurements, collecting samples for water quality analysis, perhaps limited pumping tests could be conducted on existing wells.

5.0 WATER SUPPLY FOR HOH RIVER FISH

Anadromous salmonids are an important cultural and commercial resource for the Hoh Tribe. These salmon and steelhead runs may be affected by climate change and increased frequency of drought conditions in the future. Low river flows during late summer and fall of 1987 and 2002 impeded fish passage in the Hoh River. Washington Department of Fish and Wildlife (WDFW) closed fishing on the Hoh River during low flow periods in these years to reduce impacts to returning adult spawners. Extrapolation of past hydrologic trends suggests an elevated frequency and duration of these low flow occurrences in the future, increasing the possibility of detrimental impacts to Hoh River fisheries. This report discusses possible solutions for maintaining healthy anadromous populations within the Hoh River.

The Hoh Basin drains approximately 299 square miles of land, mostly in Jefferson County, Washington (Figure 5-1). The Hoh River itself is a large, glacially influenced river with its headwaters in the Olympic Mountains. Approximately half of the Hoh River drainage is located within the Olympic National Park.

The Hoh River generally flows from east to west with the Pacific Ocean on the Washington coast at its terminus. River flow within the Hoh and its tributaries is maintained by the generous amount of rainfall the watershed receives; an average of 150 inches of annual precipitation (NOAA NCDC 2005) makes it one of the wettest regions in the United States. Numerous springs, and mountain glacier and winter snow-pack melt and run-off sustain streamflows during the summer months. These cool, clean waters establish important habitat for the anadromous and resident salmonid populations that use the basin for spawning and rearing.

5.1 Fish Inventory and Distribution

Life histories for anadromous salmonids of the Hoh River are described in Table 5-1. Nearly all salmon and steelhead stocks have natural production (wild spawning) with very few introductions of outside stocks. Fish numbers and the relative health of fish stocks are estimated by measuring the stock's spawning escapement and adding the estimates of that stock's contribution to each fishery throughout its migratory range for each run of fish (to the extent possible). This is then compared to the run size trends from year to year over a large number of years (especially for coho which all result from a single year brood escapement. A more rigorous method for Chinook and steelhead requires doing the previous assessment each year, and assigning each cohort through sampling of the fish returning ages (the same sets of siblings that return at different ages in successive return years) to the same class that results from one parental escapement. (For example, the 1977 Hoh fall Chinook escapement broodyear returns would be assessed as a class by assessing the number of 1980 Hoh river returns of that class [number of 3 year olds in the 1980 Hoh returning run], 1981 [the number of 4 year olds], 1982 [the number of 5 year olds], 1983 (the number of 6 year olds], and 1984 (the number of 7 year olds] returns.) As a terminal run, the number of fish caught in the tribal and sport fisheries at (or near) the river's mouth plus the escapement (as determined by seasonal spawner surveys) provides a relatively accurate estimate of that year's run size returning from the ocean.

The spring/summer Chinook run is the largest population of early running Chinook on the Olympic Peninsula, the majority of this stock spawns above the junction of the South Fork and ONP boundary (RM 30.0) in the North Fork up to RM 48.0 , in the lower 9 miles of the South Fork, and from the junction of the South Fork to the Hoh Oxbow (RM 15.2). The stock is the smallest of the commercially harvested runs on the Hoh River, though it occasionally dips below its escapement floor. It has remained relatively healthy compared to its historic levels and compared to fall Chinook, though that is a larger run. More of the life history stages of the earlier Chinook, which spawn higher in the system are located within ONP habitat, while most of the life history of the fall Chinook lies outside of park waters. Natural escapement levels for spring/summer Chinook range from approximately 500 to 2,500 fish annually with an average of approximately 1,500 from 1976 to 2004. The terminal run size for spring/summer Chinook has ranged from approximately 500 to 7,000 and averaged approximately 2,400 over the same period (Jim Jorgensen, Hoh Tribe, personal communication).

Most fall Chinook spawning occurs below the Olympic Park Hoh Ranger Station at RM 35.3 on the North Fork, but mostly below the Park boundary and RM 30.0, along the South Fork mostly below the Olympic Park boundary near RM 5.0, down the South Fork and Mainstem, within all the larger tributaries below these locations as far down as the G&L shake road at RM 3.0. Winfield Creek and the South Fork Hoh River also support significant fall Chinook spawning with lesser numbers spawning in Nolan, Owl, and Mt. Tom Creeks. Recent information (Jim Jorgensen, Hoh Indian Tribe, personal communication) on the health of the fall Chinook stock shows a decline in spawning activity within the Hoh River tributaries and the side-channels of the middle Hoh River that have been impacted by sluice-outs and channel instability. Since 1976, non-hatchery escapement numbers for fall Chinook have ranged around an average of 2,932; non-hatchery terminal run size for fall Chinook has averaged 4,131 (Jim Jorgensen, Hoh Tribe, personal communication).

Hoh chum production is insignificant which is mostly attributed to the lack of a significant estuary compared to the Grays Harbor where chum are strong. Winter Steelhead have maintained at healthy levels within the Hoh system. Their juvenile freshwater residence is among the longest for salmonids which have a directed harvest by tribal and recreational fisheries.

5.2 Limiting Factors

The term "limiting factors" refers to any condition that negatively affects the salmonid population abundance. Limiting factors may include water quantity, water quality, and other physical habitat characteristics such as pools, riffles, large woody debris, riparian condition, sediment levels in spawning gravels, etc.. Variations in these conditions influence the population size of the salmonid species at various life history stages. The Hoh River basin is affected by a number of limiting factors, but especially low streamflow during summer and fall months. These low streamflows can affect upstream migration, particularly of fall Chinook. Low flows can affect fish passage in the following ways:

- At the river's mouth – Most fish come in on the tides into the river during low flows, but will stack up below certain shallow riffles in the fall.
- Flows as a "signal" – fish tend to move upriver in response to freshets, in response to cooler water, and generally at higher flows. (Fish also tend to move during high tide). Higher flows and greater depth probably reduce probability of predation.
- Fish passage from river's main stem into tributaries – Fish passage from a river's main stem into tributaries will be blocked during low flows, possibly because of passage problems but also behaviorally it is thought that many tributary spawners will not enter a tributary until they are ready to spawn, and only when spawning conditions are favorable at the same time they are prepared to spawn. Poorly-designed culvert installations can cause height, velocity and turbulence barriers to fish that are enticed to move up tributaries during spawning flows.

Low flows can also affect rearing by reducing the water's area and depth. Hoh River has two stocks of Chinook (spring/summer and fall), coho, and steelhead – these stocks' abundance is currently generally limited by rearing area. Research shows that coho abundance is limited in the summertime by pool area and in wintertime by off-channel habitat such as side-channels, ponds, and oxbows (Cederholm and Scarlett, 1981; Narver, 1978; Peterson, 1980).

Low flows can affect juvenile outmigration. Springtime flows carry smolts seaward. Predation is the biggest cause of mortality at the juvenile life stage. Research shows that survival of outmigrating juveniles increases linearly with flow, and then levels off at higher flow levels. These studies were conducted where reservoir releases affected flow levels (e.g., municipal water supply, hydropower). In the Hoh River basin, springtime flows are primarily a function of snowmelt.

5.2.1 Redd Dewatering and Isolation

Flow reduction has the potential of dewatering redds on gravel or sand bars in the main channel or isolating the redds in river side channels. Dewatering causes direct mortality of embryos and alevins due to insufficient oxygen levels, dessication, waste metabolite toxicity, and thermal stress. Isolation of redds in side channels can result in mortality due to the above factors plus starvation and increased predation on the emergent fry.

Within the Hoh basin, the dewatering of redds or isolation of fish by low flows usually would become the most critical at the cusp between late spring/summer Chinook spawn timing and the beginning of fall Chinook spawning about Oct. 10. More extreme rain or overwinter precipitation conditions beginning earlier in the year could advance this to progressively affect earlier spawn timing (though this has not recently been experienced) or more late extreme dry conditions would merely extend the low flow period to later in the season causing later migratory and spawning groups of fall Chinook as was evidenced in 1987 and 2002. This timing of blocked upstream movement could become critical to the normal distribution and density of spawners and any subsequent surviving offspring if it extended into the middle of November (i.e., about the peak of fall spawning) or beyond.

5.2.2 Juvenile Isolation

Isolation of running juveniles can occur when flows within the Hoh River increase to levels that inundate side channels and then subsequently recede, stranding the fish in unconnected pockets of water. While this process is known to naturally occur, the effects of severely reduced river volumes can amplify mortality rates as the interconnectedness of side channels to the main channel is further reduced, such as by channel downcutting (see Chapter 3). Insufficient oxygen levels, dessication, waste metabolite toxicity, and thermal stress will increasingly affect juvenile salmonids as the length of time they are stranded in side-channels increases.

5.2.3 Spawning Adult Isolation

Low flows observed in late summer and fall of 1987 and 2002 caused water levels to become so shallow that fall Chinook were unable to move upstream beyond a point on the lower river near the G & L Shake Company (approximately RM 3.0). There was visual observation that all salmon attempting to pass certain riffles (especially the riffle at G&L Shake Road, RM 3.0) in 2002 by the end of October were unsuccessful and all were observed to fall back to the lower pool. There was consensus between WDFW and the Tribe that these conditions could critically threaten the fall Chinook run if they persisted for long. Therefore, both parties curtailed their respective fisheries and began making hydraulic modifications at RM 3.0 to facilitate fish passage. Fortunately, in both years rains occurred in time that the low flow conditions did not last long enough to critically affect escapement levels. Possible relationship of such low flows to climate conditions are analyzed in some detail in Section 5.3.

5.2.4 Other Limiting Factors in the Hoh Basin

Although the focus of this assessment is flow-related passage, several other salmonid habitat limiting factors have been identified by Smith (2000). Anthropogenic (human) activities have created access problems for fish migrating up and down the Hoh River. The construction of roads in riparian zones, some of which closely parallel the streams, can confine the channel and disconnect potential off-channel (floodplain) habitat, and increase sediment inputs into the stream. Culverts can also block fish passage and prevent upstream migration. Logging waste wood left over from salvage operations (cedar spalts) has a tendency to impede water flows leading to warmer water temperatures and can also degrade water quality by leaching in tannins (Smith, 2000)

Increase in landslides in the Hoh River basin has resulted in a reduction of macroinvertebrates, which is an indicator of salmonid habitat quality and a food web item for salmonids. Fine sediment deposition in channels may accumulate in spawning gravels and degrade critical spawning habitat.

Loss of off-channel habitat lowers production of salmonid species, particularly coho. Wetlands and vegetated depressions provide important stable habitat for over-wintering salmon and is the site of significant exchange between nutrient rich groundwater and surface water. Alteration of this habitat is likely contributing to degraded groundwater inputs and reduced water quality (Smith, 2000).

Water quality problems such as a reduction in dissolved oxygen, increased acidity, and increased water temperatures have worked to decrease the quality of salmon habitat. These water conditions appear to result in a lack of aquatic invertebrates that the fish need for food. Alterations to the alluvial aquifers may be responsible for the degraded water quality. Removal of upland vegetation has decreased the infiltration of groundwater into the hillslopes and reduced baseflows into the Hoh which, in turn, reduces aquatic productivity and water temperature buffering (Smith, 2000).

5.3 Correlation of Flows with Climate

Low river flows during the summers of 1987 and 2002 impeded fish passage in the Hoh River. These low flows may be related to climate variability in the Hoh River watershed. Future climate change may lead to further declines in river flows and fish passage could be adversely impacted on a regular basis. One purpose of this assessment is to provide a rough conceptual model of how streamflows may respond to predicted climate change. It is important to remember that predicted climate changes are uncertain, as are the hydrologic impacts related to climate change.

5.3.1 Runoff Processes in the Hoh River Watershed

The Hoh River watershed (Figure 5-1) receives an average of 150 inches of annual precipitation, making it one the wettest regions in the United States. The bulk of the rainfall occurs in the winter and spring. The summer months of June through August average a total of only 10 inches of precipitation, or just 7 % of the annual average.

Streamflows in the Hoh River are typical of streams on the Olympic Peninsula. Flow levels peak in the early winter in response to increased rainfall, and typically peak again in the early summer as a response to snowmelt in the upper elevation areas. Peak flows are highest in the winter, and individual storm hydrographs during the winter are considered "flashy" because they respond quickly to rainfall then recede sharply after storms. The thin soils, shallow bedrock, and steep terrain that is prevalent throughout much of the watershed allows for little groundwater storage and recharge. Instead, rainfall moves quickly from the hillslopes to the tributary channels, and then down to the main stem of the Hoh River.

The upper portion of the Hoh River watershed is considered a "transient–snow" basin because winter precipitation falls as a mix of rain and snow. Snowfall in the upper watershed is very important because snowmelt in the spring helps sustain river levels in the summer and fall. Glaciers at the top of the watershed also play a key role in maintaining summer and fall flows. In effect both the snowfall and the glaciers act as storage reservoirs that store water in the winter and release it when air temperatures increase in the summer and early fall. Without these storage reservoirs, baseflows would be much lower because there is little rainfall or release from groundwater storage during the summer.

5.3.2 Climate Change Impacts

Most projected climate change scenarios show that the Pacific Northwest will become warmer and wetter in the future. The University of Washington Climate Impacts Group predicts temperatures in the Pacific Northwest will increase through the foreseeable future. Precipitation is expected to increase by up to 9%, but this prediction is less certain. Regardless, increases in summer precipitation may be negligible given that little rain falls in the summer, and any increase in precipitation may be cancelled out by increased evapotranspiration resulting from higher temperatures.

Projected Increases in Temperature and Precipitation

(UW CIG, 2004)

Temperature Change	**Precipitation Change**	
Annual Average	Oct-Mar	Apr-Sept
2020s		
+ 2.7 ºF	8%	4%
2040s		
+ 4.1 ºF	9%	2%

The hydrologic cycle of transient snow basins, such as the Hoh, will be more impacted by climate change than rain-dominated or snow-dominated basins. A few degrees warming can dramatically shift precipitation over a large area in the upper basin from snowfall to rainfall. This reduced snowpack will lower summer streamflows. For example, a climate change model developed for a transient snow basin the Cascade Mountains, resulted in a 35% reduction in summer streamflows when temperatures were increased by 4.5°F, as is predicted to occur within 40 years (UW CIG, 2004).

Future warming will also affect the size of the glaciers in the upper watershed. Glaciers maintain equilibrium when the amount of water released from the glacier in the summer is equal to the amount of water deposited by snowfall in the winter. Research on glaciers in the Olympic Mountains indicates that global warming trends have altered this equilibrium, which is causing glaciers to shrink. It appears this shrinking is related to warmer winter temperatures, which has decreased snowfall and minimized the extent to which the glaciers are replenished over the winter (Conway and others, 1999). This trend is most pronounced over the past 20 years when the Blue and Cascade glaciers have lost, on average, 0.5 and 0.8 meters of water per year (Rasmussen and Conway, 2001). Because summer temperatures have remained fairly constant (Conway and others, 1999), the baseflow contribution from glacial runoff has probably not increased.

Unfortunately the data-set developed from glaciers in the Olympic Mountains is not large enough to fully account for the influences of natural climatic variability on glacier size. The Pacific Decadal Oscillation (PDO; 20-30 year cycles) and the El Nino/Southern Oscillation (ENSO; 2-3 year cycles) are natural cycles of Pacific Ocean sea temperatures that influence climate variability worldwide. In terms of their effects on Pacific Northwest climate, warm phase PDO and ENSO may result in reduced snowpack and lower summer streamflows, while cool phase cycles may increase both snowpack and summer streamflows. For the sake of clarity in this report, warm phase PDOs are referred to as dry phase and cool phase PDOs are referred to as wet phase.

Analysis of glaciers in the North Cascades suggests that the overall trend of shrinking glaciers is not simply a function of PDO influences. Cool PDO cycles appear to slow the rate of glacial recession in the Cascades but the net balance over time is that the glaciers are shrinking. Long-term estimates at the South Cascade Glacier, for example, suggest its volume has declined from 0.49 km^3 to 0.16 km^3 between 1650 and 2001 (Josberger and Bidlake, 2003).

The extent to which glacial runoff contributes to summer baseflow levels has not been quantified in the Hoh River watershed. Therefore, the future impact to streamflows resulting from receding glaciers is speculative. Clearly, some proportion of summer flows is derived from glaciers in the upper watershed. The receding glaciers will continue to supply water to the river as they melt and water that was previously stored in the glacier is moved out of the basin (and lost). As the glaciers shrink, the baseflow contribution will decrease, and this decline may be non-linear. If the glaciers melt completely, obviously their baseflow contribution will be zero. Under these conditions, baseflows would be supported only be summer rainfall and groundwater storage, both of which are small.

5.3.3 Streamflow Trends in the Hoh River

An analysis of historic streamflows at the Hoh River USGS gage (#12041200) near the Highway 101 bridge indicates that minimum flows have been generally declining since the 1960s. Figure 5-2 shows the average 7-day annual minimum flow from 1961-2003. For clarification, this flow represents the lowest average weekly flow in a given year. Although the natural variability is high, the linear trend clearly shows decreased minimum flows with time. Over the past forty years the 7-day minimum flow has decreased, on average, at a rate of about 5 cfs per year.

The two lowest years on record occurred in 1987 and 2002, when the 7-day minimum flow dropped below 300 cfs (Figure 5-2). In these years, fish passage was obstructed by lows flows in the Hoh River. Therefore, a 7-day minimum flow of 300 cfs may be considered a threshold for fish passage. If the trend shown in Figure 5-2 is linear and continues at the current rate, the average 7-day minimum flow in a given year will drop below the 300 cfs threshold by 2045.

Figure 5-3 depicts streamflows over the course of 1987 and 2002 relative to the long-term mean. In 1987 and 2002 streamflows in the Hoh River were not below normal from January to June, but began dropping below the long-term mean in about July. Figure 5-4 provides a more detailed view of this critical late summer/fall low flow period. The minimum flows occurred in October and early November in 1987 and 2002, which is about one month later than normal. During most years streamflow will begin to increase in the early fall as a response to precipitation. In 1987 and 2002 years, precipitation was minimal in the early fall and therefore allowed streamflows to decline into the fall. Total precipitation between August and October was about 3.1 inches in 1987 and 4.4 inches in 2002; compared to the long-term mean of 18.9 inches.

While summer flows are sustained by snowmelt and glacial runoff, fall streamflows are sustained by late summer and early fall rainfall because much of the snowpack is gone and decreased temperatures limit runoff from glaciers. Fall streamflows can drop to low levels during years when fall precipitation is minimal, as evidenced in 1987 and 2002. If snowmelt and glacial runoff become negligible, the typical summer flows will likely resemble the fall flows in 1987 and 2002 because the summer precipitation is generally very low. General climate predictions are for longer drier summers. Fall streamflows during dry years will likely drop to even lower levels.

Figure 5-5 shows the most recent flows in 2005 relative to 1987, 2002, and the long-term mean. In May 2005 streamflows were quite high relative to the long-term mean, and is interpreted to be a response to precipitation. But streamflows dropped dramatically in June 2005, and illustrates how quickly the river can decline to very low levels in the early summer. It appears that late summer and early fall flows this year could drop to levels similar to those measured in 1987 and 2002, depending on precipitation patterns.

5.3.4 Effects of PDO Cycles on Streamflow

The 1961-2003 streamflow data-set for the Hoh River is somewhat incomplete because it does not include a complete wet/dry PDO cycle. Streamflow data are available from 1927-1963 at an upstream gage on the Hoh river, and these two gages together span a complete PDO cycle, and more importantly, each data set spans a dry portion of a PDO cycle. The older gage was situated upstream of the more recent gage so the data are not directly comparable, but the two gages can be analyzed independently to illustrate the effects of the PDO cycles.

Figure 5-6 shows the 7-day annual minimum streamflows at the two historic gages on the Hoh for two dry phase and one wet phase PDO. The PDO cycles appear to have some influence on minimum streamflows. The effects are more pronounced in the more recent data set (1961-2003), where the mean annual streamflow during the wet phase was about 16% higher than during the most recent dry phase (1977-1998). In the older data (1927-1963), the mean streamflow during the wet phase was only 8% higher than the following dry phase.

The recent declines in streamflows in the Hoh River are not simply residual effects of PDO cycles. One interesting observation is that the minimum flows measured at the old gage during the 1925-1946 dry PDO phase are about 6% higher than the minimum flows measured at the current gage during the most recent dry phase (1977-1998). This trend is quite unusual because the drainage basin area the older gage is about 20% less than that of the downstream gage. In other words, discharge at the upstream gage should lower than the downstream gage under similar climatic conditions, not higher, because numerous tributaries increase flows in the Hoh River as you move downstream. This anomaly may represent long-term changes reflecting global warming influences.

Based on the available data it seems reasonable to conclude that climate change is contributing to declines in baseflows in the Hoh River. The exact effect of climate change versus PDO cycles is difficult to quantify because the data-set on the Hoh River is small compared to the length of a typical PDO cycle. However, recent minimum flows appear to be lower than historical flows and this can be explained by a change in hydrologic processes associated with climate change. Furthermore, the general consensus of the scientific community is that warming is occurring and will likely result in decreased summer streamflows (UW CIG, 2004).

5.3.5 Projected Future Water Balance

A water-balance analysis can be used to show potential changes in future streamflows in the Hoh River. The water balance is particularly useful in this context because the contributions from snowmelt can be minimized to reflect future streamflow scenarios. Data from the recent work conducted by the Bureau of Reclamation (BoR) were used to characterize current and future monthly streamflows under changing climate conditions. Figure 5-7 shows mean monthly streamflows for 1) the historical period of record, 2) as simulated by the BOR, and 3) adjusted for possible future climate conditions.

The current conditions model was developed by the Bureau of Reclamation (BoR) and included in the WRIA 20 Phase II Technical Assessment (Golder, 2004), with the only difference being that the basin outlet in this report is at the USGS gage instead of the mouth of the river. The future conditions models include projected climatic changes in the year 2040, as predicted by the UW CIG (2004) . Monthly precipitation is increased by 9% from October to March and by 2% from April to September. Monthly temperatures are increased by 4.1° F over the entire year. Evapotranspiration estimates were obtained by taking the values calculated by the BoR and increasing them proportionally to the projected increase in monthly temperatures.

The simulated current conditions (BoR) tend to underestimate the average monthly summer flows and overestimate the fall flows relative to the measured USGS data. At the USGS gage, the lowest mean monthly streamflow occurs in October, while the predicted value occurs in July. These differences are related to monthly distribution of snowmelt in the BOR water balance model. Also, the BOR water balance does not consider the soil moisture deficit that accumulates over the summer, which is a potential reason why the measured streamflows are lower than predicted in the fall. At the same time, the principle concerns are the minimum flows and the predicted minimum flow in July is within 30% of the measured minimum flow in October. Based on the number of simplifying assumptions in the water balance, a 30% error is not unreasonable. Regardless, analysis based on the BoR simulations to characterize the future response of streamflow to climate change remain valid with respect to the trends derived.

The future conditions models are best used as index of potential future streamflows relative to the predicted current conditions. The intent is to illustrate how changing conditions can lead to drastically reduced minimum flows. The projected future conditions probably underestimate the minimum flows given that the predicted current conditions under estimate actual minimum flows by 30%. However, the projected flows are so low that a 30% error does not impact the general trends. For example, a 50% reduction in snowpack results in a mean July streamflow of 390 cfs, which is very close to 300 cfs fish passage threshold. Under the worst case scenario of 25% snowpack, July flows are reduced to just 150 cfs. Even if this scenario is off by 30%, the July minimum flows are still well below 300 cfs.

These projected future conditions are based on simple, back of the envelope calculations, and should not be considered 100% accurate. Projecting climatic change is not a simple science, and the hydrologic response to this change is also difficult to predict. Regardless, the water balance models clearly illustrate how projected climate change could have devastating consequences to streamflows, and fisheries, in the Hoh River.

5.4 Possible Solutions

Salmonids typically have a return cycle of several years. In a quadrennial cycle (such as is typical for Chinook; returning after four years), if one year's run is compromised by conditions such as low flows, diminished returns will be observed four years later as an "echo." Although the predominance of one year's run may adhere to a four-year cycle, some of that run will return in three or five years, and restore the one year's run that was compromised. This maintains the resilience of the complete run to episodic deleterious events. However, if conditions such as low flows are repeated too frequently, the entire run may be at risk. For this reason, and in the face of predicted significant changes in the flow regime of the Hoh River, appropriate responses should be formulated. Such responses are presented below in the form of hatcheries and stream flow augmentation.

5.4.1 Fish Hatchery

In the event that recurring low flows significantly affect the viability of natural salmonid runs, a fish hatchery may fulfill a sustaining role. A prospective hatchery site may be considered from just above Owl Creek at River Mile 27 down to near Morgan's Crossing at River Mile 22.

5.4.2 Flow Augmentation

The principal habitat component being addressed is the low flows in the later summer through mid-fall. Fish encounter obstacles (tree falls, small cascades, etc.) naturally during migration and typically wait for precipitation events to overcome the obstacles. Unfortunately, if current trends persist, the Hoh River will be deficient in water quantity to the point that precipitation may not occur with sufficient quantity or frequency to allow a fish population to migrate past obstacles without an elevated mortality. Flow augmentation on the Hoh River during dry periods can allow migrating fish to overcome the obstacles blocking upstream migration. Reservoir waters stored upstream of the low flow barriers to fish passage could be released in adequate quantities during fish migration to allow passage to upstream spawning habitat.

Historic flow data has been made available by the United States Geological Survey (USGS Gage #12041200) by an active stream gage at RM 15.4, approximately 250 feet downstream from U.S. Highway 101. It appears that stream flows as low as 300 cfs impede upstream fish migration near the G&L Shake Co. reach of the river (approximately RM 3.0).

Reservoir construction at one of more locations along the Hoh River or its tributaries could allow for the storage of surface water for release during critical low flow periods when fish passage is affected. Fish passage is dependent upon river stage. The amount of flow augmentation is dependent upon channel geometry to obtain the required increase in river stage to allow fish to overcome the obstacle. Therefore, a stage-flow relationship for a specific fish passage site is needed to determine flow levels that would provide adequate depth for fish passage.

However, predicted changes in mean monthly flows (Figure 5-7) are almost directly proportional to changes in snowmelt contributions. If a 25% reduction of snow melt contribution occurs under future climate change, stream baseflows are predicted to decrease approximately 25%. (Most of the summer baseflow is derived from snow melt, with minor amounts from precipitation and groundwater.) Given that the current critical low flow relative to fish passage is 300 cfs, a 25% augmentation would be 75 cfs. Therefore a range of 50-100 cfs augmentation is considered.

Salmonids do not require a continuous supply of high flows. During low flow periods, they typically congregate below a passage obstacle until a freshet or runoff pulse is generated by rains. Because augmentation at high rates would require a large reservoir, smaller reservoirs are considered with controlled pulse releases. This will allow more judicious use of the available stored water. Ramping up and ramping down of releases may be needed to avoid flushing of juveniles (if present) and stranding during the release of each pulse. Typical ramping rates are on the order of a rise of one inch in river stage per hour. This is an operational concern with large changes in released flows, and may not be a significant with respect to the flows being considered in this application. Site specific studies would have to be conducted to determine appropriate ramping rates.

Necessary flow augmentation can be estimated using the following assumptions:

- Augmentation flows of 50 to 100 cfs;
- Augmentation water supplied in 12 or 24-hour pulses; and,
- Two to ten augmentation events occur.

5.4.2.1 Reservoir Sites

Flow augmentation and reservoir storage calculations require data on precipitation and basin size above the proposed dams. For the purposes of this study, we have considered two dams on Owl Creek, one dam on Maple Creek, and one dam on Nolan Creek (Figures 5-8 through 5-11). Owl Creek is a stream that flows west from the upland area on the south side of Huelsdonk Ridge, south of the Hoh River. At the base of Huelsdonk Ridge, Owl Creek flows north across a glacial drift plain before entering the Hoh River. Maple Creek is a small basin south of Owl Creek that also flows west from the upland areas on the south side of the Hoh River. Like Owl Creek, Maple Creek flows north across a glacial drift plain before entering the Hoh River. Nolan Creek is located in the lower Hoh Valley and flows into the Hoh River at approximately River Mile 6. While a reservoir on Nolan Creek would address the low flow fish barrier at River Mile 3, it will not be able to address low flow barriers higher in the valley should they develop as a result of changing channel morphology.

Estimated runoff from annual precipitation in these catchments was significantly more than the estimated reservoir volumes (Tables 5-2 through 5-4). Therefore, annual precipitation is not a limiting factor in reservoir sizing.

The estimated augmentation water volumes range from a minimum of approximately 100 acre-feet for two pulse of 50 cfs augmentation for 12 hours duration, to a maximum of approximately 2,000 acre-feet for ten pulses of 100 cfs augmentation for 24 hour duration. Number of pulses and flow levels for each storage volume are detailed in Tables 5-5 through 5-8. Storage volumes are largely a function of dam height (Table 5-4).

As Tables 5-5 through 5-8 demonstrate, preliminary estimates for storage volumes for proposed reservoirs on both Owl (Site No. 1) and Maple Creeks show that a dam 120 feet high would be required to meet the larger flow augmentation demand of the ten 24-hour, 50 to 100 cfs augmentation events for Maple Creek and 60 to 100 cfs for Owl Creek Site No. 1.

An 80-foot high dam constructed on Owl Creek Site No. 1 would allow for a storage volume of approximately 1,044 acre-feet. For Owl Creek Site No. 1 this water volume would meet up to ten 12-hour flow augmentation pulses for flows of 50 – 100 cfs. For the 24-hour pulse, an 80-foot dam height at Owl Creek Site No. 1 would allow up to 10 pulses at 50 cfs, or five pulses at 100 cfs. For the full range of water volumes, number of pulses, and flow levels on Owl Creek Site No. 1, see Table 5-5.

An 80-foot high dam constructed on Owl Creek Site No. 2 would allow for a storage volume of approximately 908 acre-feet. This water volume would meet up to ten 12-hour flow augmentation pulses for flows of 50 – 90 cfs. For the 24-hour pulse, an 80-foot dam height at Owl Creek Site No. 2 would allow up to five pulses at 90 cfs. For the full range of water volumes, number of pulses, and flow levels on Owl Creek Site No. 2, see Table 5-6.

An 80-foot high dam on Maple Creek would have a storage volume of 856 acre-feet. This water volume would meet up to ten 12-hour flow augmentation pulses for flows of up to 80 cfs. For the 24-hour pulse, an 80-foot dam height on Maple Creek, this storage volume would allow up to five pulses at 80 cfs. For the full range of water volumes, number of pulses, and flow levels on Maple Creek, see Table 5-7.

An 80-foot high dam on Nolan Creek would have a storage volume of 1,847 acre-feet. This water volume would exceed the required water volume needed for ten 12-hour flow augmentation pulses for flows of up to 100 cfs. For the 24-hour pulse, an 80-foot dam height on Nolan Creek, this storage volume would allow up to ten pulses at 90 cfs. For the full range of water volumes, number of pulses, and flow levels on Nolan Creek, see Table 5-8.

5.4.2.2 Limitations Associated with Streamflow Augmentation

Limitations on the feasibility of augmenting streamflows with a surface water reservoir are:

- Costs associated with reservoir construction in remote area;
- Reservoir permitting; and,
- Geotechnical suitability of any proposed location.

Sediment runoff from the catchment into a reservoir will eventually diminish the reservoir capacity. Sediment may be primarily natural from unstable slopes. Additional sediment may be generated from forest harvest. It is understood that a significant portion of the Owl Creek drainage has been logged, potentially creating slope stability problems in the area and the associated generation of additional sediment. Infilling of a reservoir by sediment may reduce the operational life of a surface water reservoir.

5.4.3 Channel Modification

The objective of channel modification would be to increase river depth in problematic areas. Reducing channel width to increase depth by emplacement of sandbags, engineered logjams, coffer dams or more permanent structures can address fish passage problems in low-depth reaches.

Fish passage is limited by the depth of flow (i.e. stage), not necessarily the volume of flow (i.e. discharge). While flow depths are a function of flow volumes, the exact stage-discharge relationship at any point on a river is controlled by the dimensions of the channel. It may be possible, through engineered channel modifications, to increase flow depths without altering flow volumes.

In the past sand bags have been used as a temporary modification tool to increase flow depths on the Quillayute River. Essentially, the sand bags are used to constrict the flow and increase flow depths. Similar permanent structures, such as rocks or logs, could be constructed in the channel for the same effect. Engineered logjams are particularly effective because they create aquatic habitat, in addition to their engineered applications.

Channel modification is only an effective solution if fish passage problems are limited to isolated areas in the channel. If the area around the G& L Shake Company is the only area of concern, then channel modification is probably the most effective strategy. However, numerous other areas of concern are known to exist upstream, but the location of these areas may not be discovered until the fish are able to pass the area by the G& L Shake Company during times of critical low flows. Furthermore, additional problem areas could arise in the future due to lower minimum flows or natural channel morphological changes.

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TABLES

TABLE 2-1

Artifical Recharge Methods

Recharge Method		Recharge Water Source	Constaints	Benefits	Relative Cost
Wells		Treated Peak Flows	Cloggin, Need suitable aquifer, water quality	May be able to retrofit existing wells	High
Surface Infiltration	Spreading Basins	Larger area needed, Peak flows, Stormwater,	Unconfined aquifers, surface flooding	Inexpensive, could use existing gravel pits in favorable areas	Low-Moderate
	Dry Wells	Peak flows, Stormwater, Treated Wastewater	Unconfined aquifers	Small area, can be localized	Moderate
	Wetlands	Peak flows, Stormwater, Treated Wastewater	Unconfined aquifers, connection with groundwater system, surface flooding	May provide some additional treatment	Moderate

TABLE 2-2

Summary of Groundwater Anti-Degradation Criteria and Hoh River Water Quality

	Constituent	Anti-Degradation Criteria	Hoh River Data[a] Minimum	Maximum	Average	Units	Comment
Primary Contaminants	Barium*	1				mg/L	
	Cadmium*	0.01				mg/l	
	Chromium*	0.05				mg/l	
	Lead*	0.05				mg/l	
	Mercury*	0.002				mg/l	
	Selenium*	0.01				mg/l	
	Silver*	0.05				mg/l	
	Fluoride	4				mg/l	
	Nitrate (as N)	10	<0.01	0.45	0.10	mg/l	Analysis of Nitrate+Nitrite
	Endrin	0.0002				mg/l	
	Methoxychlor	0.1				mg/l	
	1,1,1-Trichloroethane	0.2				mg/l	
	2-4 D	0.1				mg/l	
	2,4,5-TP Silvex	0.01				mg/l	
	Total Coliform Bacteria	1/100	<1	280	13	CFU/100 ml	Analysis of fecal coliform
Secondary Contaminants	Copper*	1				mg/l	
	Iron*	0.3				mg/l	
	Manganese*	0.05				mg/l	
	Zinc*	5				mg/l	
	Chloride	250				mg/l	
	Sulfate	250				mg/l	
	Total Dissolved Solids	500				mg/l	
	Foaming Agents	0.5				mg/l	
	pH	6.5 to 8.5	6.40	8.20	7.41	s.u.	
	Corrosivity	noncorrosive				-	
	Color	15	0	64	12	color units	
	Odor	3				TON	
Radionuclides	Gross Alpha Particle Activity	15				pCi/l	
	Gross Beta Particle Radioactivity						
	Gross Beta Activity	50				pCi/l	
	Tritium	20,000				pCi/l	
	Strontium-90	8				pCi/l	
	Radium 226 & 228	5				pCi/1	
	Radium -226	3				pCi/1	
Carcinogens							
	Acrylamide	0.02				μg/L	
	Acrylonitrile	0.07				μg/L	
	Aldrin	0.005				μg/L	
	Aniline	14				μg/L	
	Aramite	3				μg/L	
	Arsenic*	0.05	<0.1	0.5	0.28	μg/L	Total Recoverable Analyses
	Azobenzene	0.7				μg/L	
	Benzene	1				μg/L	
	Benzidine	0.0004				μg/L	
	Benzo(a)pyrene	0.008				μg/L	
	Benzotrichloride	0.007				μg/L	
	Benzyl chloride	0.5				μg/L	
	Bis(chloroethyl)ether	0.07				μg/L	
	Bis(chloromethyl)ether	0.0004				μg/L	
	Bis(2-ethylhexyl) phthalate	6				μg/L	
	Bromodichloromethane	0.3				μg/L	
	Bromoform	5				μg/L	
	Carbazole	5				μg/L	
	Carbon tetrachloride	0.3				μg/L	
	Chlordane	0.06				μg/L	
	Chlorodibromomethane	0.5				μg/L	
	Chloroform	7				μg/L	
	4 Chloro-2-methyl aniline	0.1				μg/L	
	4 Chloro-2-methyl analine hydrochloride	0.2				μg/L	
	o-Chloronitrobenzene	3				μg/L	
	p-Chloronitrobenzene	5				μg/L	
	Chlorthalonil	30				μg/L	
	Diallate	1				μg/L	
	DDT (includes DDE and DDD)	0.3				μg/L	
	1,2 Dibromoethane	0.001				μg/L	
	1,4 Dichlorobenzene	4				μg/L	

TABLE 2-2

Summary of Groundwater Anti-Degradation Criteria and Hoh River Water Quality

	Constituent	Anti-Degradation Criteria	Hoh River Data[a] Minimum	Maximum	Average	Units	Comment
	3,3' Dichlorobenzidine	0.2				μg/L	
	1,1 Dichloroethane	1				μg/L	
	1,2 Dichloroethane (ethylene chloride)	0.5				μg/L	
	1,2 Dichloropropane	0.6				μg/L	
	1,3 Dichloropropene	0.2				μg/L	
	Dichlorvos	0.3				μg/L	
	Dieldrin	0.005				μg/L	
	3,3' Dimethoxybenzidine	6				μg/L	
	3,3 Dimethylbenzidine	0.007				μg/L	
	1,2 Dimethylhydrazine	60				μg/L	
	2,4 Dinitrotoluene	0.1				μg/L	
	2,6 Dinitrotoluene	0.1				μg/L	
	1,4 Dioxane	7				μg/L	
	1,2 Diphenylhydrazine	0.09				μg/L	
	Direct Black 38	0.009				μg/L	
	Direct Blue 6	0.009				μg/L	
	Direct Brown 95	0.009				μg/L	
	Epichlorohydrin	8				μg/L	
	Ethyl acrylate	2				μg/L	
	Ethylene dibromide	0.001				μg/L	
	Ethylene thiourea	2				μg/L	
	Folpet	20				μg/L	
	Furazolidone	0.02				μg/L	
	Furium	0.002				μg/L	
	Furmecyclox	3				μg/L	
	Heptachlor	0.02				μg/L	
	Heptachlor Epoxide	0.009				μg/L	
	Hexachlorobenzene	0.05				μg/L	
	Hexachlorocyclohexane (alpha)	0.001				μg/L	
	Hexachlorocyclohexane (alpha) (technical)	0.05				μg/L	
	Hexachlorodibenzo-p-dioxin, mix	0.00001				μg/L	
	Hydrazine/Hydrazine sulfate	0.03				μg/L	
	Lindane	0.06				μg/L	
	2 Methoxy-5-nitroaniline	2				μg/L	
	2 Methylaniline	0.2				μg/L	
	2 Methylaniline hydrochloride	0.5				μg/L	
	4,4' Methylene bis(N,N'-dimethyl) aniline	2				μg/L	
	Methylene chloride (dichloromethane)	5				μg/L	
	Mirex	0.05				μg/L	
	Nitrofurazone	0.06				μg/L	
	N-Nitrosodiethanolamine	0.03				μg/L	
	N-Nitrosodiethylamine	0.0005				μg/L	
	N-Nitrosodimethylamine	0.002				μg/L	
	N-Nitrosodiphenylamine	17				μg/L	
	N-Nitroso-di-n-propylamine	0.01				μg/L	
	N-Nitrosopyrrolidine	0.04				μg/L	
	N-Nitroso-di-n-butylamine	0.02				μg/L	
	N-Nitroso-N-methylethylamine	0.004				μg/L	
	PAH	0.01				μg/L	
	PBBs	0.01				μg/L	
	PCBs	0.01				μg/L	
	o-Phenylenediamine	0.005				μg/L	
	Propylene oxide	0.01				μg/L	
	2,3,7,8-Tetrachlorodibenzo-p-dioxin	0.0000006				μg/L	
	Tetrachloroethylene (perchloroethylene)	0.8				μg/L	
	p,α,α,α-Tetrachlorotoluene	0.004				μg/L	
	2,4 Toluenediamine	0.002				μg/L	
	o-Toluidine	0.2				μg/L	
	Toxaphene	0.08				μg/L	
	Trichloroethylene	3				μg/L	
	2,4,6-Trichlorophenol	4				μg/L	
	Trimethyl phosphate	2				μg/L	
	Vinyl chloride	0.02				μg/L	

Notes:
a. Data from http://www.ecy.wa.gov/apps/watersheds/riv/station.asp?theyear=2003&tab=final_data&scrolly=558&wria=20&sta=20B070
Blank cells: no data
*metals are measured as total metals

TABLE 2-3

Surface Water Source Limitation Letters

Water Body	Letter Date	Recommendation
Beaver Creek (tributary to Sol Duc River)	9-Dec-92	Recommended denial of application for 0.6 cfs, recommended no diversions when flow < 215 cfs October-June or flow <145 cfs July-September
Bogachiel River (tributary to Quillayute River)	12-Sep-91	Denial of application, concerns for Coho salmon
Lake Pleasant (tributary to Sol Duc River)	31-Mar-93	Denial of application, concerns for Coho salmon
Sol Duc River (tributary to Quillayute River)	27-Feb-92	Denial of application, concerns for Coho salmon
Sol Duc River (tributary to Quillayute River)	5-May-89	Recommended low flow provisions of 250 cfs October-June and 145 cfs July-September measured at Snider Creek Ranger Station Gage
Snider Creek (tributary to Sol Duc River)	11-Jan-93	Recommended low flow provisions of 215 cfs October-June and 145 cfs July-September measured at Snider Creek Ranger Station Gage (Sol Duc River)

TABLE 2-4

Summary of Evaluated Areas

<table>
<tr><th colspan="2">Area</th><th>Approximate Aquifer Thickness (feet)</th><th>Approximate Well Yields (gpm)</th><th>Potential Recharge Water Source(s)</th><th>Positives for Artificial Storage</th><th>Uncertainties for Artificial Storage</th><th>Groundwater Supply Potential</th><th>Artificial Recharge Potential</th></tr>
<tr><td colspan="2">Forks Prairie</td><td>10 to 15</td><td>5 to 400</td><td>Treated wastewater, stormwater, peak flows</td><td>• Moderately permeable and confined aquifers
• Water quality is generally good</td><td>• Extent of aquifer
• Continuity with Calawah and Bogachiel Rivers
• Amount of available aquifer capacity</td><td>Moderate-High</td><td>Moderate</td></tr>
<tr><td colspan="2">Quillayute Prairie</td><td>5 to 20</td><td><5 to 70</td><td>Peak flows</td><td>• Moderately permeable and confined aquifer(s)</td><td>• Extent of confined aquifer
• Continuity with Quillayute and Sol Duc Rivers (and adjacent shallow alluvial aquifers
• Amount of available aquifer capacity</td><td>Moderate</td><td>Moderate</td></tr>
<tr><td colspan="2">Three Rivers</td><td>10 to 30</td><td><5 to 300</td><td>Peak flows</td><td>• Moderately to highly permeable aquifer(s)
• High permeability = Limited interference between wells</td><td>• Lateral extent of sand and gravel aquifer
• Continuity with the Quillayute, Sol Duc and Bogachiel Rivers, potential for Groundwater Under the Direct Influence of Surface Water (GUI)
• Potential for salt water intrusion near tidally influenced Quillayute River
• Pumping capacity of aquifers</td><td>Moderate-High</td><td>Low-Moderate</td></tr>
<tr><td colspan="2">Lower Hoh</td><td>5 to 20</td><td><5 to 100</td><td>Peak flows</td><td>• Moderately permeable and confined aquifer(s)
• Areas of known groundwater discharge (springs) that could support wells</td><td>• Lateral extent of permeable outwash sand and gravel
• Saturated thickness of the permeable sand and gravel
• Continuity with the Hoh River
• Water quality (low pH, high Fe/Mn)
• Amount of available recharge</td><td>Low-Moderate</td><td>Low</td></tr>
<tr><td rowspan="4">Upper Hoh</td><td>Groundwater Development</td><td rowspan="4">5 to 10(?)</td><td rowspan="4">10 to 40(?)</td><td rowspan="4">Peak flows</td><td>• Pumped water would be returned to stream - no net impairment to streamflow</td><td>• Hydrogeologic conditions in the Upper Hoh area are uncertain.</td><td rowspan="4">Low-Moderate</td><td rowspan="4">Low-Moderate(?)</td></tr>
<tr><td>Augmentation of Streamflow with Groundwater</td><td rowspan="3">• Augmenting streamflow will help maintain productivity of salmon runs</td><td>• Aquifer area is limited to the Hoh River valley (< 1 mile wide). Pumping of high-capacity wells would likely induce recharge from the river in a relatively short time, reducing flows in the river
• Hydrogeologic conditions in the Upper Hoh area are uncertain. Well yields may be less than 500 gpm and a number of wells would be required to supply the desired augmentation quantities
• Estimated costs for the wells may be significantly higher because of site access and preparation and the distance to suitable electrical service</td></tr>
<tr><td>Augmentation of Streamflow with Bank Storage</td><td>• A surface water diversion structure will need to be constructed and maintained
• A conveyance structure from the diversion point to the recharge area will be needed (abandoned side channel, canal, or transmission main)
• Lag time between recharge and seepage back to the stream may be too short to provide significant benefits during the desired augmentation period</td></tr>
<tr><td>Augmentation of Streamflow with Surface Water Storage</td><td>• Actual augmentation flows, duration and frequency need to be determined
• Difficulty in reservoir permitting
• The geotechnical suitability of any proposed location has to be confirmed</td></tr>
<tr><td colspan="2">Beaver/Lake Pleasant</td><td>1 to 40</td><td>1 to 60</td><td>Peak flows, induced recharge from lake</td><td>• Moderately permeable aquifer(s)
• Aquifer is confined</td><td>• Lateral extent of the outwash sand and gravel aquifer(s)
• Continuity of the aquifer(s) with the Lake Pleasant and the Sol Duc River, potential for Groundwater Under the Direct Influence of Surface Water (GUI)
• Amount of available aquifer capacity
• Pumping capacity of the aquifer(s)
• Water availability for Lake Pleasant sockeye</td><td>Low-Moderate</td><td>Low - Moderate</td></tr>
<tr><td colspan="2">Ozette/Trout Creek *</td><td>1 to 10(?)</td><td>1 to 10</td><td>Peak flows, induced recharge from lake</td><td>• Two storage options: bank storage for streamflow augmentation, and the use of forest roads along the river valleys to impound water, creating wetlands that could be used for storage or habitat enhancement</td><td>• Limited existing hydrogeologic data, shallow bedrock
• Surface water diversion structure will need to be constructed and maintained
• A conveyance structure from the diversion point to the recharge area will be needed (abandoned side channel, canal, or transmission main)
• Lag time between recharge and seepage back to the stream may be too short to provide significant benefits during the desired augmentation period</td><td>Low-Moderate</td><td>Low</td></tr>
</table>

Note
See Figure 2-X for area locations.
All aquifer materials area glacial and alluvial materials over bedrock, except Beaver/Lake Pleasant, which does not have substantial alluvial material
* Very few well logs are available in the Ozette/Trout Creek area

TABLE 4-1

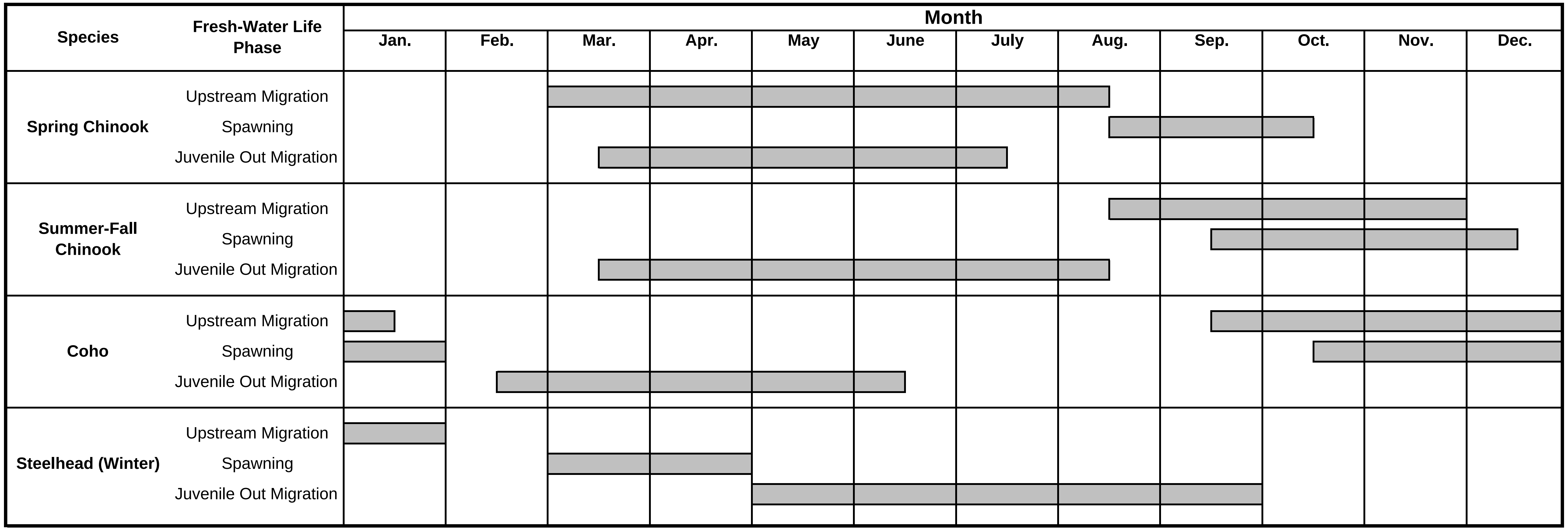
City of Forks
Groundwater Certificates

Control Number	Certificate Number	Local Name	TRS	Priority Date	Primary Qi (gpm)	Supplemental Qi (gpm)	Primary Qa (acre-feet/year)	Supplemental Qa (acre-feet/year)	Depth of Well (ft bgs)	Screened Intervals (ft bgs)
G2-*03542CWRIS	2108-A	Wells 1 & 2	T28N/R13W-04 SW/SE	2/11/1954	500		504		Well 1: 178	125-135
									Well 2: 161	109-113
G2-*05930CWRIS	4120-A	Well 3	T28N/R13W-04 SW/SE	5/2/1961		290		464	Well 3: 114	102-109
G2-24829CWRIS		Wells 4 & 5	T28N/R13W-09 NE/NW	3/15/1978	600		446	504	Well 4: 130	118-128
									Well 5: 132	117-128
				Total:	**1,100**		**950**			

Note: all certificates are for municipal supply

Table 5-1

Life Cycles of Selected Salmonids



Note: Bull Trout / Dolly Varden - Listed by the US Fish and Wildlife Service under the Endangered Species Act as Threatened
Limited information available on quantity and distribution of chum, summer steelhead, and lampreys.

Source: A Catalog of Washington Streams and Salmon Utilization; Volume 2: Coastal; Washington Department of Fisheries, 1975.

Table 5-2
Precipitation Summary

Month	**Owl Creek #1** (Inches)	**Owl Creek #2** (Inches)	**Maple Creek** (Inches)	**Nolan Creek** (Inches)
January	21.8	21.8	21.7	18.4
February	17.8	17.8	17.6	15.0
March	15.6	15.6	15.6	13.3
April	10.1	10.1	9.9	8.5
May	6.3	6.3	6.2	5.3
June	4.4	4.4	4.4	3.7
July	2.8	2.8	2.9	2.5
August	3.3	3.3	3.3	2.8
September	5.8	5.8	5.9	5.5
October	13.9	13.9	13.9	11.9
November	19.4	19.4	19.4	16.5
December	25.4	25.4	25.2	21.4
Annual	*147*	*147*	*146*	*125*

Table 5-3
Available Water to Fill Reservoir
(acre feet)

Month	Owl Creek #1	Owl Creek #2	Maple Creek	Nolan Creek
January	4,682	3,548	1,539	2,006
February	3,831	2,903	1,247	1,636
March	3,340	2,531	1,106	1,451
April	2,170	1,644	704	926
May	1,353	1,025	437	581
June	935	708	312	408
July	592	449	202	271
August	711	539	235	310
September	1,254	950	420	597
October	2,984	2,261	987	1,300
November	4,171	3,161	1,377	1,804
December	5,447	4,127	1,789	2,329
Annual	*31,463*	*23,842*	*10,360*	*13,610*

Notes:
Estimates assume that half of the water quantity is lost to infiltration, evapotranspiration, and flow-through to maintain streamflows.

Table 5-4
Water Volume Requirements

Owl Creek #1 - near start of dog leg						
Dam Height (ft)	Reservoir Surface Area (acres)	Reservoir Capacity (AF)	Dam Length (ft)	V/L	Catchment above Dam (sq mi)	Water Available to Fill Reservoir (AF)[1]
40	9.6	384	275	1.4	8.05	31,463
80	16.5	1,044	455	2.3	8.05	
120	34.4	2,419	630	3.8	8.05	
Owl Creek #2 - at the fork further upstream						
Dam Height (ft)	Reservoir Surface Area (acres)	Reservoir Capacity (AF)	Dam Length (ft)	V/L	Catchment above Dam (sq mi)	Water Available to Fill Reservoir (AF)[1]
40	6.3	252	215	1.2	6.10	23,842
80	16.4	908	330	2.8	6.10	
120	32.7	2,216	480	4.6	6.10	
Maple Creek #1 - closest to start of dog leg						
Dam Height (ft)	Reservoir Surface Area (acres)	Reservoir Capacity (AF)	Dam Length (ft)	V/L	Catchment above Dam (sq mi)	Water Available to Fill Reservoir (AF)[1]
40	5.2	208	440	0.5	2.66	10,360
80	16.2	856	585	1.5	2.66	
120	31.4	2,112	740	2.9	2.66	
Nolan Creek #1 - near Mt. Octopus						
Dam Height (ft)	Reservoir Surface Area (acres)	Reservoir Capacity (AF)	Dam Length (ft)	V/L	Catchment above Dam (sq mi)	Water Available to Fill Reservoir (AF)[1]
40	13.5	538	580	0.9	4.09	13,610
80	32.7	1,847	845	2.2	4.09	
120	56.2	4,096	1,025	4.0	4.09	

Notes:

Estimates assume that half of the water quantity is lost to infiltration, evapotranspiration, and flow-through to maintain streamflows.

Table 5-5
Owl Creek Site No. 1 Volume Comparison

Water Volume (acre-feet) Needed for a 12-hour Duration Pulse

Number of Pulses	Flow (cfs) 50	60	75	80	90	100
2	*99*	*119*	*149*	*159*	*179*	*198*
5	*248*	*298*	*372*	397	446	496
10	496	595	744	793	893	992

Water Volume (acre-feet) Needed for a 24-hour Duration Pulse

Number of Pulses	Flow (cfs) 50	60	75	80	90	100
2	*198*	*238*	*298*	*317*	*357*	397
5	496	595	744	793	893	992
10	992	1190	1488	1587	1785	1983

Notes:
40, 80, or 120 foot dam.
80 or 120 foot dam
120 foot dam

Table 5-6
Owl Creek Site No. 2 Volume Comparison

Water Volume (acre-feet) Needed for a 12-hour Duration Pulse

Number of Pulses	Flow (cfs)					
	50	**60**	**75**	**80**	**90**	**100**
2	*99*	*119*	*149*	*159*	*179*	*198*
5	*248*	298	372	397	446	496
10	496	595	744	793	893	992

Water Volume (acre-feet) Needed for a 24-hour Duration Pulse

Number of Pulses	Flow (cfs)					
	50	**60**	**75**	**80**	**90**	**100**
2	*198*	*238*	298	317	357	397
5	496	595	744	793	893	992
10	992	1190	1488	1587	1785	1983

Notes:
40, 80, or 120 foot dam.
80 or 120 foot dam
120 foot dam

Table 5-7
Maple Creek Volume Comparison

Water Volume (acre-feet) Needed for a 12-hour Duration Pulse

Number of Pulses	Flow (cfs)					
	50	**60**	**75**	**80**	**90**	**100**
2	*99*	*119*	*149*	*159*	*179*	*198*
5	248	298	372	397	446	496
10	496	595	744	793	893	992

Water Volume (acre-feet) Needed for a 24-hour Duration Pulse

Number of Pulses	Flow (cfs)					
	50	**60**	**75**	**80**	**90**	**100**
2	*198*	238	298	317	357	397
5	496	595	744	793	893	992
10	992	1190	1488	1587	1785	1983

Notes:
40, 80, or 120 foot dam.
80 or 120 foot dam
120 foot dam

Table 5-8
Nolan Creek Volume Comparison

Water Volume (acre-feet) Needed for a 12-hour Duration Pulse

Number of Pulses	Flow (cfs)					
	50	60	75	80	90	100
2	*99*	*119*	*149*	*159*	*179*	*198*
5	*248*	*298*	*372*	*397*	*446*	*496*
10	*496*	595	744	793	893	992

Water Volume (acre-feet) Needed for a 24-hour Duration Pulse

Number of Pulses	Flow (cfs)					
	50	60	75	80	90	100
2	*198*	*238*	*298*	*317*	*357*	*397*
5	*496*	595	744	793	893	992
10	992	1190	1488	1587	1785	1983

Notes:
40, 80, or 120 foot dam.
80 or 120 foot dam
120 foot dam

FIGURES

Areas Considered for ASR and Other Options

1. Forks Prairie
2. Quillayute Prairie
3. Three Rivers
4. Beaver / Lake Pleasant
5. Lower Hoh
6. Upper Hoh
7. Ozette / Trout Creek / Big River

LEGEND

Geology Type and Description

Unlithified
- Alluvium
- Drift (undifferentiated)
- Outwash
- Till

Lithified
- Marine Sedimentary Rocks
- Bedrock (mainly basalt)
- Ice

- WRIA 20 Boundary
- WRIA 20 Proposed Sub-Basins
- WRIA Boundary
- Waterbody
- County Boundary
- Rivers and Streams
- Indian Reservation

Note: Geology was consolidated from 1:100,000 digital coverage (WDNR, 2001). Tectonic zones, intrusive igneous and metamorphic rocks comprise a small portion of the WRIA and were included in the area labeled "Bedrock".

Pacific 1-5: Independent Pacific Drainages

N

0 30,000
Scale 1" = 30,000 feet

Map Projection: Washington State Plane, North Zone, NAD 83, Feet

Source: Washington State Department of Natural Resources, United States Geologic Survey, Washington State Department of Ecology, Washington State Department of Transportation, United States Department of Transportation, Golder Associates Inc.

This figure was originally produced in color. Reproduction in black and white may result in a loss of information.

Generalized Geology and Areas of Interest

Clallam/WRIA 20 Watershed Planning/WA

Drawn: KAV	Revision: 3	Date: Jun. 14, 2005	Figure: 1-1

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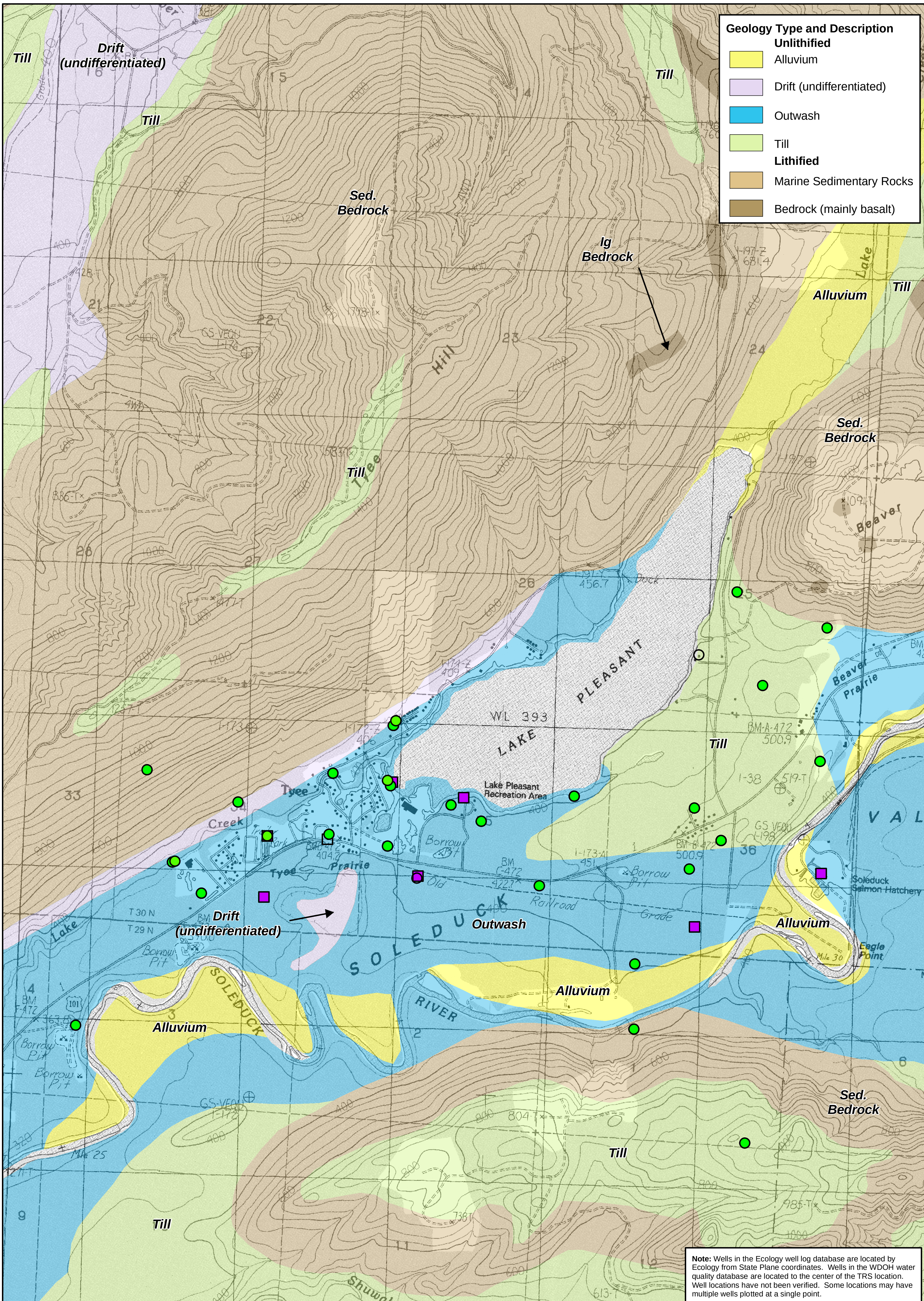
Golder Associates



LEGEND

- Well Location (Ecology)
- Dry Well Location (Ecology)
- Well Location (WDOH)
- Inactive Well Location (WDOH)

0 2,000

Scale in Feet

Map Projection:
Washington State Plane,
North Zone, NAD 83, Feet

Source: USGS, Golder Associates Inc., WDNR, WDOE, WSDOH

N

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Beaver / Lake Pleasant Area - Generalized Geology and Well Locations

Clallam/WRIA 20 Watershed Planning/WA

Drawn: KAV	Revision: 2	Date: Jun. 14, 2005	Figure: 2-1

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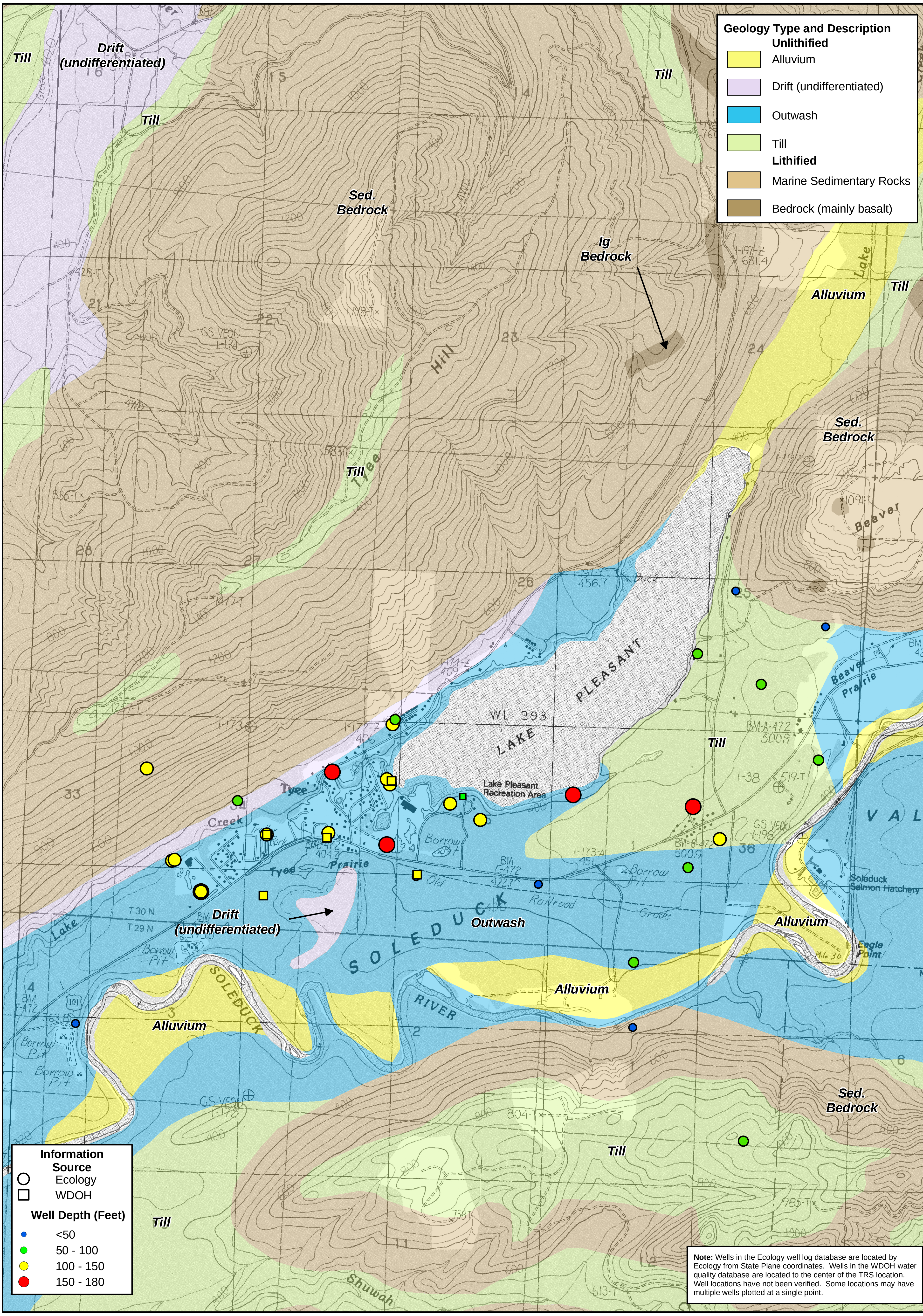
Golder Associates



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0 2,000

Scale in Feet

Map Projection:
Washington State Plane,
North Zone, NAD 83, Feet

Source: USGS, Golder Associates Inc., WDNR, WDOE, WSDOH

N

Beaver / Lake Pleasant Area - Generalized Geology and Well Depth

Clallam/WRIA 20 Watershed Planning/WA

Drawn: KAV	Revision: 2	Date: Jun. 14, 2005	Figure: 2-2

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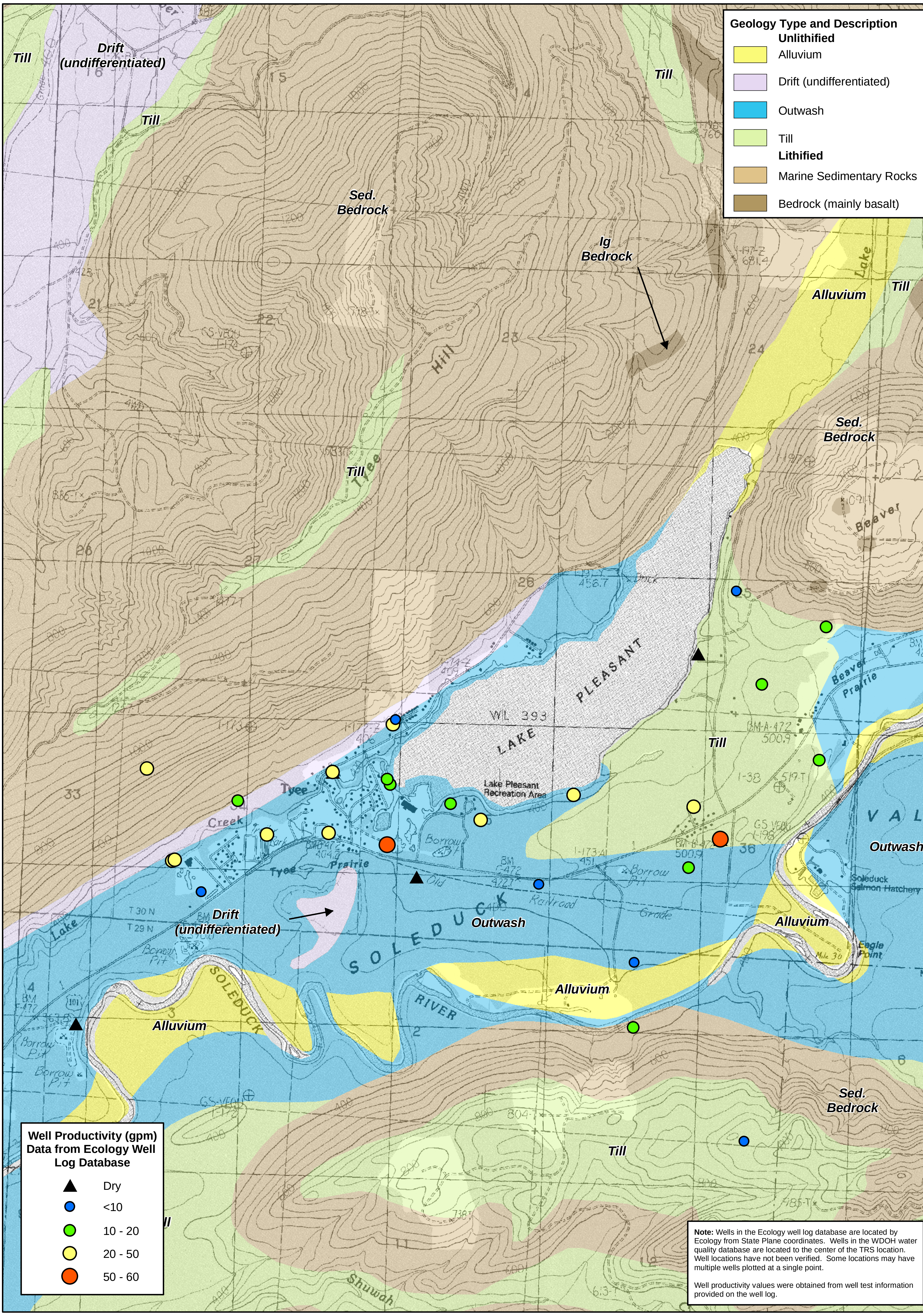
Golder Associates



LEGEND

0 2,000

Scale in Feet

N

Map Projection:
Washington State Plane,
North Zone, NAD 83, Feet

Source: USGS, Golder Associates Inc., WDNR, WDOE, WSDOH

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Beaver / Lake Pleasant Area - Generalized Geology and Well Productivity

Clallam/WRIA 20 Watershed Planning/WA

Drawn: KAV	Revision: 1	Date: Jun. 14, 2005	Figure: 2-3

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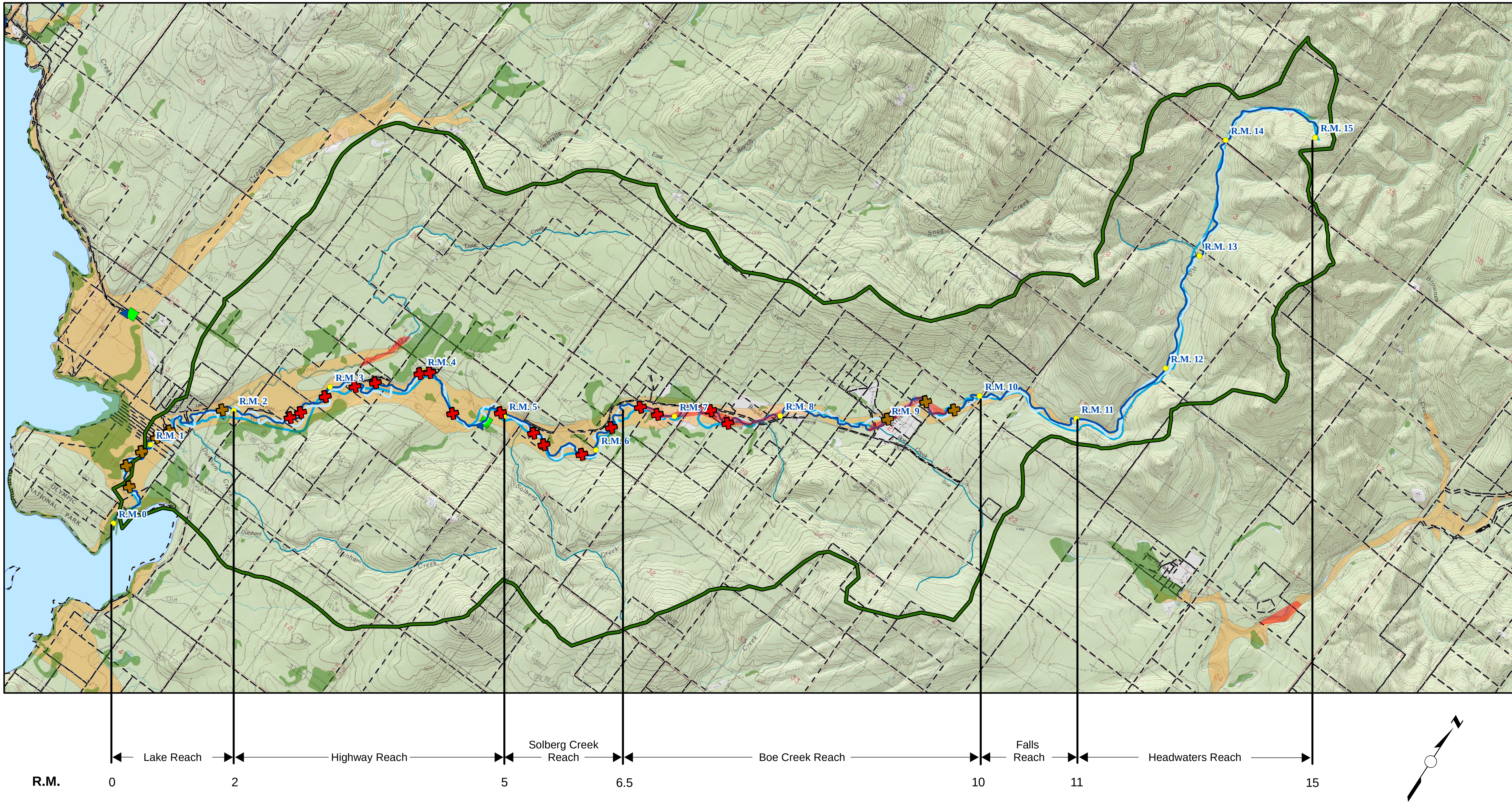

Legend

Log Jam - (Kramer, 1953)
- Existing, Assumed left in place
- Removed

Channel Migration Zone
FEMA Flood Plain
Wetland
Big River - 1996
River - 1956/1957
River -1935/1942
Stream Gage
Toe Width Station
Parcel Line

Clallam/WRIA 20, Sol Duc-Hoh WS/WA

Big River Basin Site Map

Golder Associates

PROJECT # 0431130 x 100- 2110			REV. 1
DESIGN	AQK	Feb. 26, 2004	
GIS	KAV	Jun. 1, 2005	
CHECK	XX	-	
REVIEW	XX	-	

FIGURE 3-1

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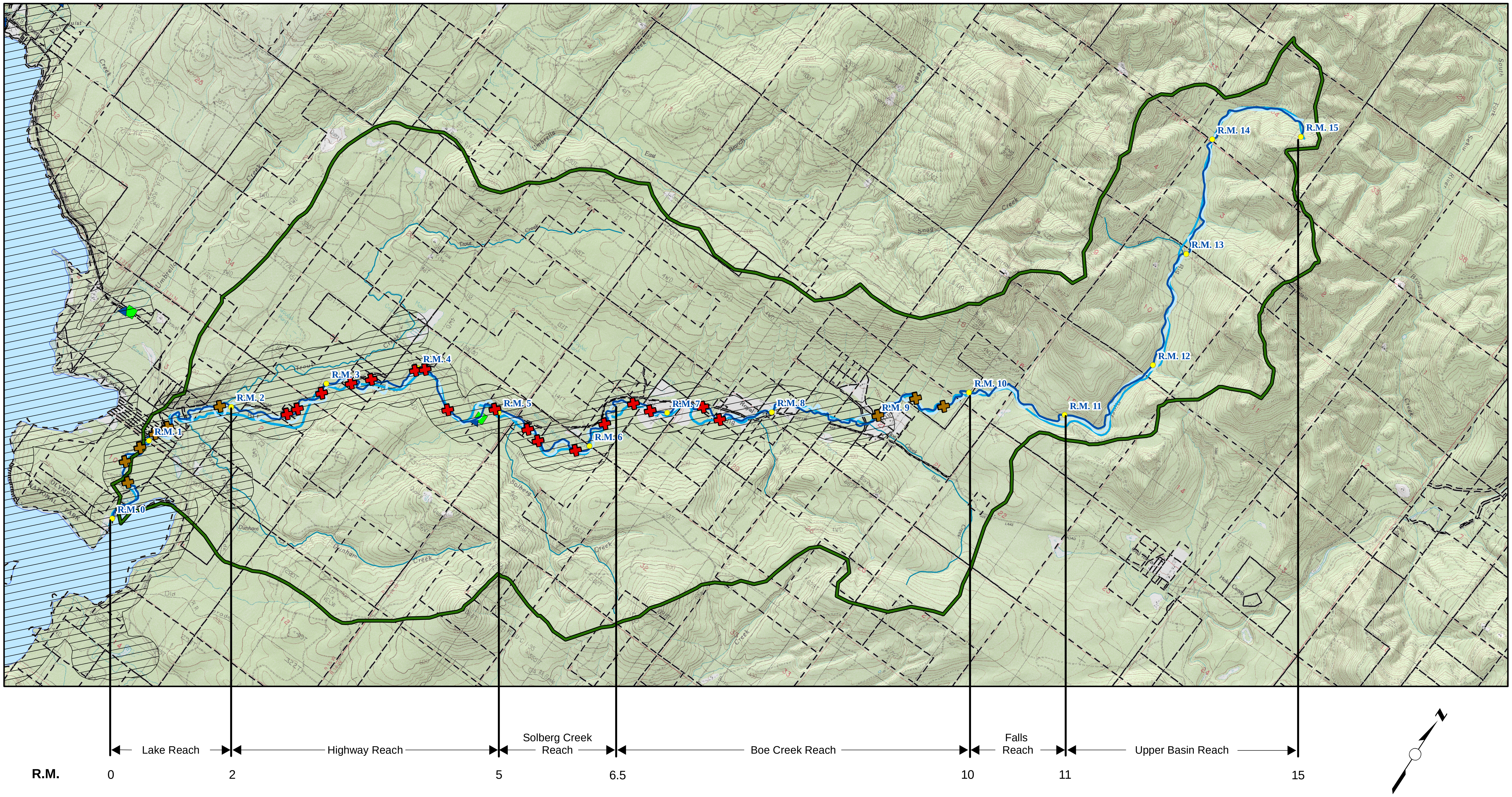

Legend

Area of LIDAR Coverage

Log Jam - (Kramer, 1953)

- Existing, Assumed left in place
- Removed

Parcel Line

Big River - 1996

River - 956/57

River -1935/42

Stream Gage

Toe Width Station

Clallam/WRIA 20 Watershed Planning/WA

Big River - 2003 Lidar Coverage

Golder Associates

PROJECT # 0431130 x 100- 2110			REV. 1
DESIGN	AQK	Feb. 26, 2004	**FIGURE 3-2**
GIS	KAV	Jun. 14, 2005	
CHECK	XX	-	
REVIEW	XX	-	

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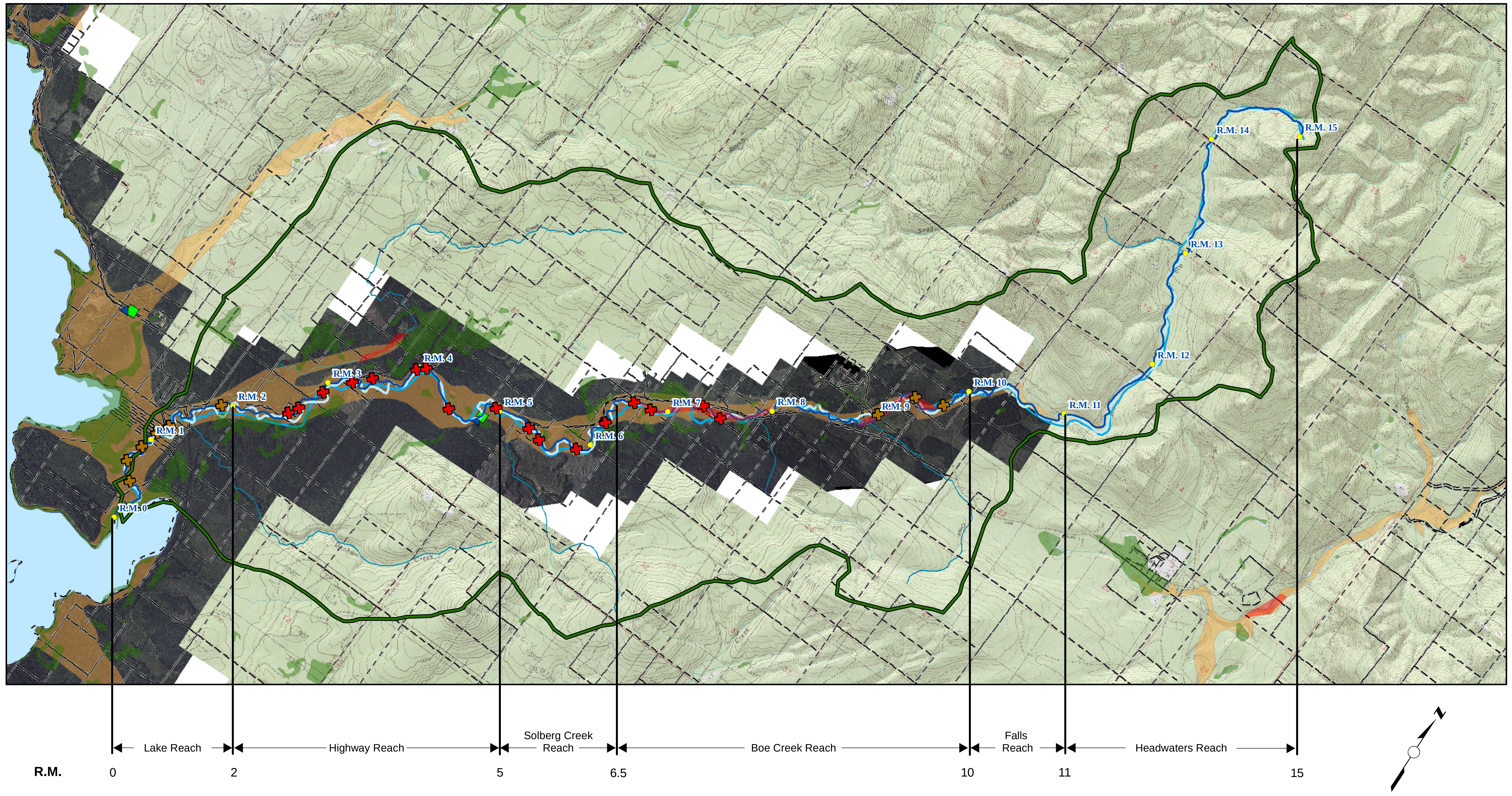

Legend

Log Jam - (Kramer, 1953)

- Existing, Assumed left in place
- Removed
- Channal Migration Zone
- FEMA Flood Plain
- Wetland
- Big River - 1996
- River - 1956/1957
- River -1935/1942
- Stream Gage
- Toe Width Station
- Parcel Line

Clallam/WRIA 20, Sol Duc-Hoh WS/WA

Big River Basin Site Map - 2003
Orthophoto Coverage

Golder Associates

PROJECT # 0431130 x 100- 2110			REV. 1
DESIGN	AQK	Feb. 26, 2004	**FIGURE 3-3**
GIS	KAV	Jun. 15, 2005	
CHECK	XX	-	
REVIEW	XX	-	

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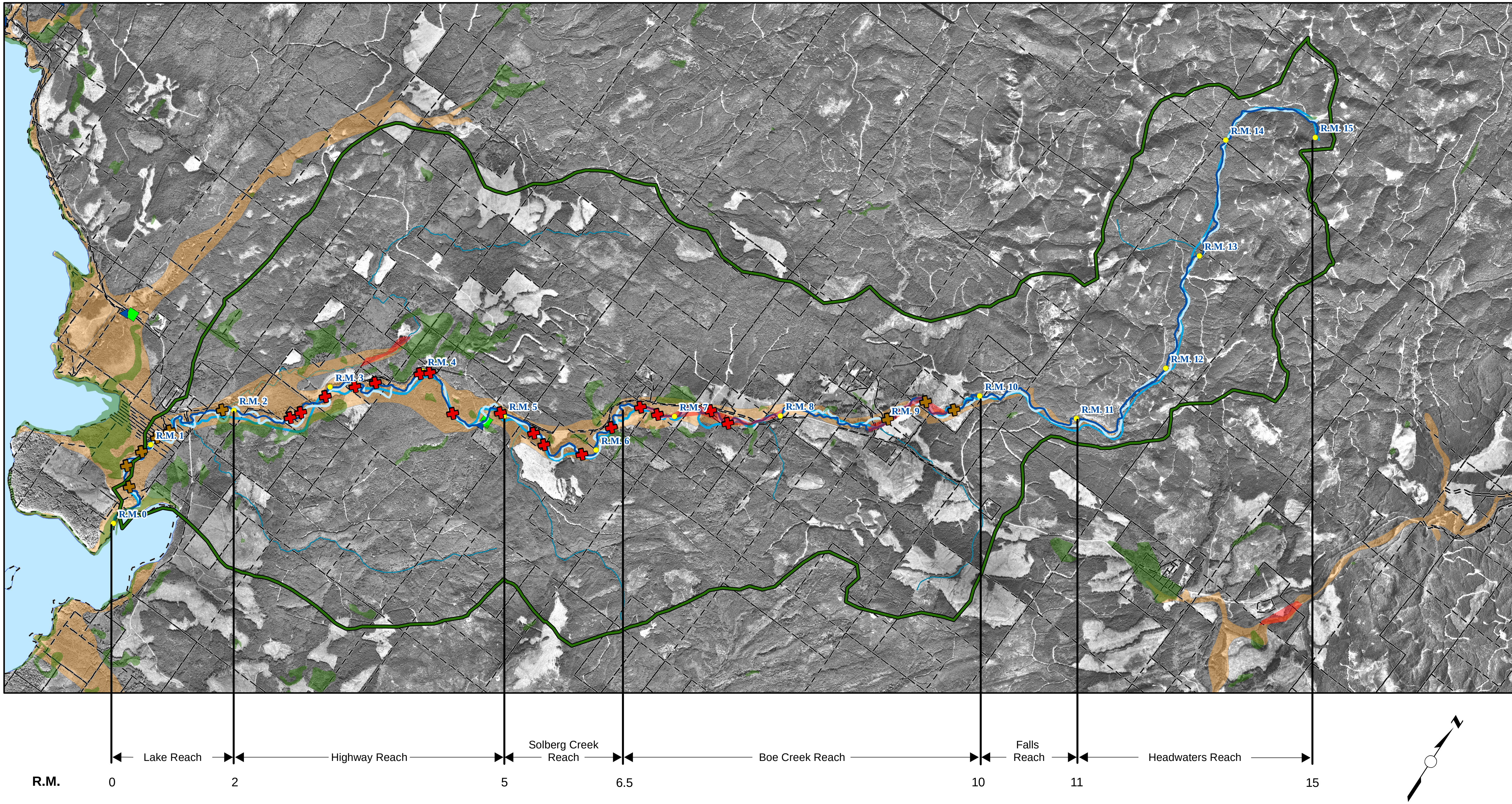

Legend

Log Jam - (Kramer, 1953)

- Existing, Assumed left in place
- Removed
- Channel Migration Zone
- FEMA Flood Plain
- Wetland
- Big River - 1996
- River - 1956/1957
- River -1935/1942
- Stream Gage
- Toe Width Station
- Parcel Line

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Clallam/WRIA 20, Sol Duc-Hoh WS/WA

Big River - 2000 Orthophoto Coverage

PROJECT # 0431130 x 100- 2110			REV. 1
DESIGN	AQK	Feb. 26, 2004	
GIS	KAV	Jun. 15, 2005	
CHECK	XX	-	
REVIEW	XX	-	

Golder Associates

FIGURE 3-4

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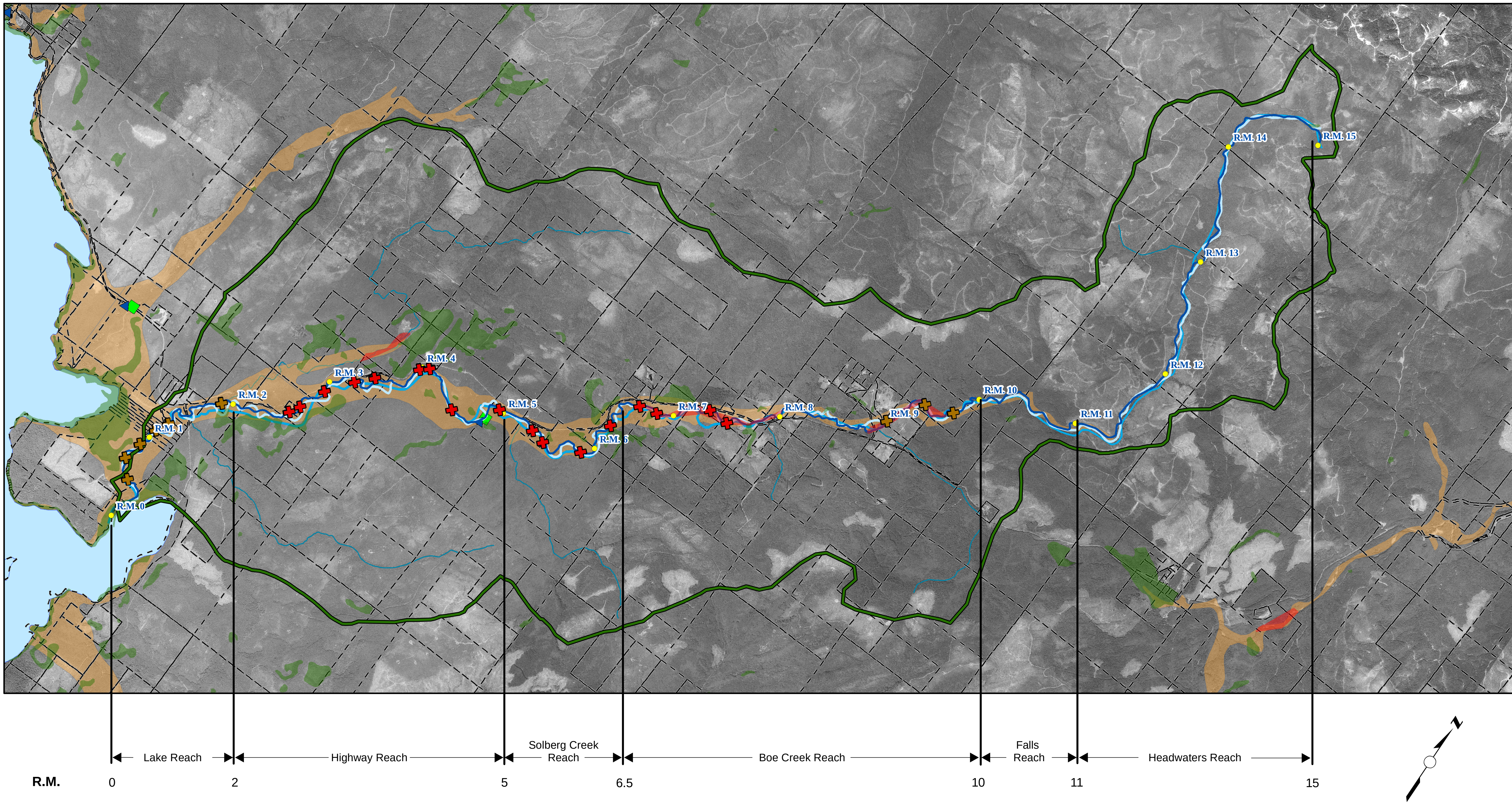

Legend

Log Jam - (Kramer, 1953)

- Existing, Assumed left in place
- Removed
- Channel Migration Zone
- FEMA Flood Plain
- Wetland
- Big River - 1996
- River - 1956/1957
- River -1935/1942
- Stream Gage
- Toe Width Station
- Parcel Line

Clallam/WRIA 20, Sol Duc-Hoh WS/WA

Big River - 1994 Orthophoto Coverage

Golder Associates

PROJECT # 0431130 x 100- 2110			REV. 1
DESIGN	AQK	Feb. 26, 2004	**FIGURE 3-5**
GIS	KAV	Jun. 14, 2005	
CHECK	XX	-	
REVIEW	XX	-	

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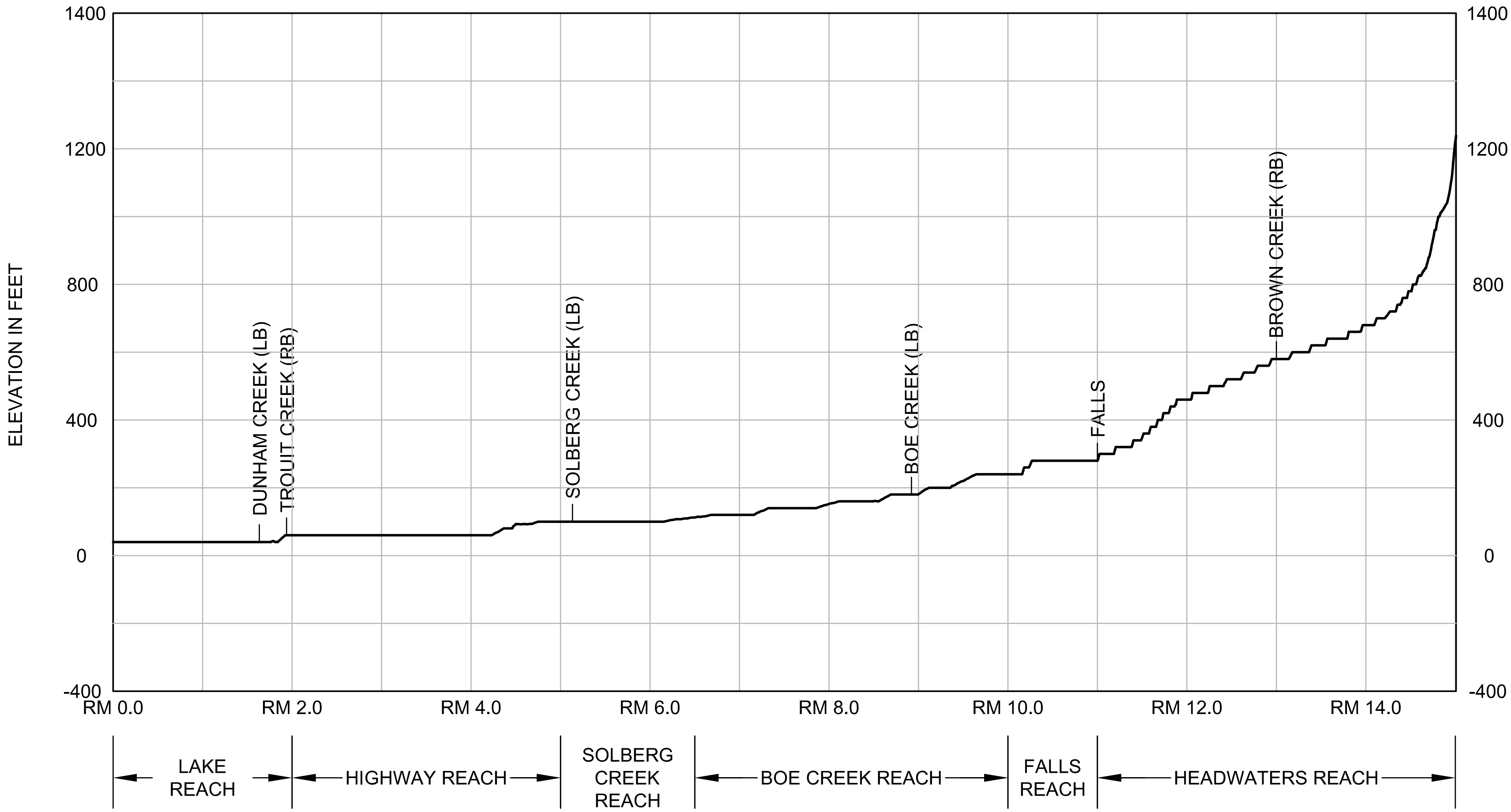


TRIBUTARY ENTERING FROM THE:

RB = RIGHT BANK (LOOKING DOWNSTREAM)

LB = LEFT BANK (LOOKING DOWNSTREAM)

0 10000 20000

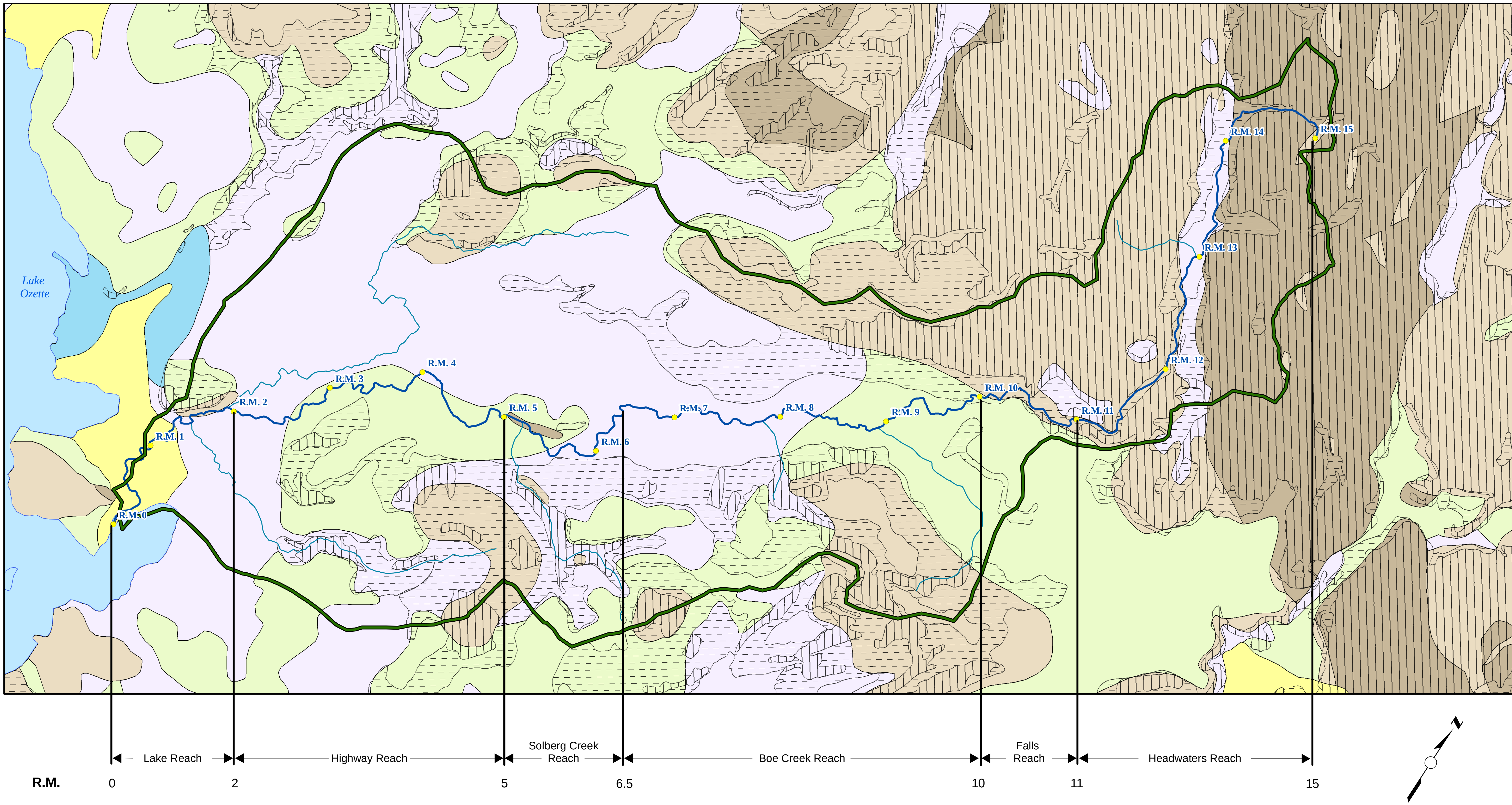
SCALE IN FEET

20X VERTICAL EXAGGERATION

FIGURE **3-6**

BIG RIVER LONGITUDINAL STREAM CHANNEL PROFILE

WRIA 20/SUPPLEMENTAL STORAGE ASSESSMENT/WA



Legend

Geology Type and Description

Unlithified

- Alluvium
- Drift (undifferentiated)
- Outwash
- Till

Lithified

- Marine Sedimentary Rocks
- Bedrock (mainly basalt)

- Erosion Hazard
- Landslide Hazard

Clallam/WRIA 20 Watershed Planning/WA

Big River Basin - Surficial Geology and Geohazard Areas

PROJECT # 0431130 x 100-2110			REV. 1
DESIGN	AQK	Feb. 26, 2004	
GIS	KAV	Jun. 14, 2005	
CHECK	XX	-	
REVIEW	XX	-	

Golder Associates

FIGURE 3-7

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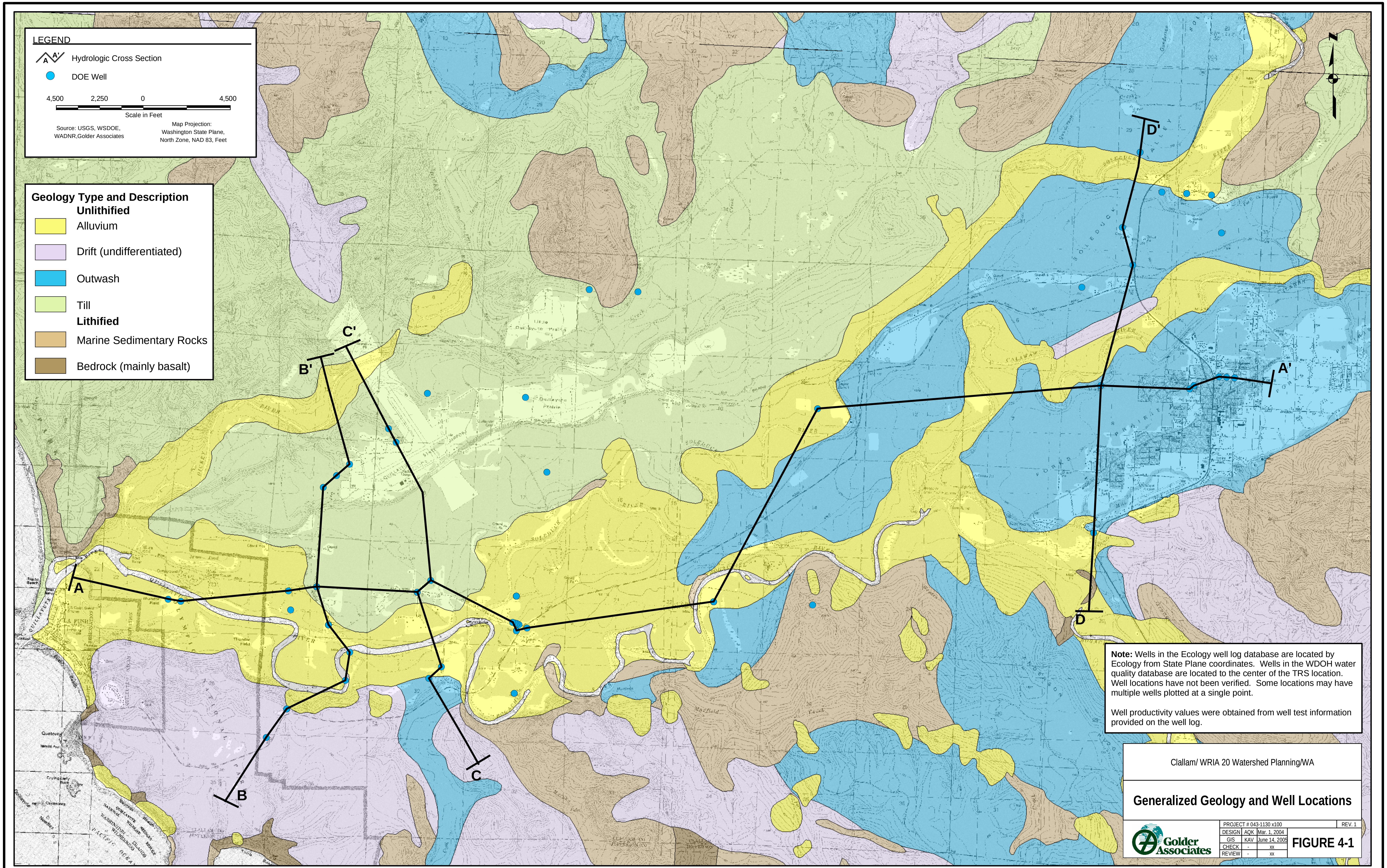

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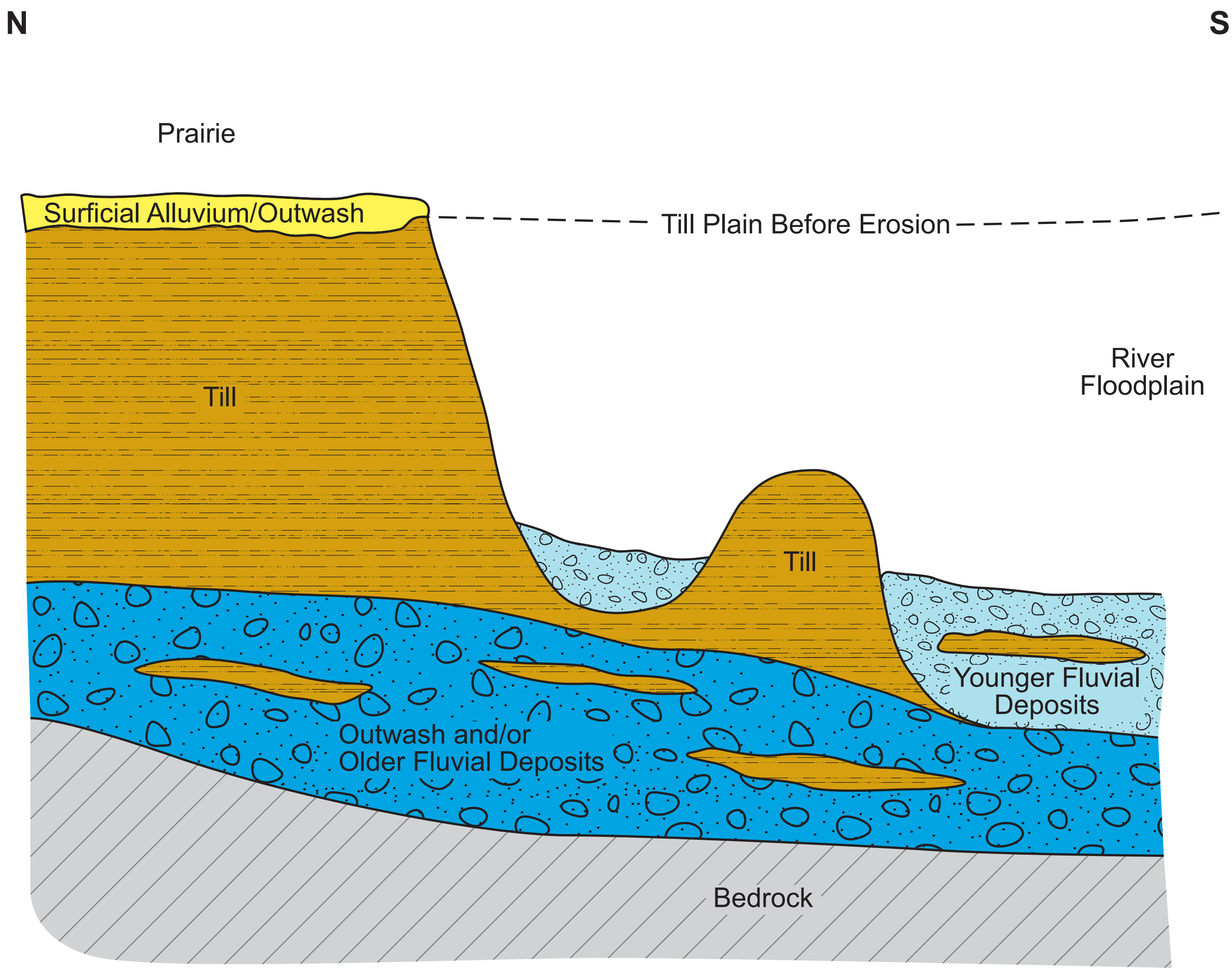
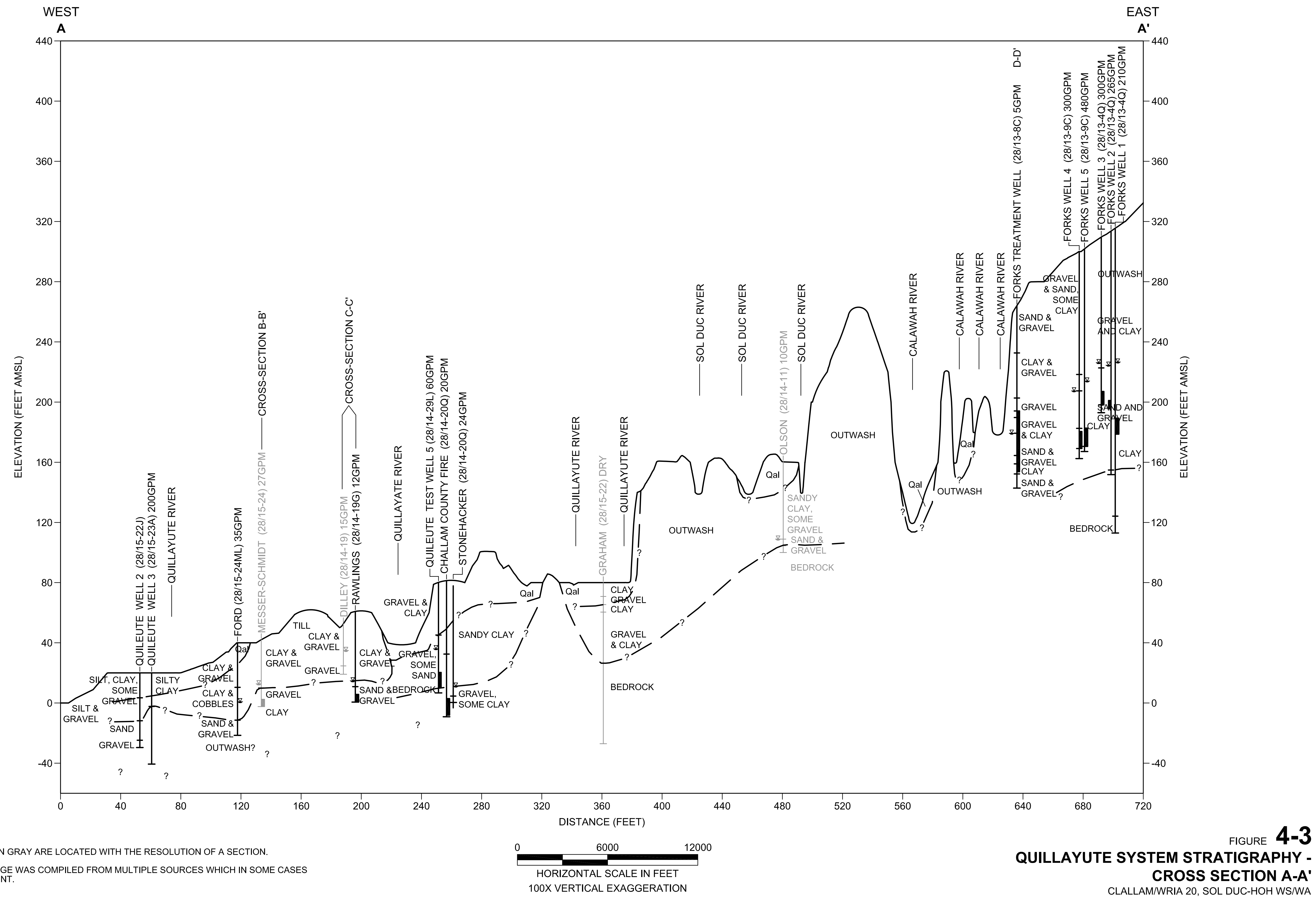


FIGURE **4-2**

CONCEPTUAL STRATIGRAPHIC CROSS SECTION OF QUILLAYUTE RIVER SYSTEM

CLALLAM/WRIA 20 WATERSHED PLAN/WA



NOTES:

WELLS INDICATED IN GRAY ARE LOCATED WITH THE RESOLUTION OF A SECTION.

GEOLOGIC COVERAGE WAS COMPILED FROM MULTIPLE SOURCES WHICH IN SOME CASES ARE NOT CONSISTENT.

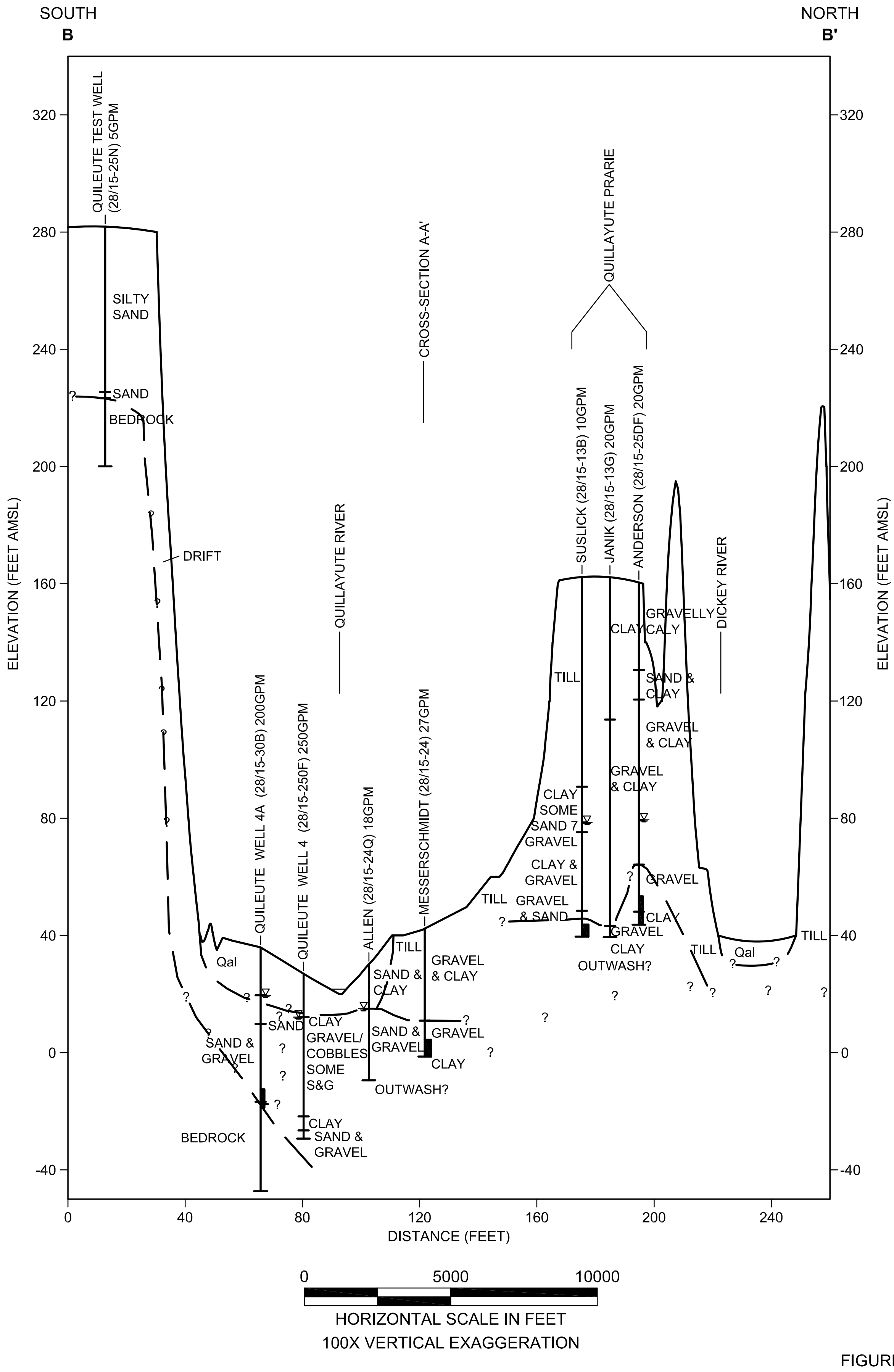
FIGURE **4-3**

QUILLAYUTE SYSTEM STRATIGRAPHY - CROSS SECTION A-A'

CLALLAM/WRIA 20, SOL DUC-HOH WS/WA

043113010022I0C01.dwg | Layout: Layout1 | Modified: 06/20/2005, 10:11 | Plotted: 06/20/2005, 10:43

Golder Associates



NOTES:

WELLS INDICATED IN GRAY ARE LOCATED WITH THE RESOLUTION OF A SECTION.

GEOLOGIC COVERAGE WAS COMPILED FROM MULTIPLE SOURCES WHICH IN SOME CASES ARE NOT CONSISTENT.

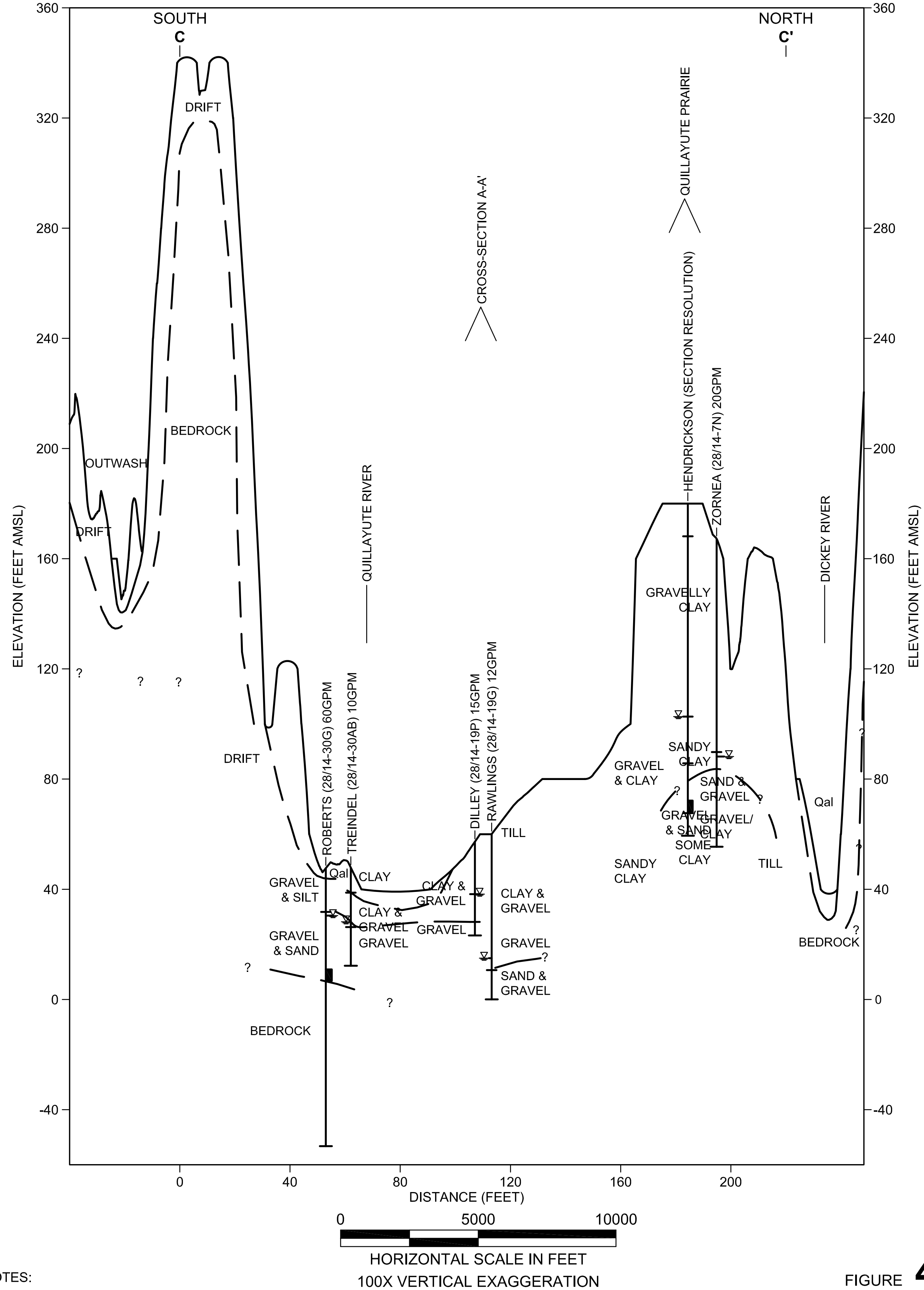
FIGURE **4-4**

QUILLAYUTE SYSTEM STRATIGRAPHY - CROSS SECTION B-B'

CLALLAM/WRIA 20, SOL DUC-HOH WS/WA

043113010022210C01.dwg | Layout: Layout5 | Modified: 06/20/2005, 10:11 | Plotted: 06/20/2005, 10:43

Golder Associates



NOTES:

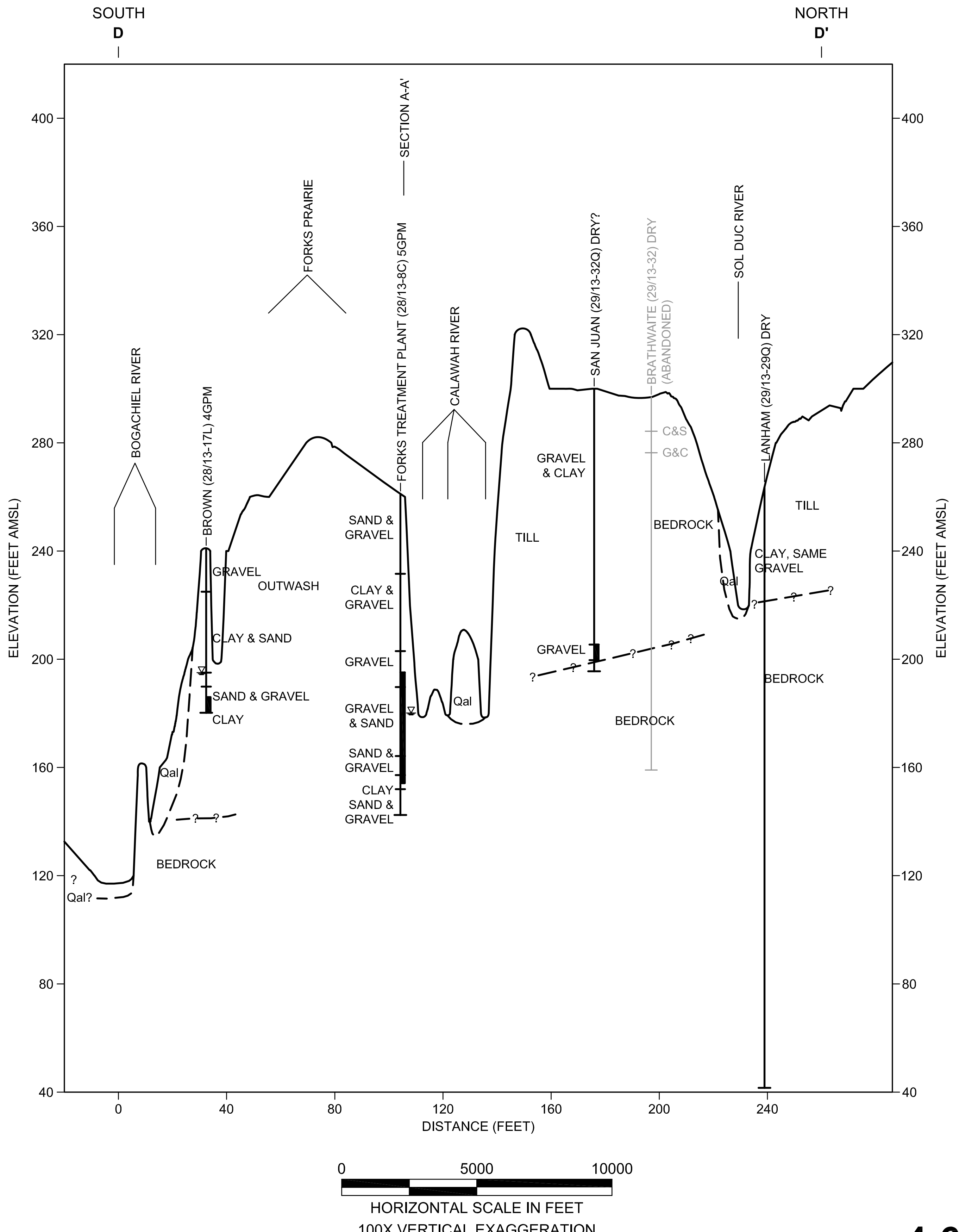
WELLS INDICATED IN GRAY ARE LOCATED WITH THE RESOLUTION OF A SECTION.

GEOLOGIC COVERAGE WAS COMPILED FROM MULTIPLE SOURCES WHICH IN SOME CASES ARE NOT CONSISTENT.

FIGURE **4-5**

QUILLAYUTE SYSTEM STRATIGRAPHY - CROSS SECTION C-C'

CLALLAM/WRIA 20, SOL DUC-HOH WS/WA



NOTES:

WELLS INDICATED IN GRAY ARE LOCATED WITH THE RESOLUTION OF A SECTION.

GEOLOGIC COVERAGE WAS COMPILED FROM MULTIPLE SOURCES WHICH IN SOME CASES ARE NOT CONSISTENT.

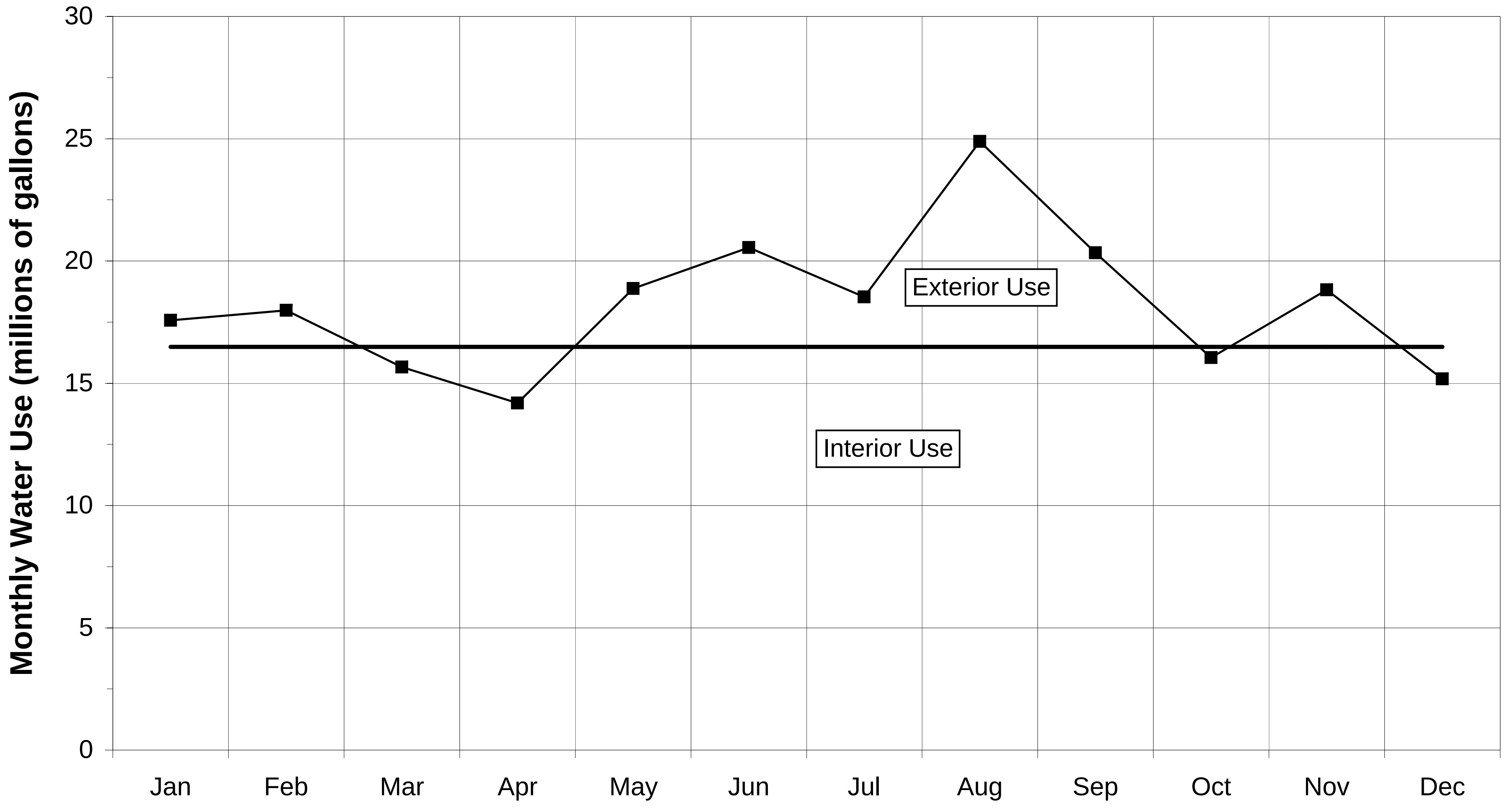
FIGURE **4-6**

QUILLAYUTE SYSTEM STRATIGRAPHY - CROSS SECTION D-D'

CLALLAM/WRIA 20, SOL DUC-HOH WS/WA

043113010022I0C01.dwg | Layout: Layout7 | Modified: 06/20/2005, 10:44 | Plotted: 06/20/2005, 10:45

Golder Associates



Average Monthly Water Use (2003-2005)

Estimated Interior Use (Nov-Apr Average)

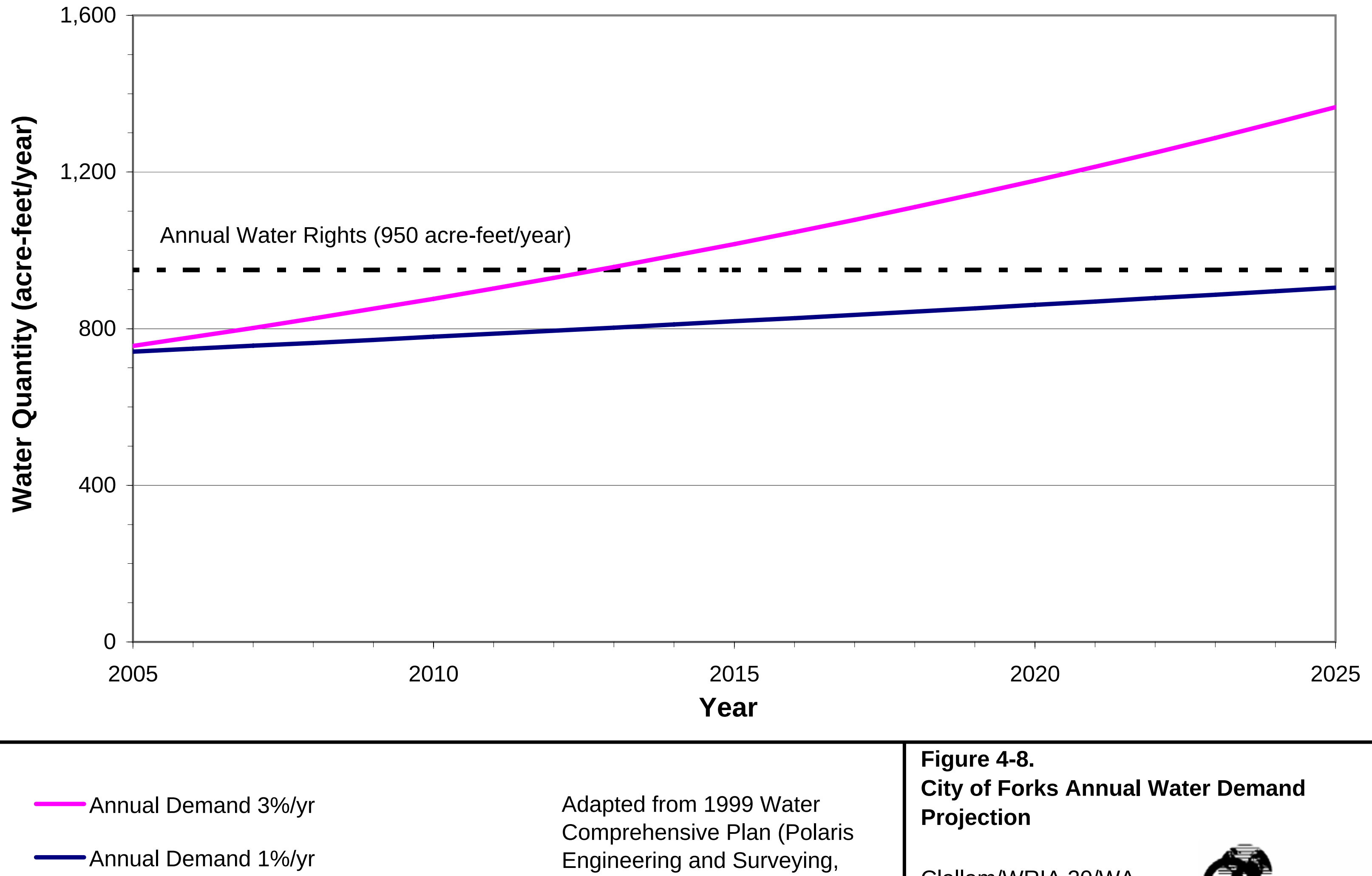
Note: average water use estimated from 2004 production data. Equivalent average daily use is approximately 0.6 MGD.

Figure 4-7.
Estimated City of Forks Monthly Water Use

WRIA 20 Storage Assessment - Forks Area
043-1130-100.2210

Golder Associates

Fig 4-7 Monthly Use.xls; Fig -47 Monthly Use

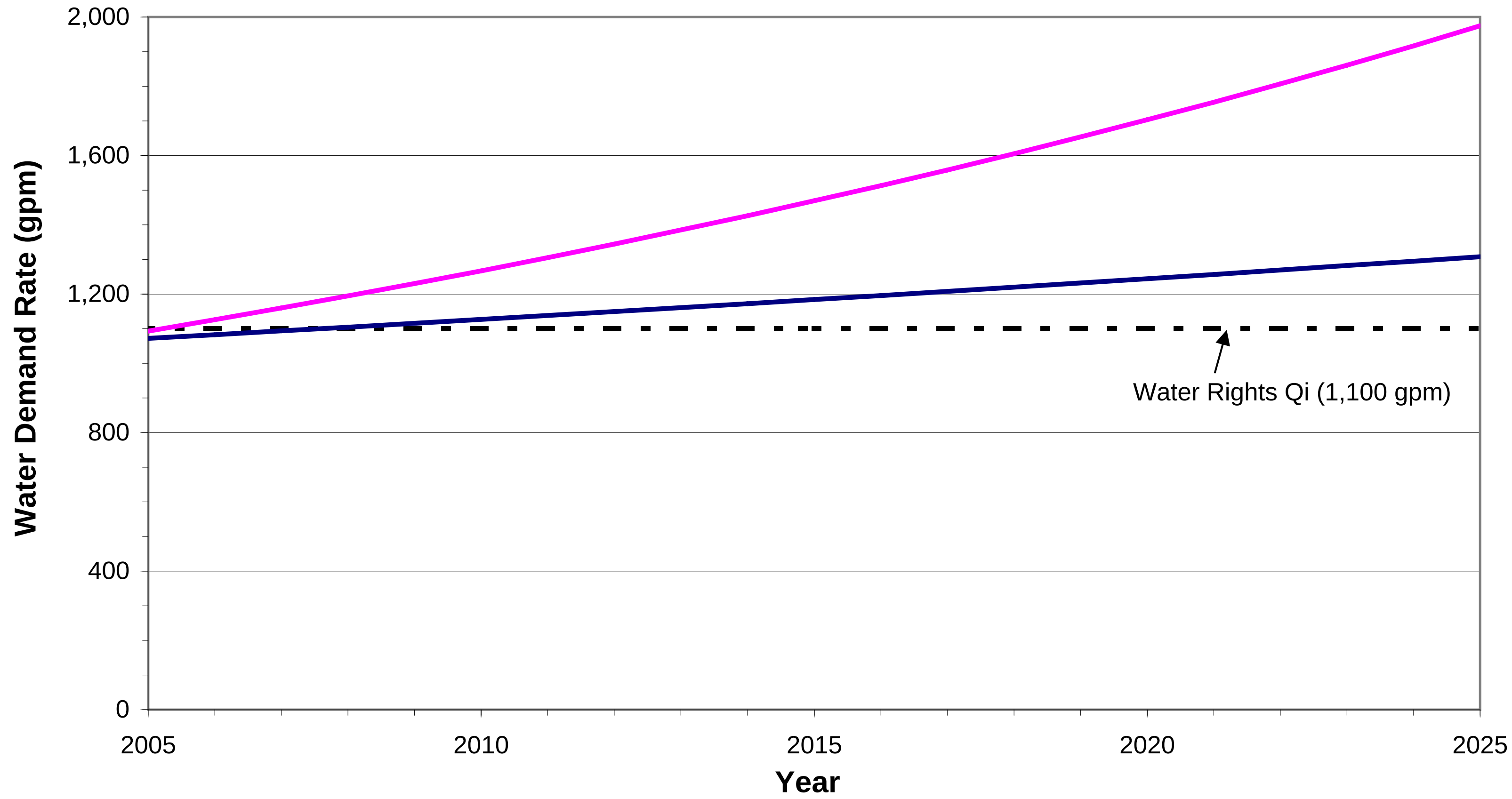


Adapted from 1999 Water Comprehensive Plan (Polaris Engineering and Surveying, 1999)

Figure 4-8.
City of Forks Annual Water Demand Projection

Clallam/WRIA 20/WA
043-1130-100.2210

Golder Associates



Daily Peaking Demand 3%/yr

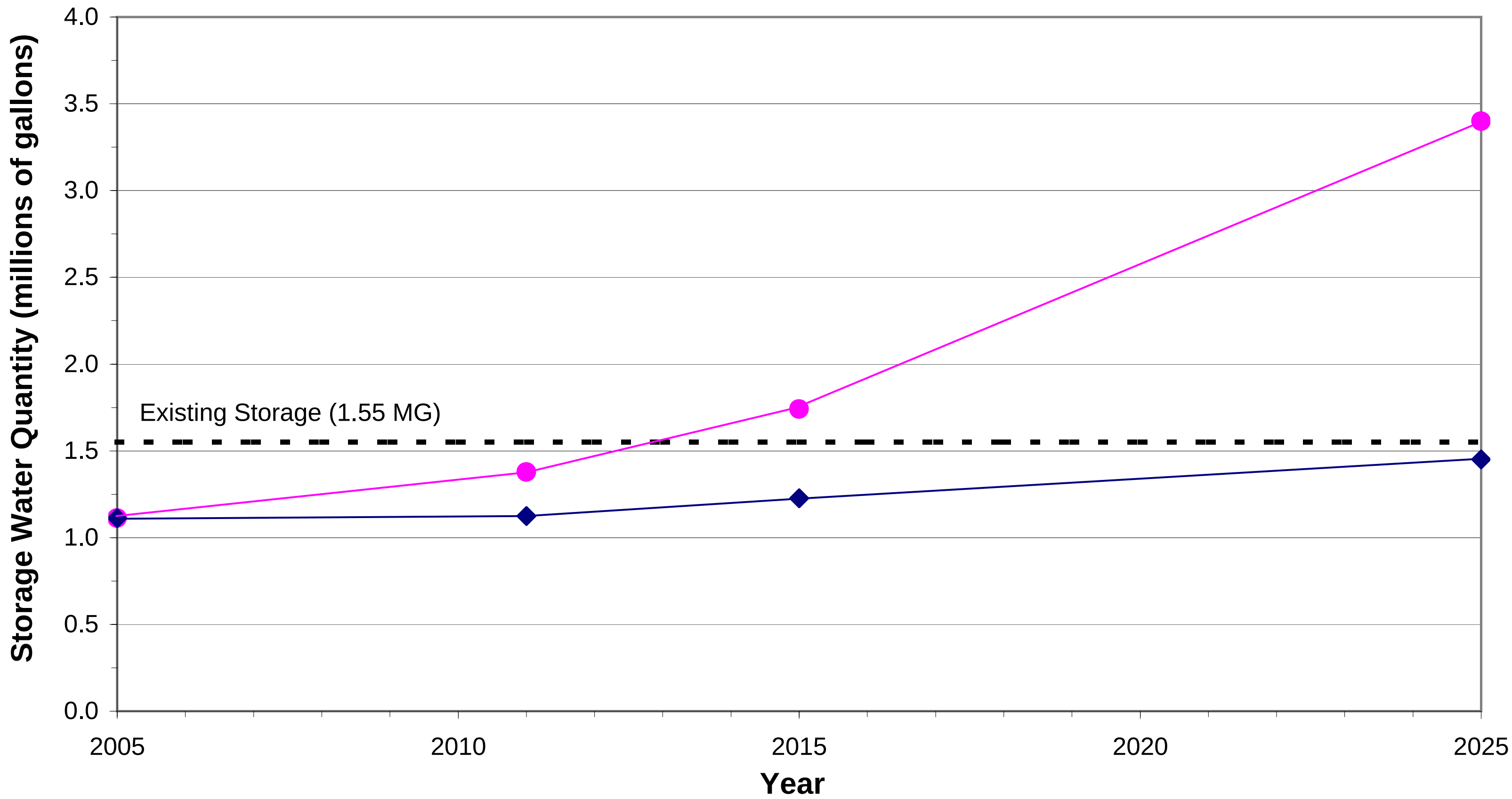
Daily Peaking Demand 1%/yr

Adapted from 1999 Water Comprehensive Plan (Polaris Engineering and Surveying, 1999)

Figure 4-9.
City of Forks Daily Water Demand Projection

Clallam/WRIA 20/WA
043-1130-100.2210

Golder Associates



● Future Storage Need 3%/yr

◆ Future Storage Need 1%yr

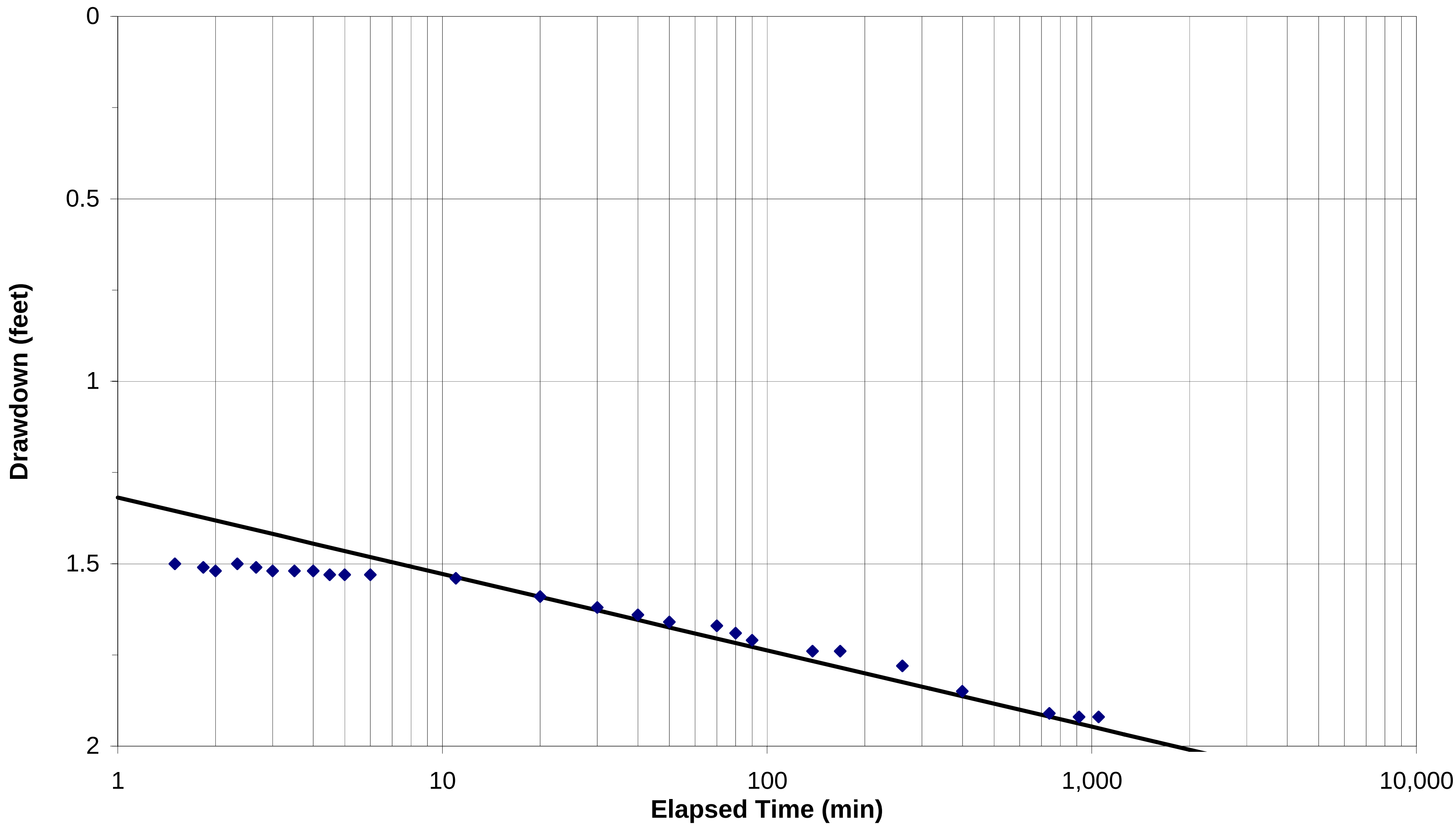
Adapted from 1999 Water Comprehensive Plan (Polaris Engineering and Surveying, 1999)

Note: Storage total does not include Tank 3 (0.15 MG) which is aging and may be replaced

Figure 4-10.
City of Forks Water Storage Need

Clallam/WRIA 20/WA
043-1130-100.2210

Golder Associates



◆ Well 3

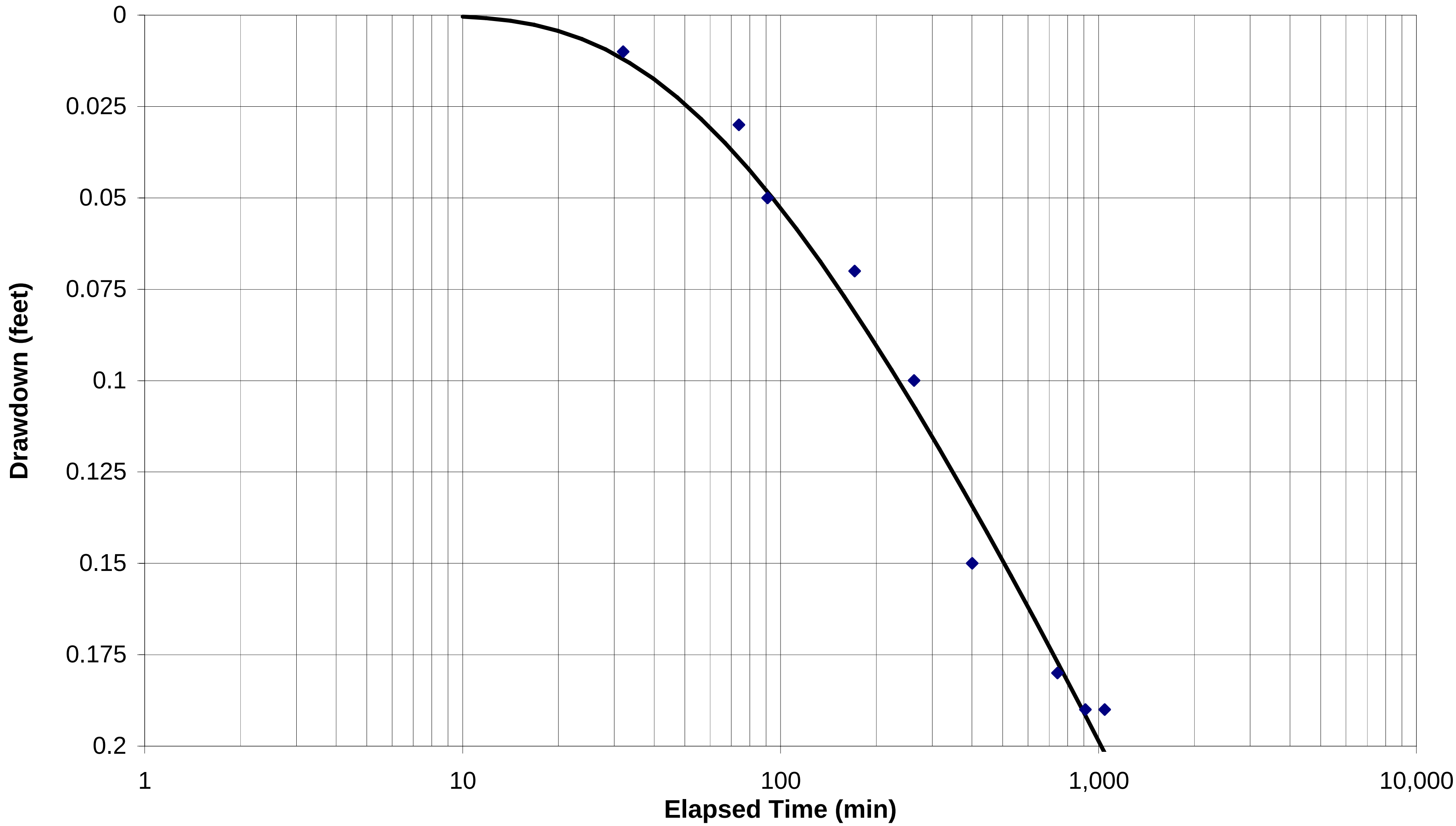
━ Hantush Type Curve

Pumping Rate = 140 gpm
Pumping Period = 17.5 hours
T = 11,800 ft^2/day

Figure 4-11.
Well 3 Semi-log Hydrograph - Well 3 Pumping Test

WRIA 20 Storage Assessment - Forks Area
043-1130-100.2210

Golder Associates



Well 2

Hantush Type Curve

r = 330 ft (east of Well 3)
Well 3 Pumping Rate = 140 gpm
Pumping Period = 17.5 hours
T = 11,700 ft^2/day
S = 0.01

Figure 4-12.
Well 2 Semi-log Hydrograph - Well 3 Pumping Test

WRIA 20 Storage Assessment
- Forks Area
043-1130-100.2210

Golder Associates

Well 3 CR Test.xls; Fig 4-12

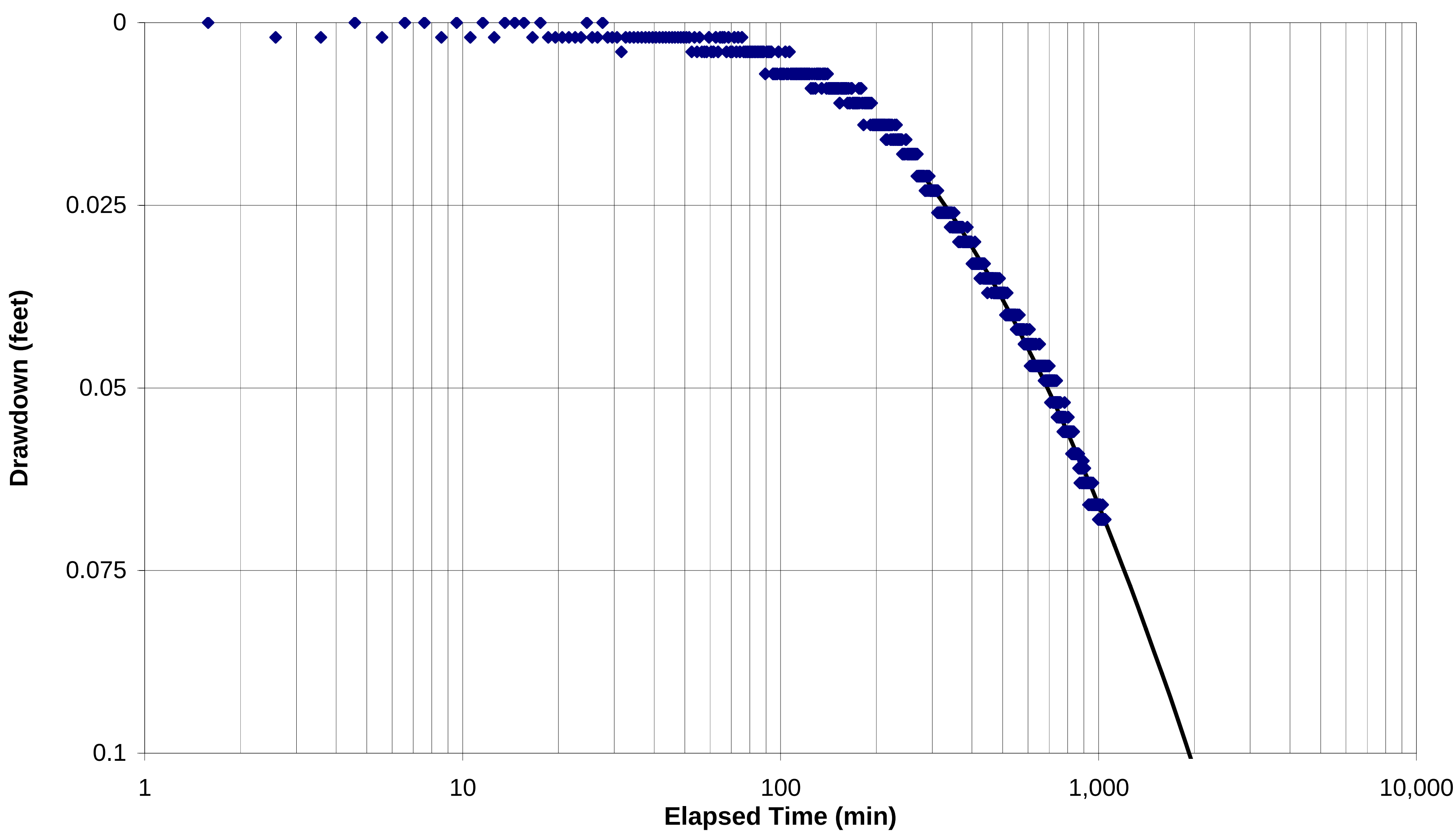
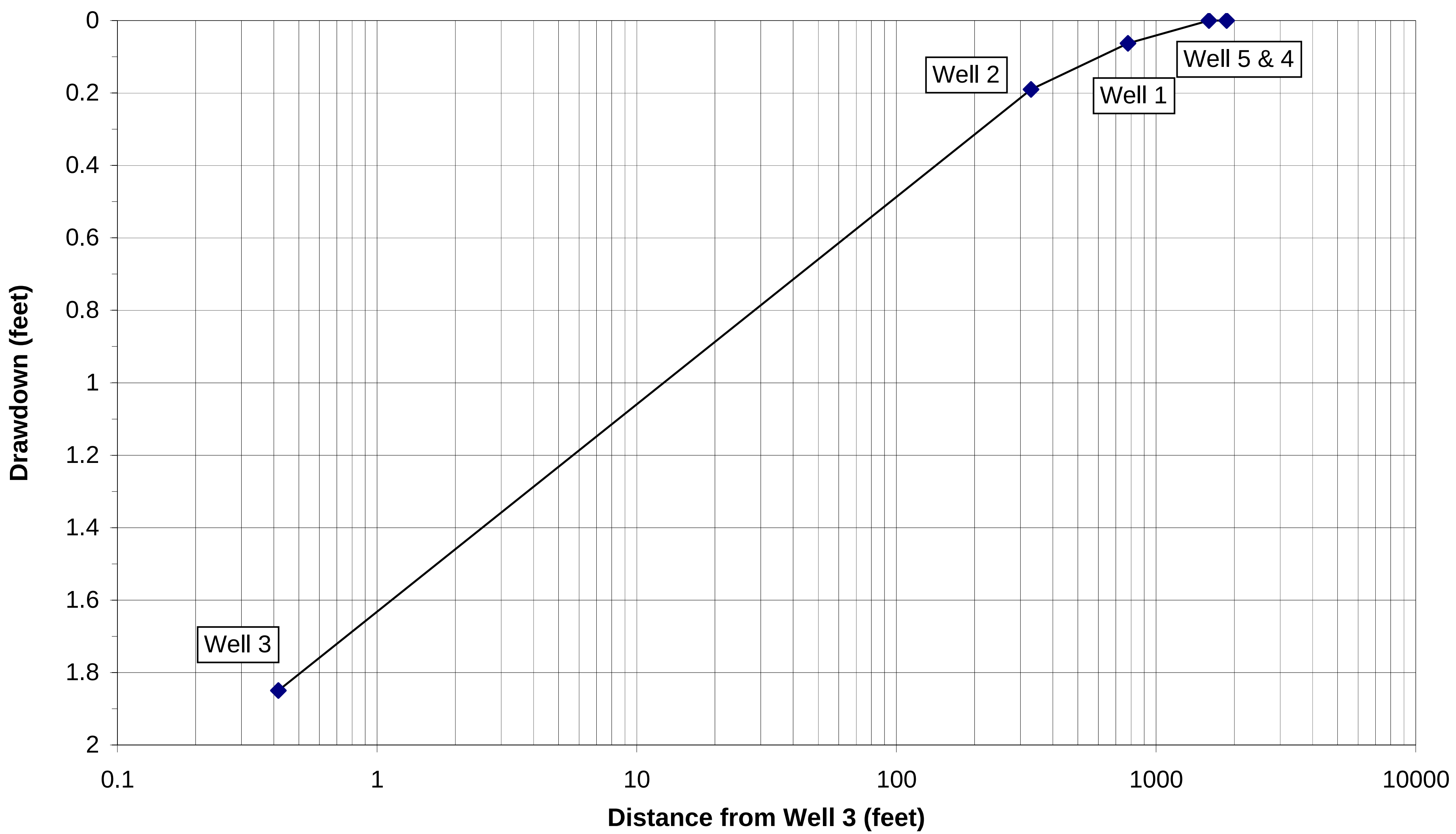


Figure 4-13.
Well 1 Semi-log Hydrograph - Well 3 Pumping Test

WRIA 20 Storage
Assessment - Forks Area
043-1130-100.2210

Golder Associates

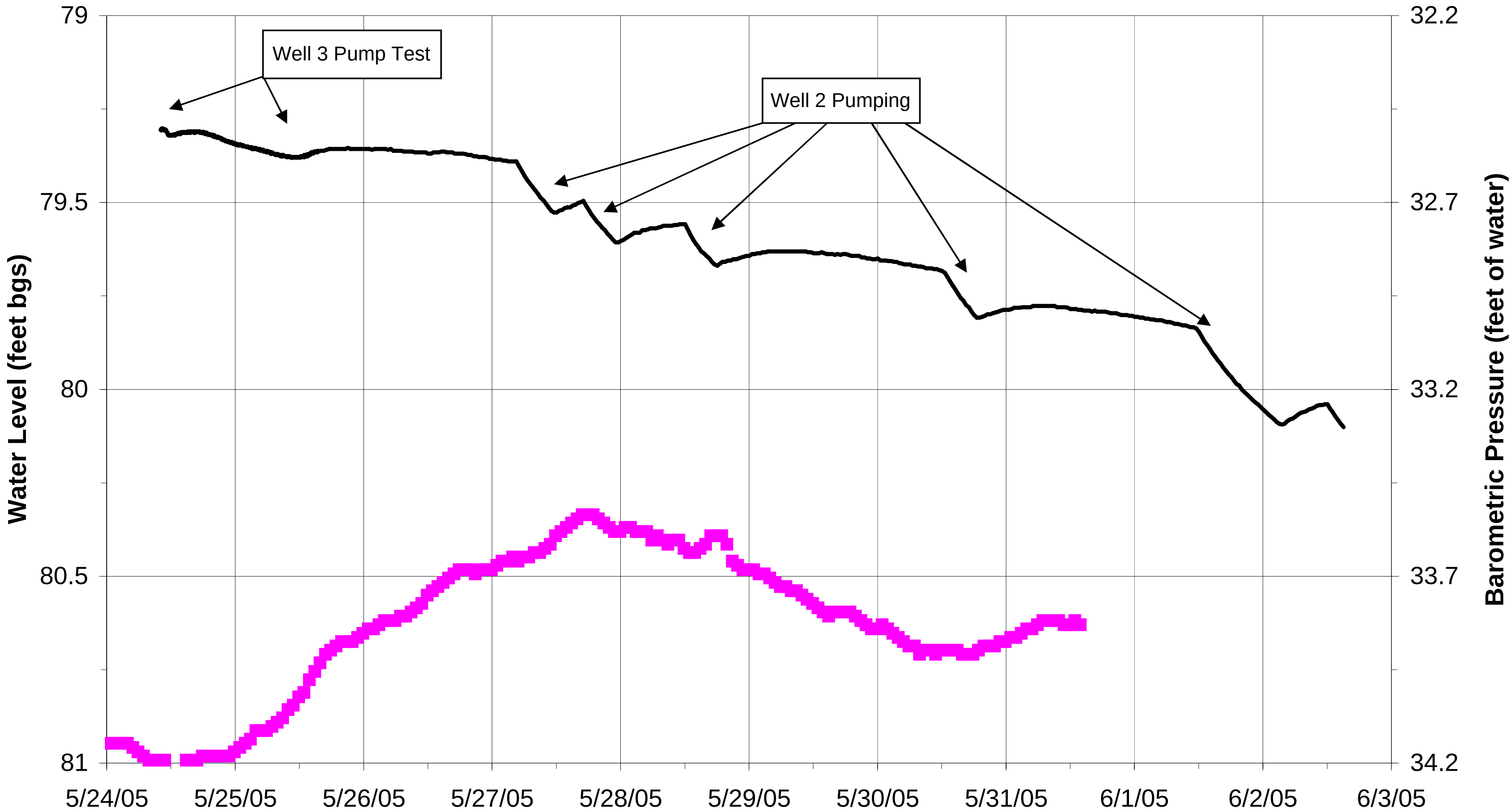


Pumping Rate = 140 gpm
Pumping Period = 17.5 hours

Figure 4-14.
Distance Drawdown Plot - Well 3 Pumping Test

WRIA 20 Storage Assessment - Forks Area
043-1130-100.2210

Golder Associates



Well 1 Water Level

Barometric Pressure Quillayute Airport

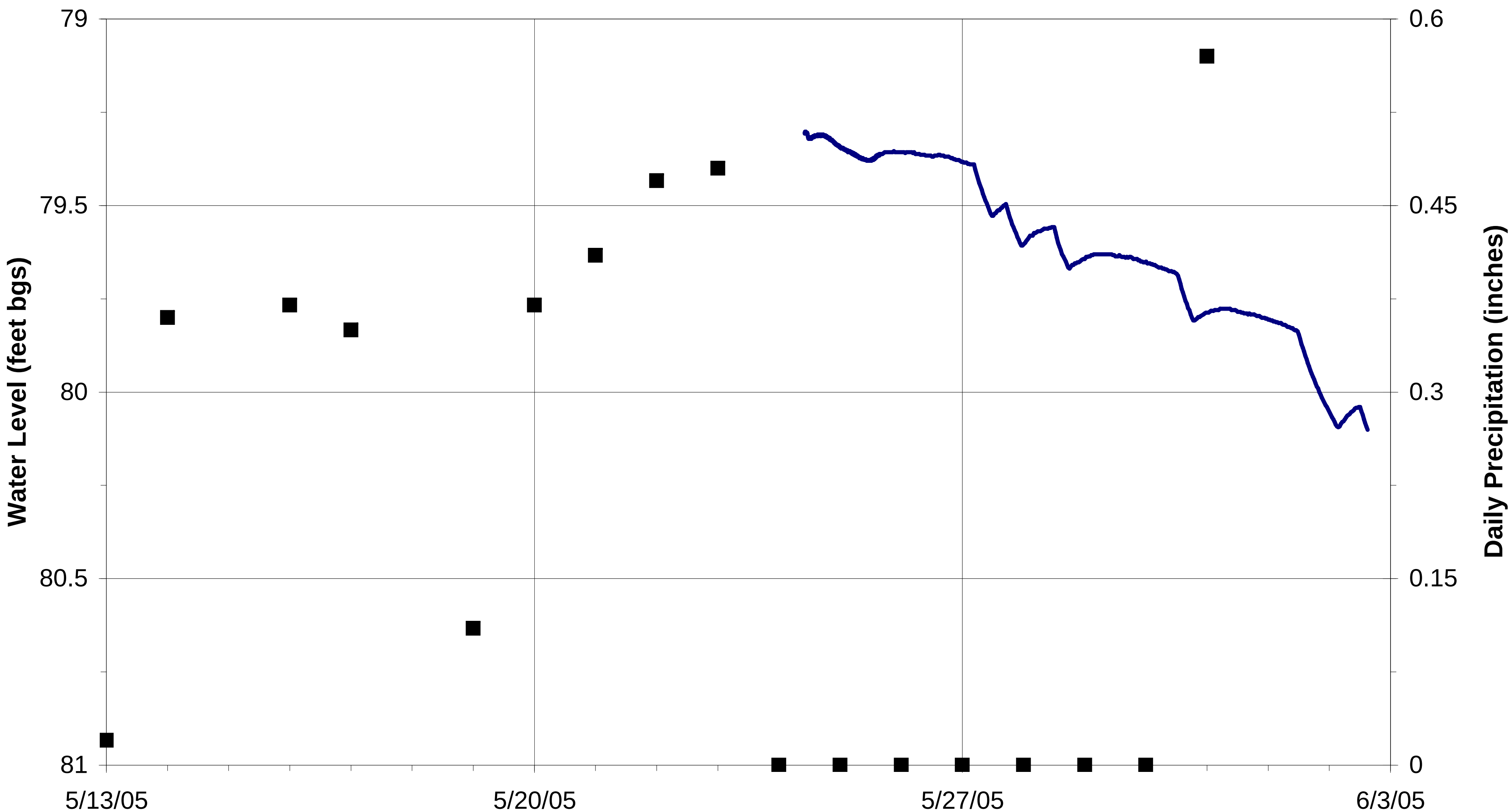
Note: Barometric pressure data from NOAA National Climate Data Center (http://hurricane.ncdc.noaa.gov/ulcd/ULCD) Data shown for May 2005 only

Figure 4-15.
Well 1 Hydrograph vs. Barometric Pressure

WRIA 20 Storage
Assessment - Forks Area
043-1130-100.2210

Golder Associates

Quil Airport Weather.xls; Fig 4-15



Well 1 Water Level

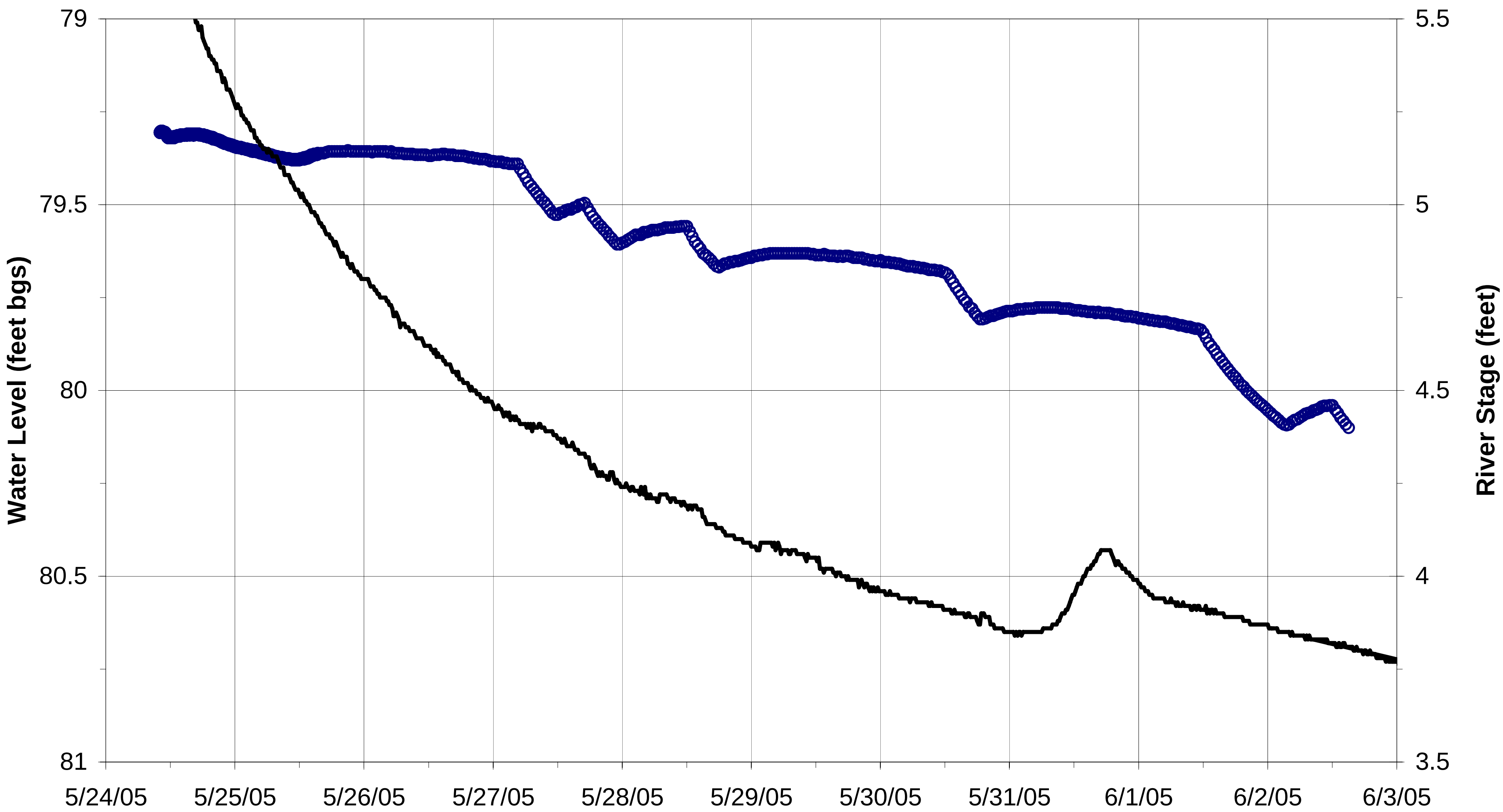
■ Daily Precipitation Quillayute Airport

Note: Precipiation data from NOAA National Climate Data Center (http://hurricane.ncdc.noaa.gov/ulcd/ULCD) Data shown for May 2005 only

Figure 4-16.
Well 1 Hydrograph vs. Precipitation

WRIA 20 Storage Assessment - Forks Area
043-1130-100.2210

Golder Associates

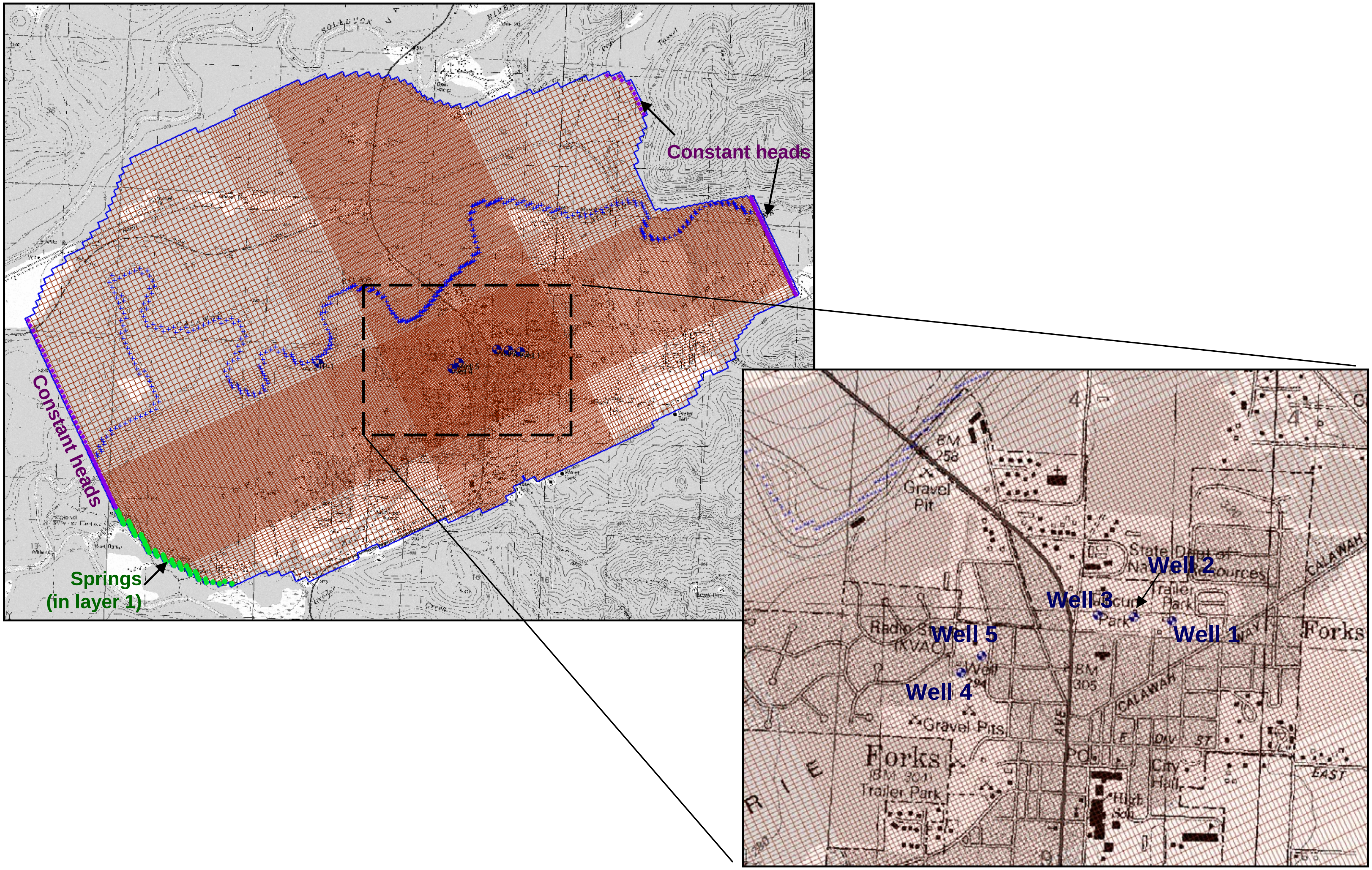


Note: River stage data is from USGS station 12043000

Figure 4-17.
Well 1 Hydrograph vs. Calawah River Stage

WRIA 20 Storage Assessment - Forks Area
043-1130-100.2210

Golder Associates



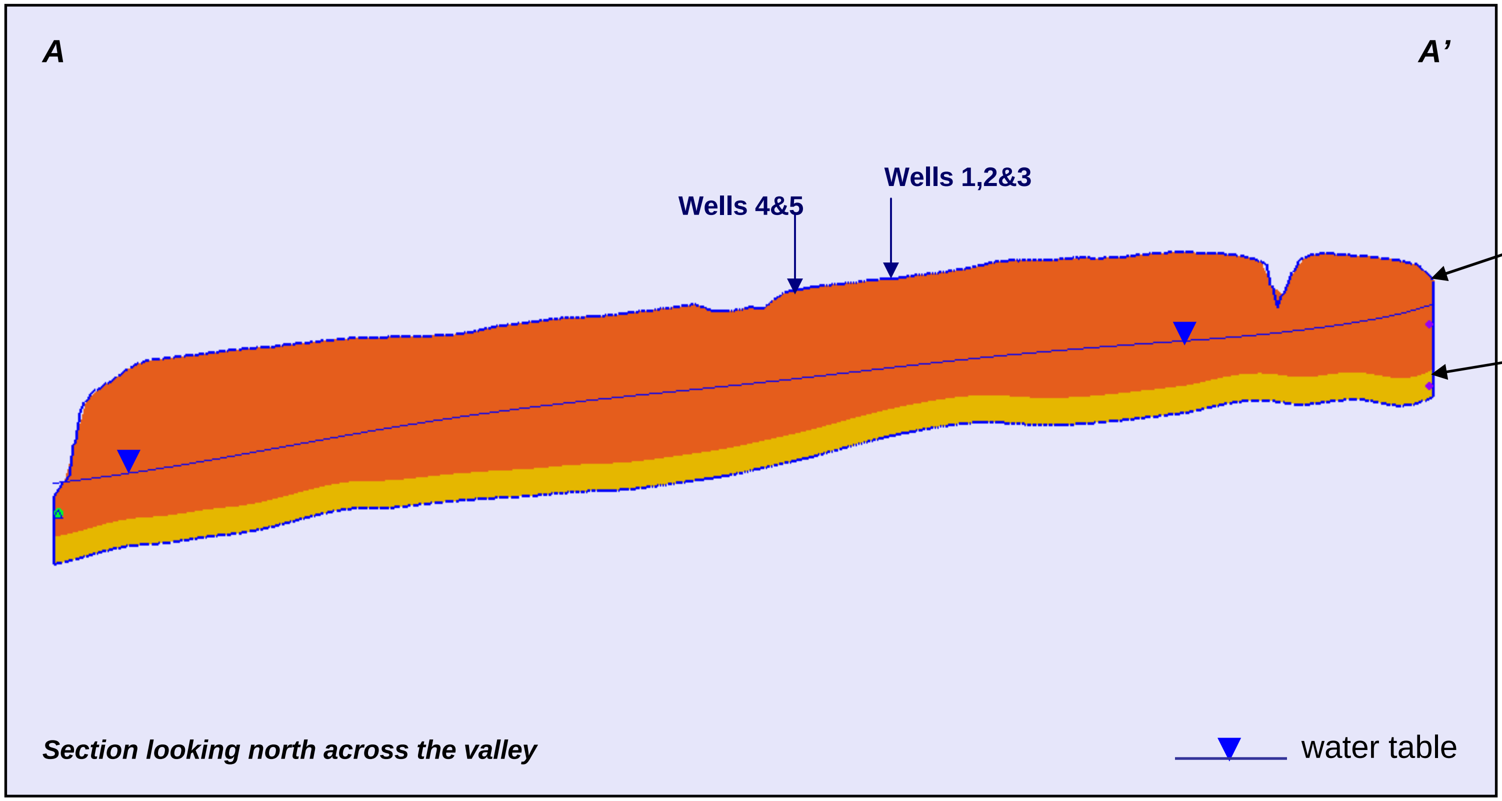
Golder Associates

WRIA 20 – City of Forks

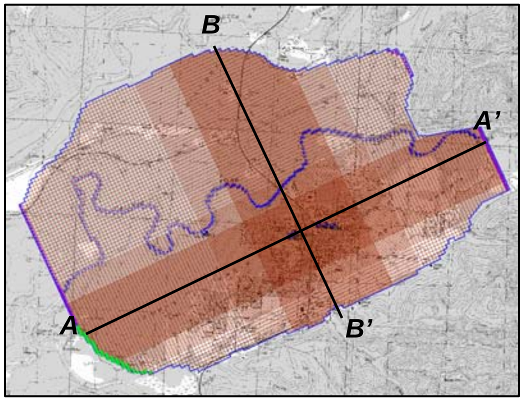
TITLE

Numerical Model Domain and Grid

DRAWN	SDT	DATE	6-8-05	PROJECT No.	043-1130
CHECKED		SCALE	na	DWG No.	na
REVIEWED		FILE No.	Figs.ppt	FIGURE No.	4-18



Vertical exaggeration = x20



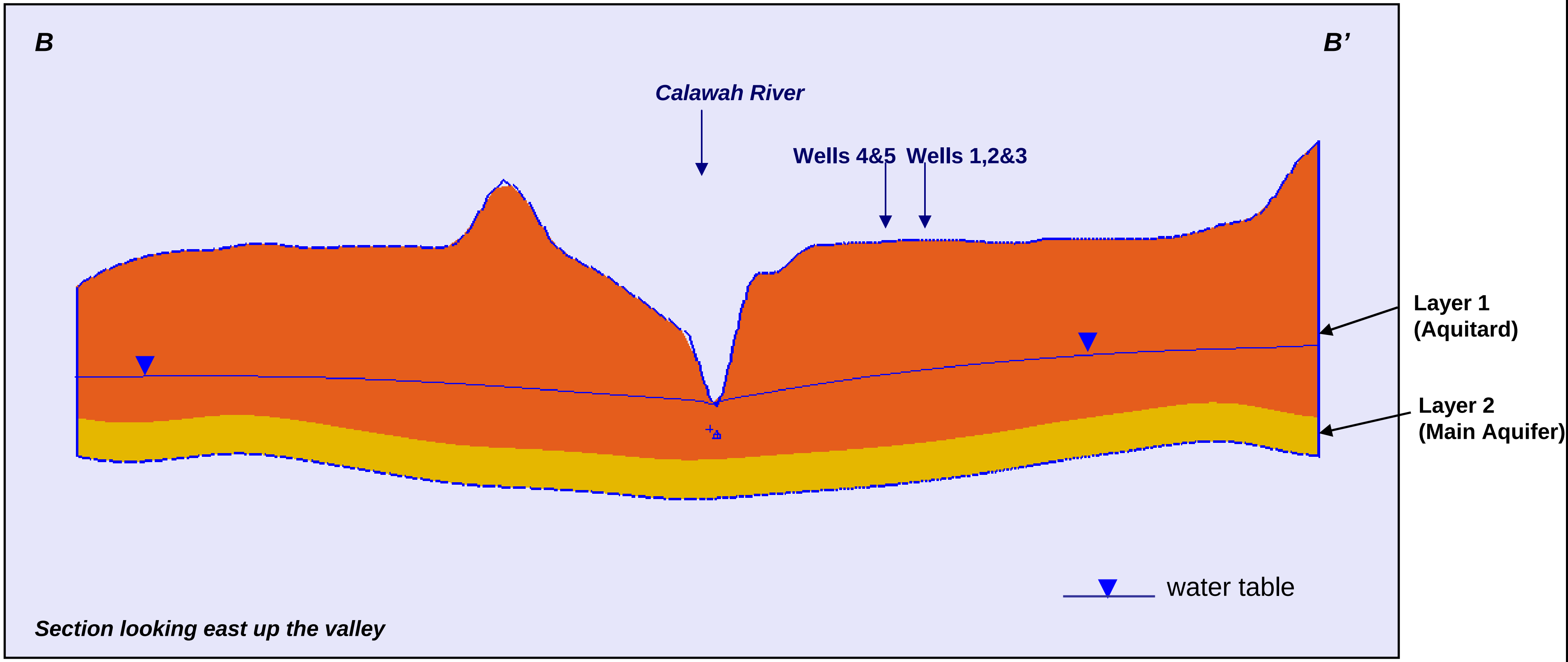
Golder Associates

TITLE

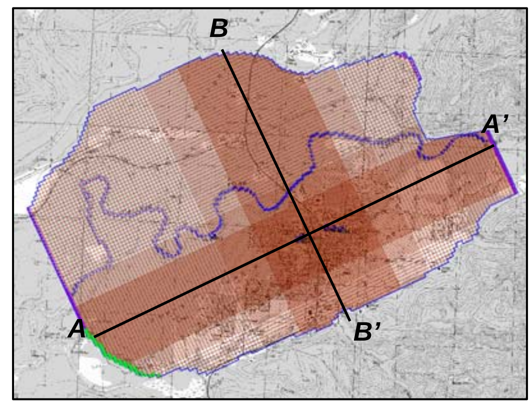
Model Cross-section A-A' through City's Wellfield

WRIA 20 – City of Forks

DRAWN	SDT	DATE	6-8-05	PROJECT No.	043-1130
CHECKED		SCALE	na	DWG No.	na
REVIEWED		FILE No.	Figs.ppt	FIGURE No.	4-19



Vertical exaggeration = x20



Golder Associates

WRIA 20 – City of Forks

TITLE

Model Cross-section B-B' through City's Wellfield

DRAWN	SDT	DATE	6-8-05	PROJECT No.	043-1130
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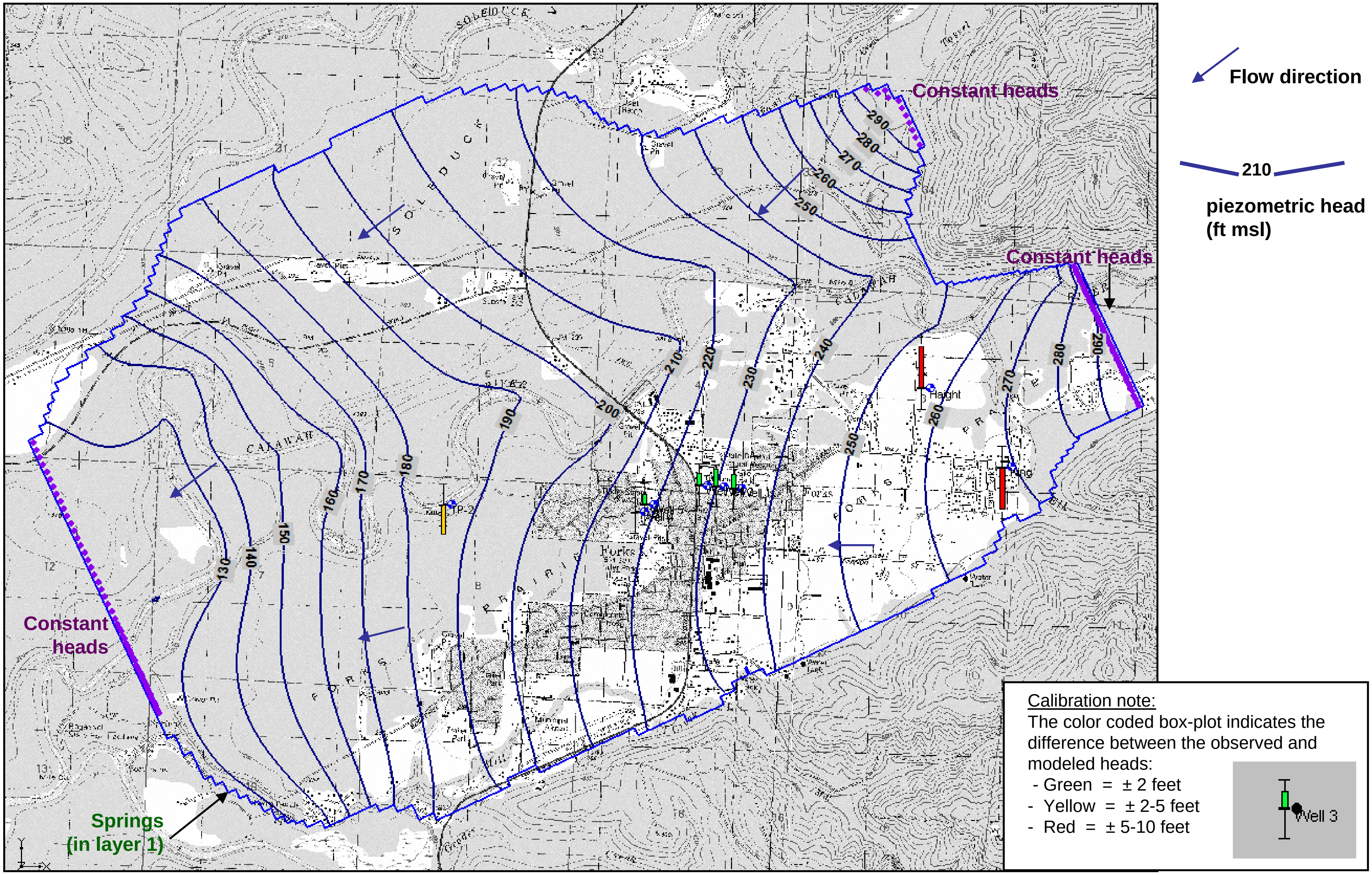
REVIEWED		FILE No.	Figs.ppt	FIGURE No.	4-20



Golder Associates

WRIA 20 – City of Forks

TITLE

Baseline Flow Field and Calibration Heads

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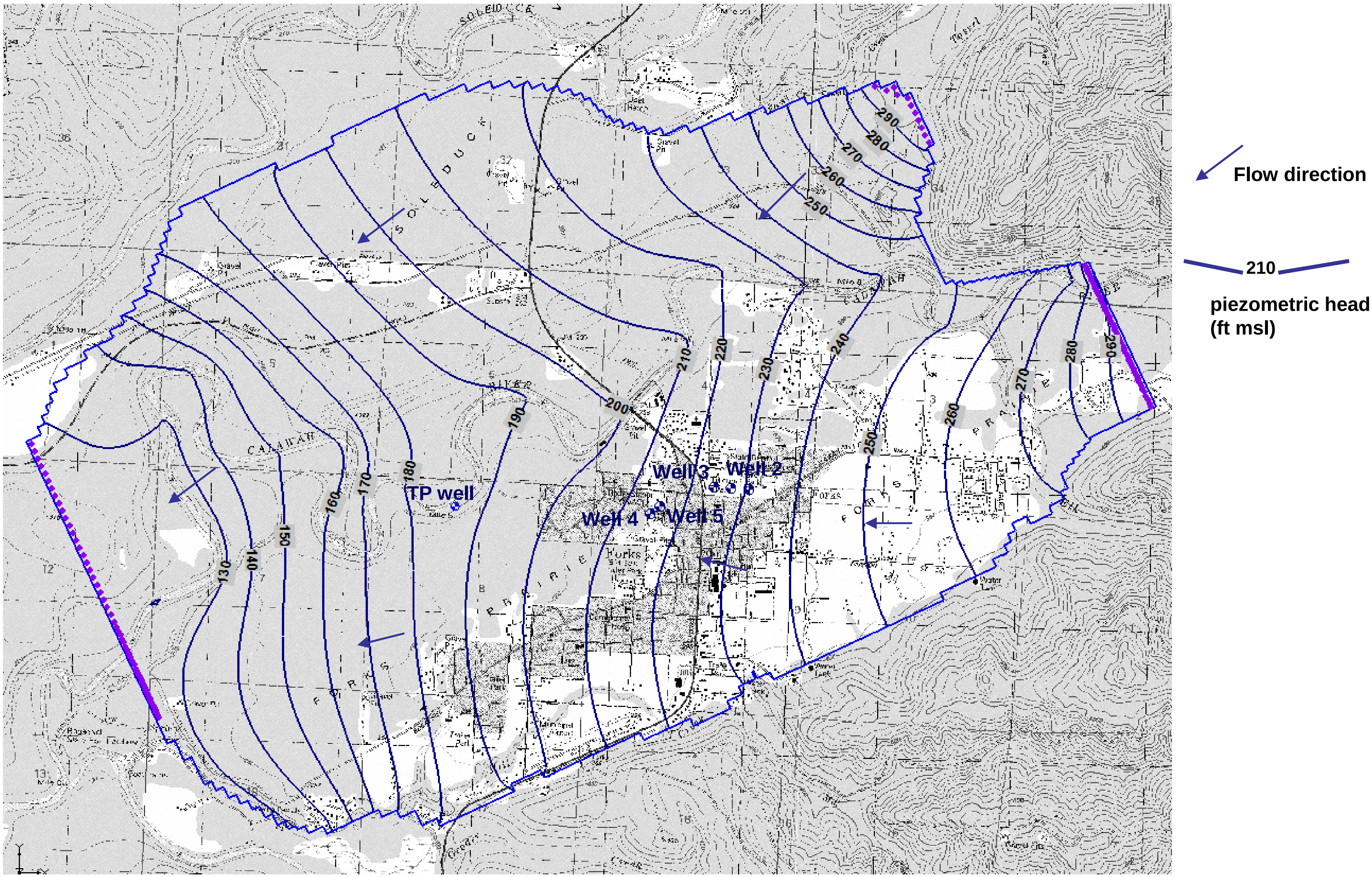
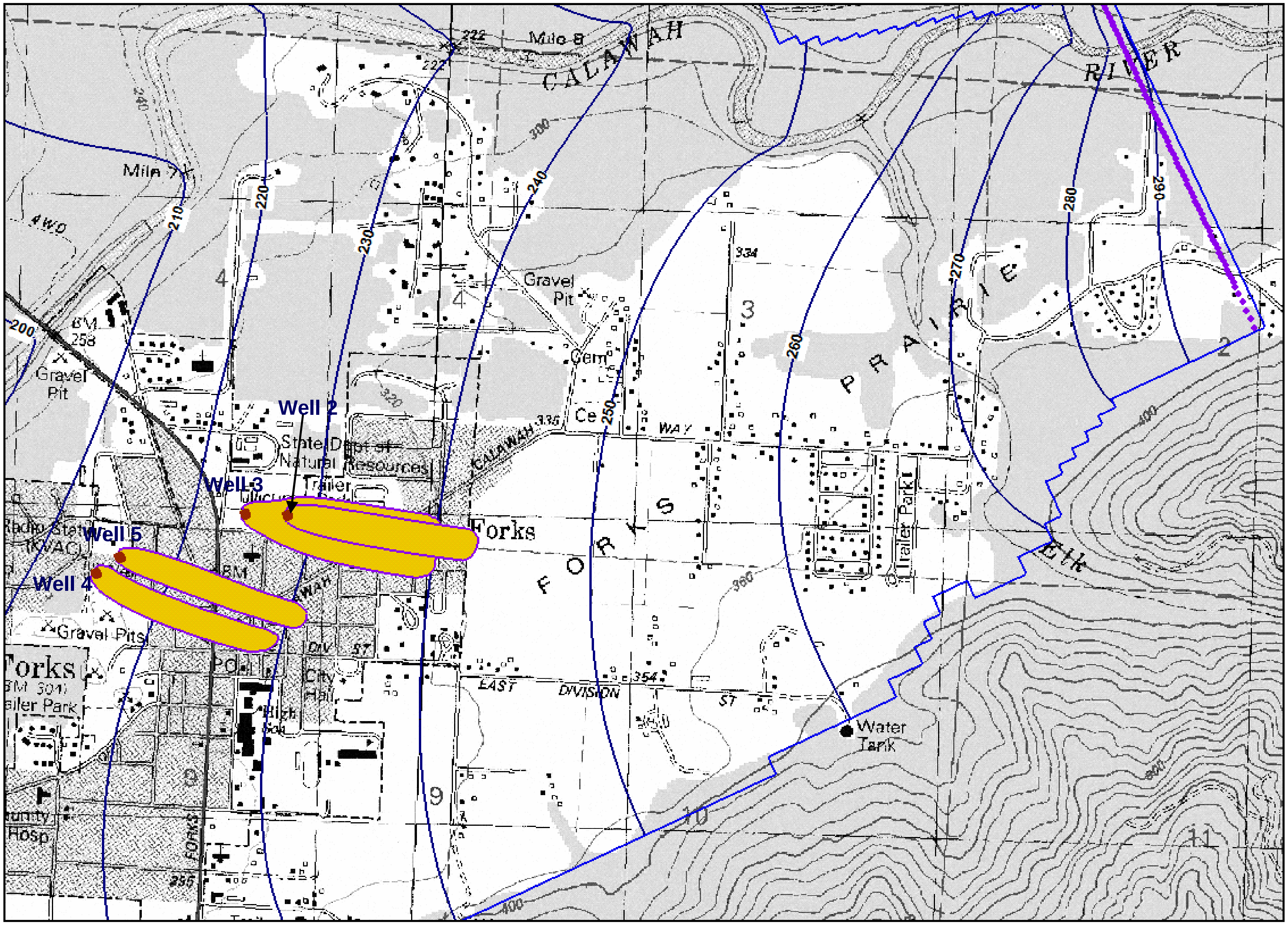
CHECKED		SCALE	na	DWG No.	na
REVIEWED		FILE No.	Figs.ppt	FIGURE No.	4-21



Golder Associates	TITLE Predicted Wellfield Operation Flow Field – wells pumping at average Qa		
WRIA 20 – City of Forks	DRAWN SDT	DATE 6-8-05	PROJECT No. 043-1130
	CHECKED	SCALE na	DWG No. na
	REVIEWED	FILE No. Figs.ppt	FIGURE No. 4-22



Golder Associates

TITLE

Predicted Capture Zones – 6 months

WRIA 20 – City of Forks

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CHECKED		SCALE	na	DWG No.	na
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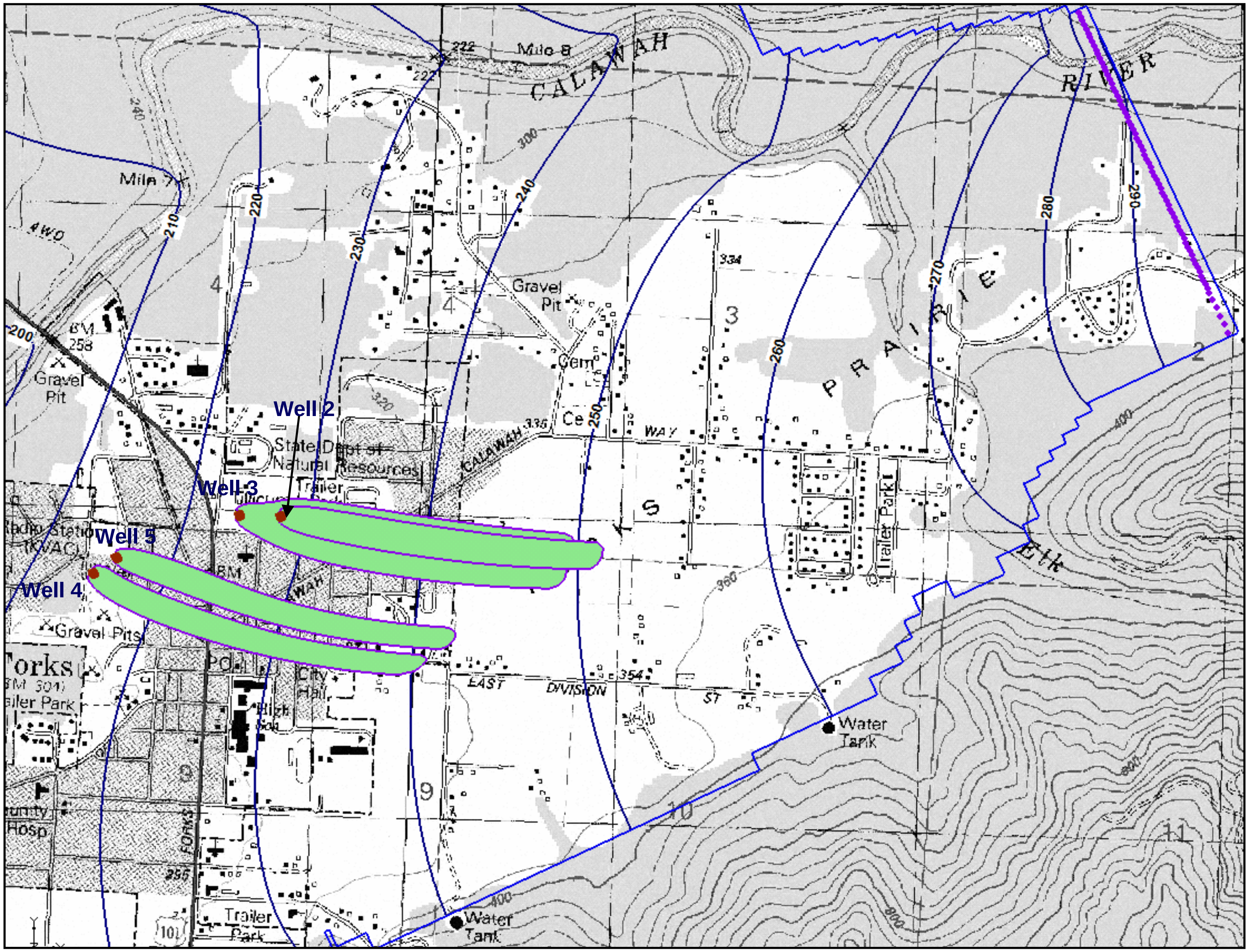

Golder Associates

TITLE

Predicted Capture Zones – 1 year

WRIA 20 – City of Forks

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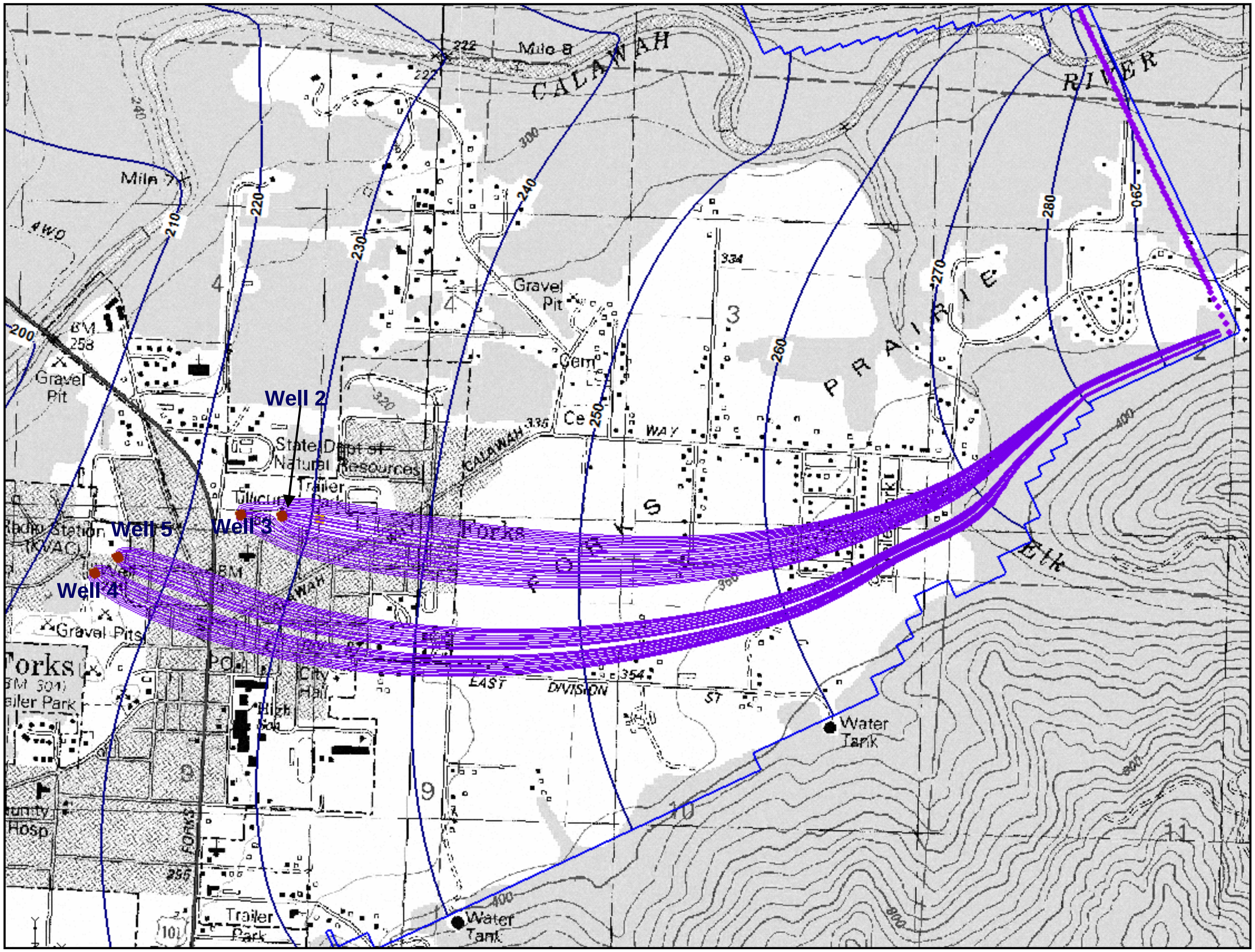
REVIEWED		FILE No.	Figs.ppt	FIGURE No.	4-24



TITLE

Predicted Capture Zones – 5 years

WRIA 20 – City of Forks

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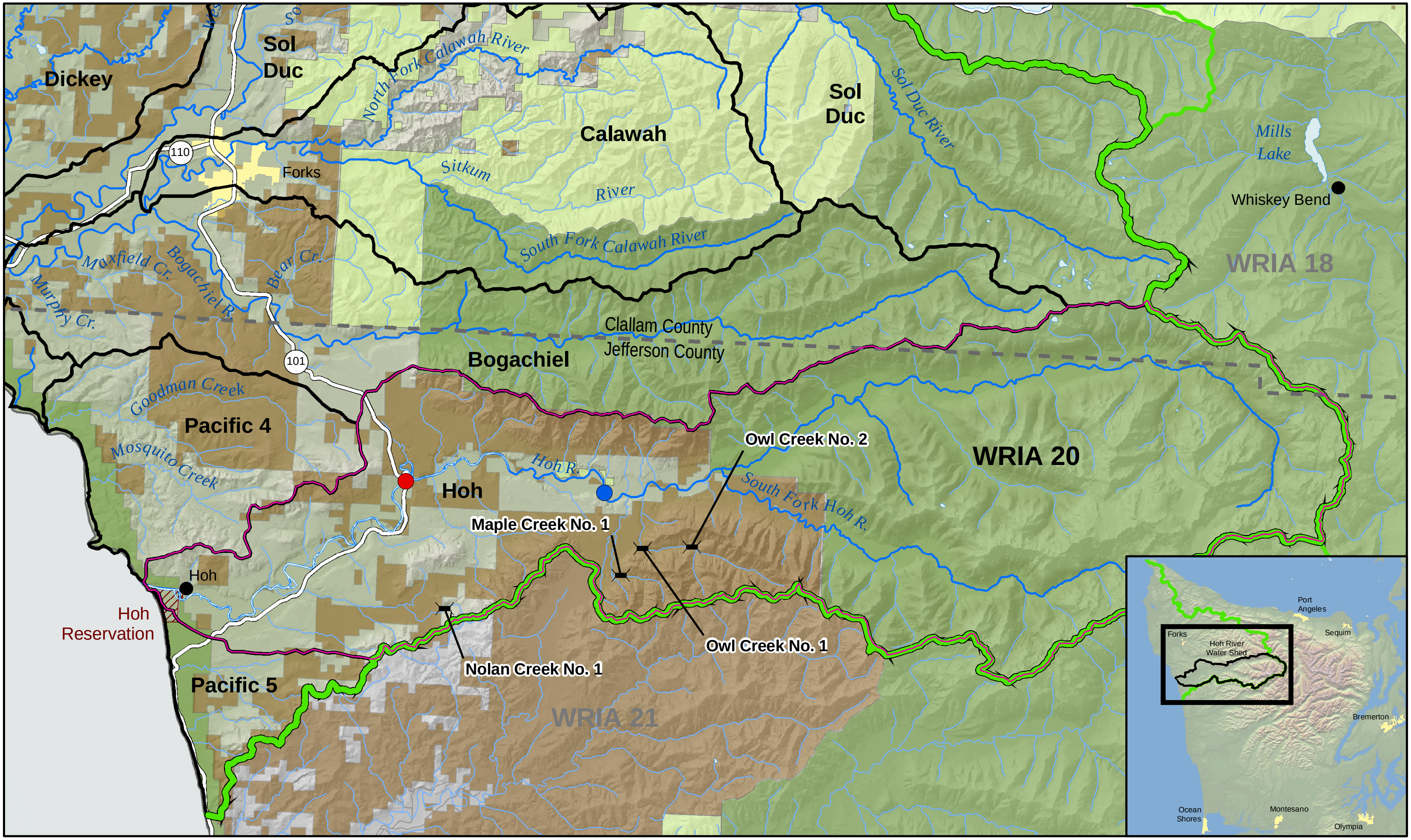
CHECKED		SCALE	na	DWG No.	na
REVIEWED		FILE No.	Figs.ppt	FIGURE No.	4-25



LEGEND

- National Park
- National Forest
- DNR Managed Lands
- WRIA 20 Boundary
- WRIA 20 Sub-Basins
- WRIA Boundary
- Urban Area
- Waterbody
- Reservation
- County Boundary
- Major Road
- Community
- Rivers and Streams
- Potential Dam Location
- USGS Gage - Active
- USGS Gage - Inactive

0 25,000

Scale in Feet

Map Projection:
Washington State Plane,
North Zone, NAD 83, Feet

Source: WSDNR, WSDOT, USGS, WSDOT, WSDOE,

N

This figure was originally produced in color. Reproduction in black and white may result in a loss of information.

Overview of the Hoh Watershed

Drawn: KAV	Revision: 1	Date: June 14, 2005	Figure: 5-1

04311301002300F02R0.mxd

Golder Associates

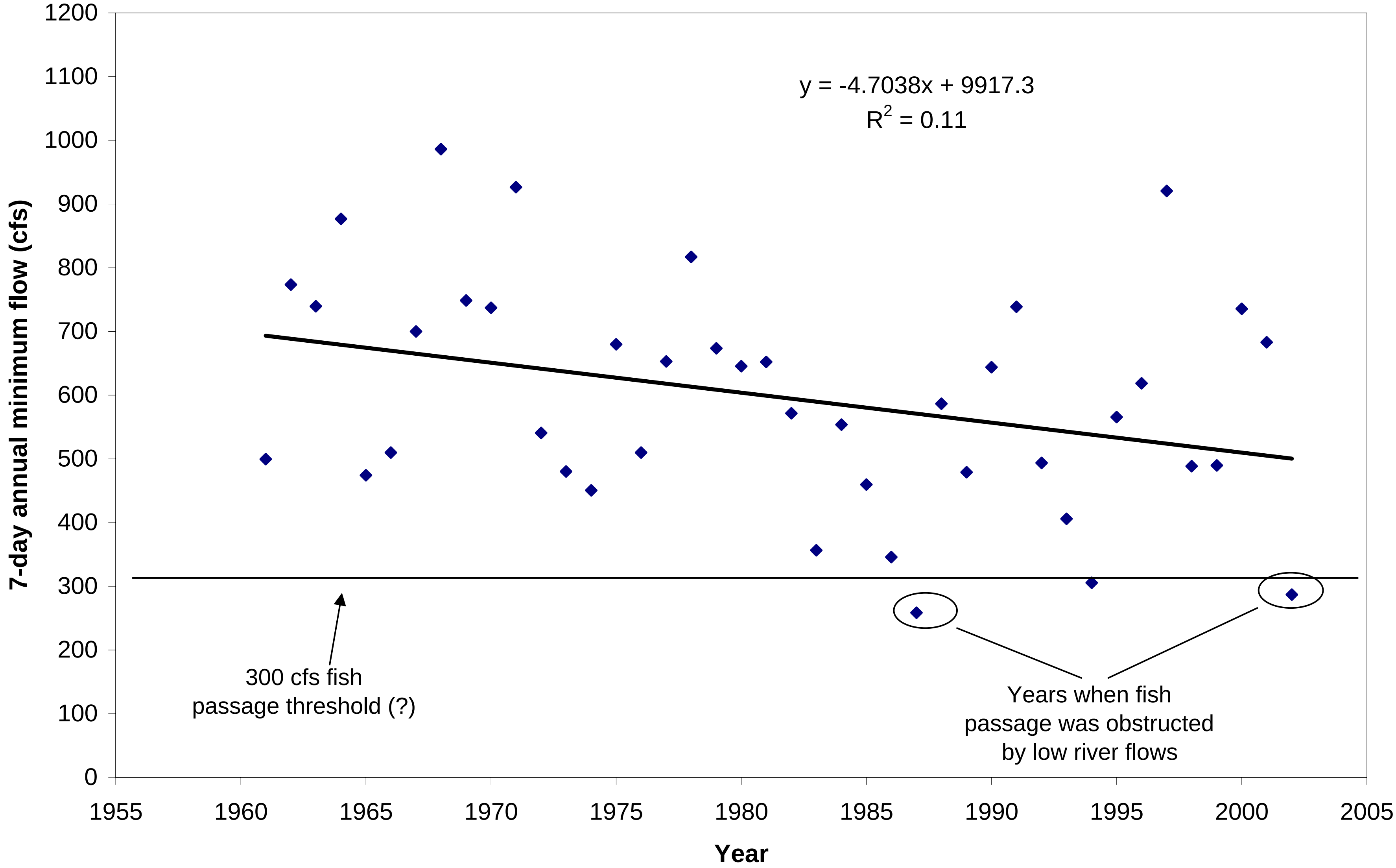


Figure 5-2.
Historic 7-day minimum flows on the Hoh River (USGS gage 12041200)

WRIA 20
043-1130-100

Golder Associates

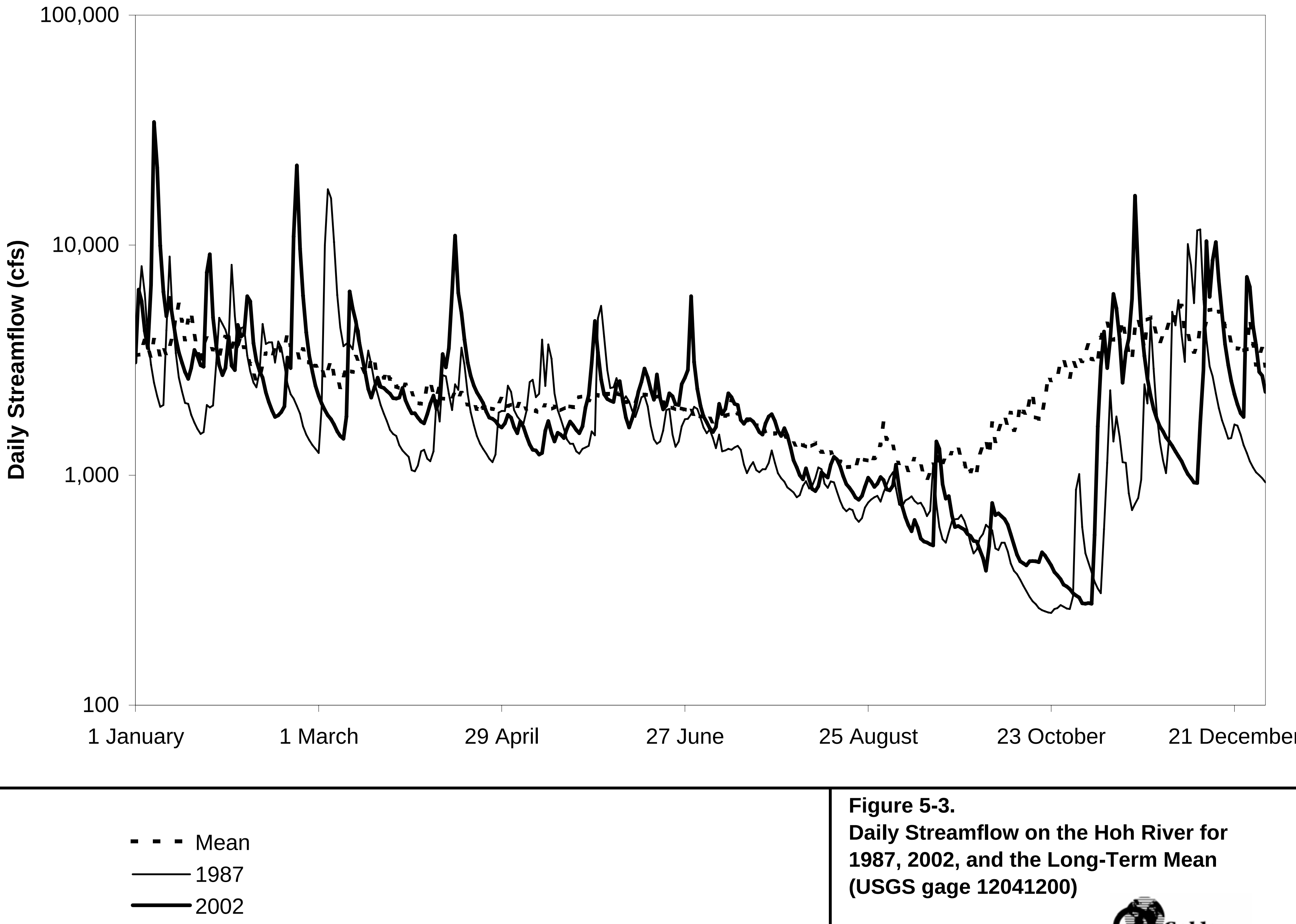


Figure 5-3.
Daily Streamflow on the Hoh River for 1987, 2002, and the Long-Term Mean (USGS gage 12041200)

WRIA 20
043-1130-100

Golder Associates

Hoh_climate change Figures.xls; F 5-3 Streamflow

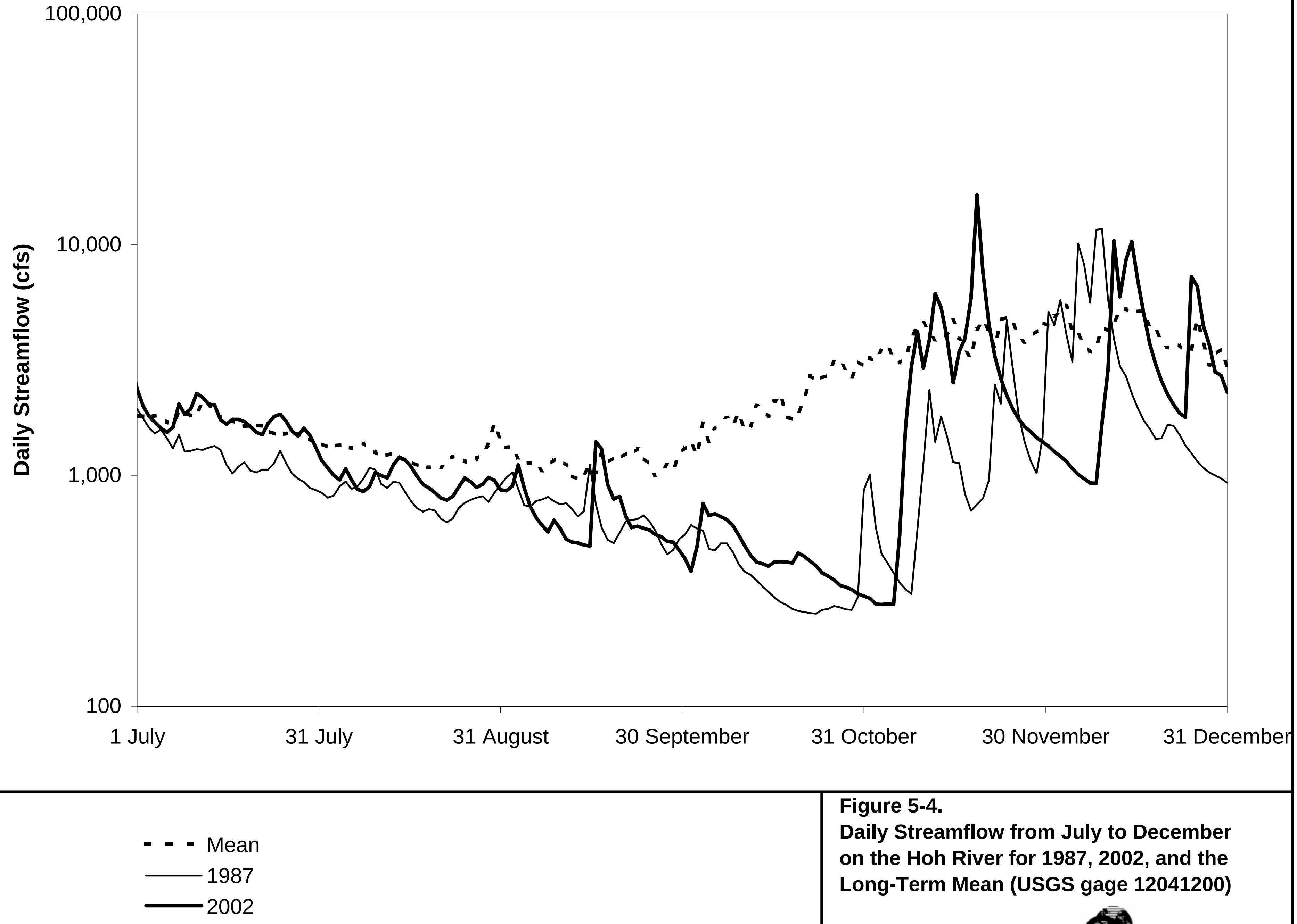


Figure 5-4.
Daily Streamflow from July to December on the Hoh River for 1987, 2002, and the Long-Term Mean (USGS gage 12041200)

WRIA 20
043-1130-100

Golder Associates

Hoh_climate change Figures.xls; F 5-4 Streamflow Detail

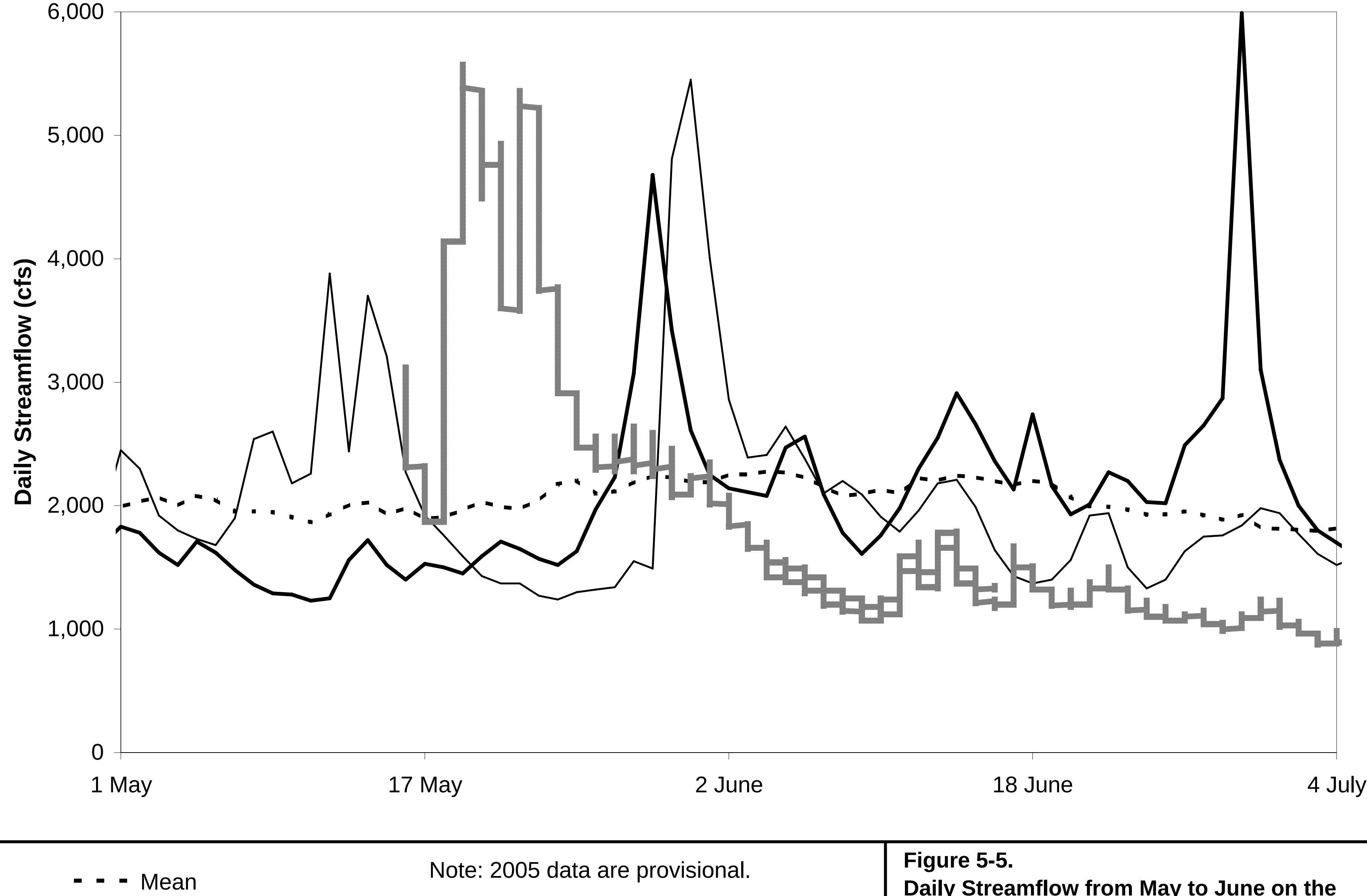
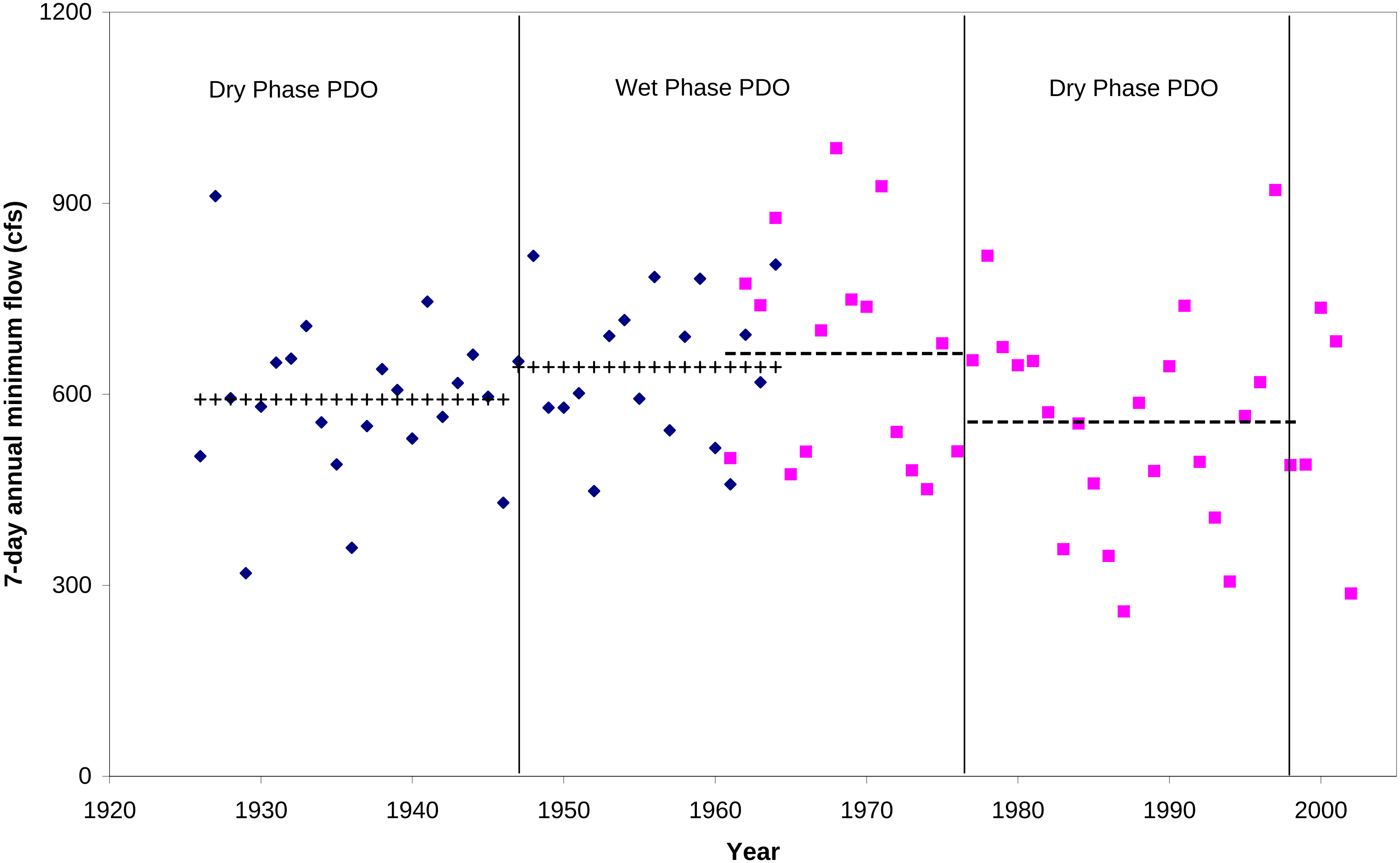


Figure 5-5.
Daily Streamflow from May to June on the Hoh River for 1987, 2002, 2005, and the Long-Term Mean (USGS gage 12041200)

WRIA 20
043-1130-100

Golder Associates



◆ USGS gage 12041000
■ USGS gage 12041200
– Mean for 12041200
+ Mean for 12041000

Figure 5-6.
7-day annual minimum streamflow at two gages on the Hoh River in relation to PDO cycles

WRIA 20
043-1130-100

Golder Associates

Hoh_climate change Figures.xls; F 5-6 PDO

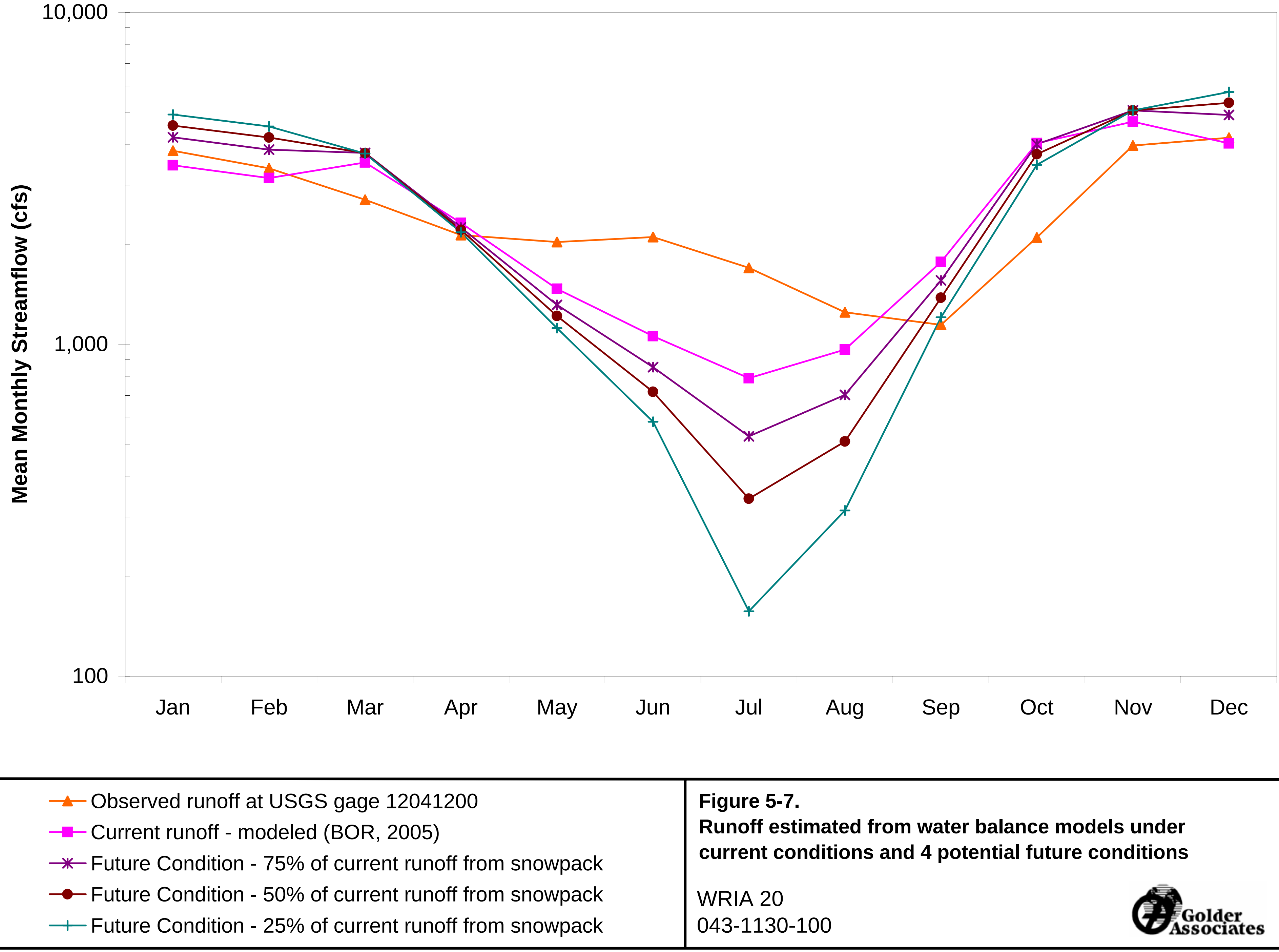


Figure 5-7.
Runoff estimated from water balance models under current conditions and 4 potential future conditions

WRIA 20
043-1130-100

Golder Associates

Hoh_climate change Figures.xls; F5-7 NoSnow

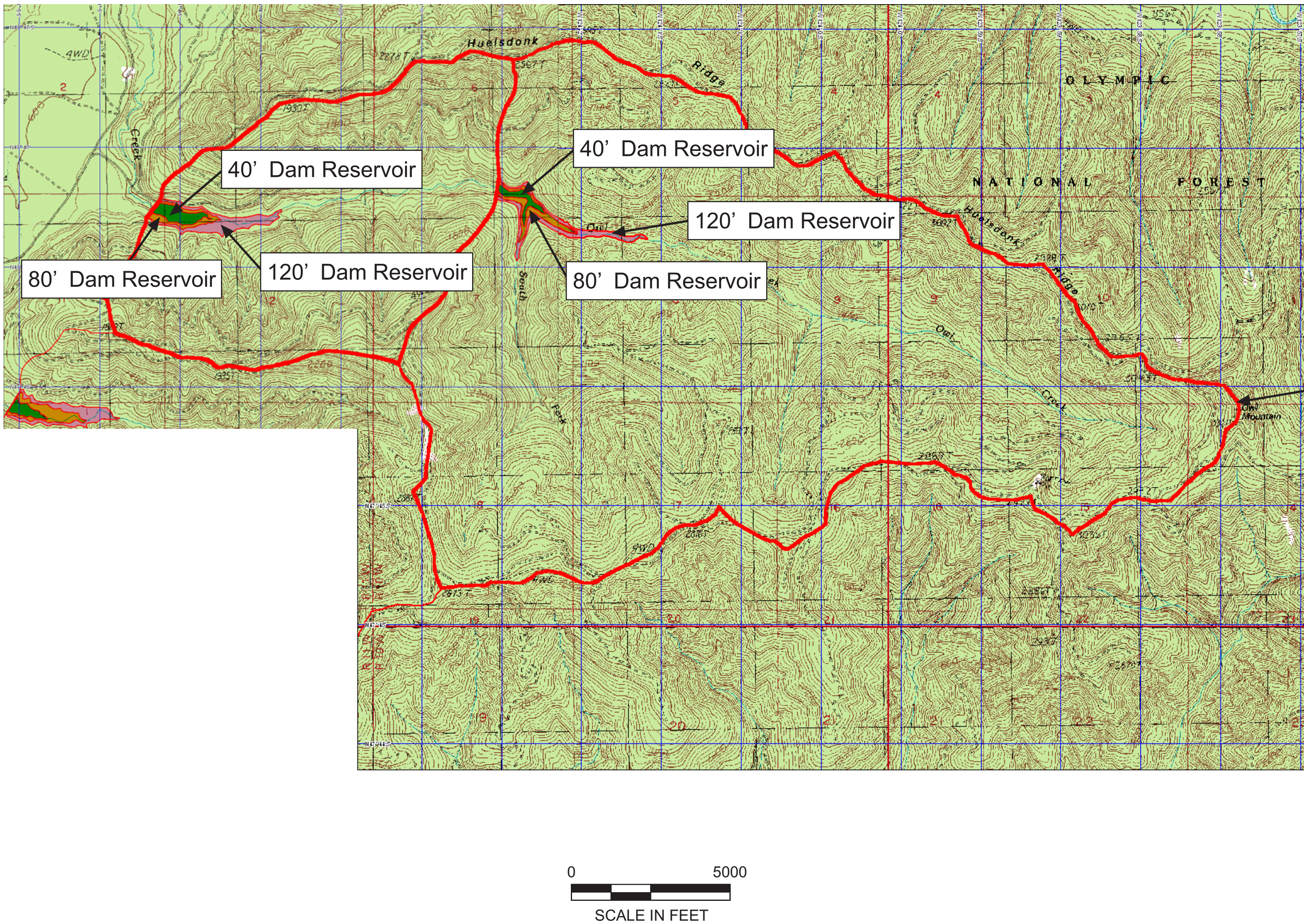


FIGURE **5-8**

OWL CREEK #1 RESERVOIR CATCHMENT

CLALLAM/WRIA 20 WATERSHED PLAN/WA

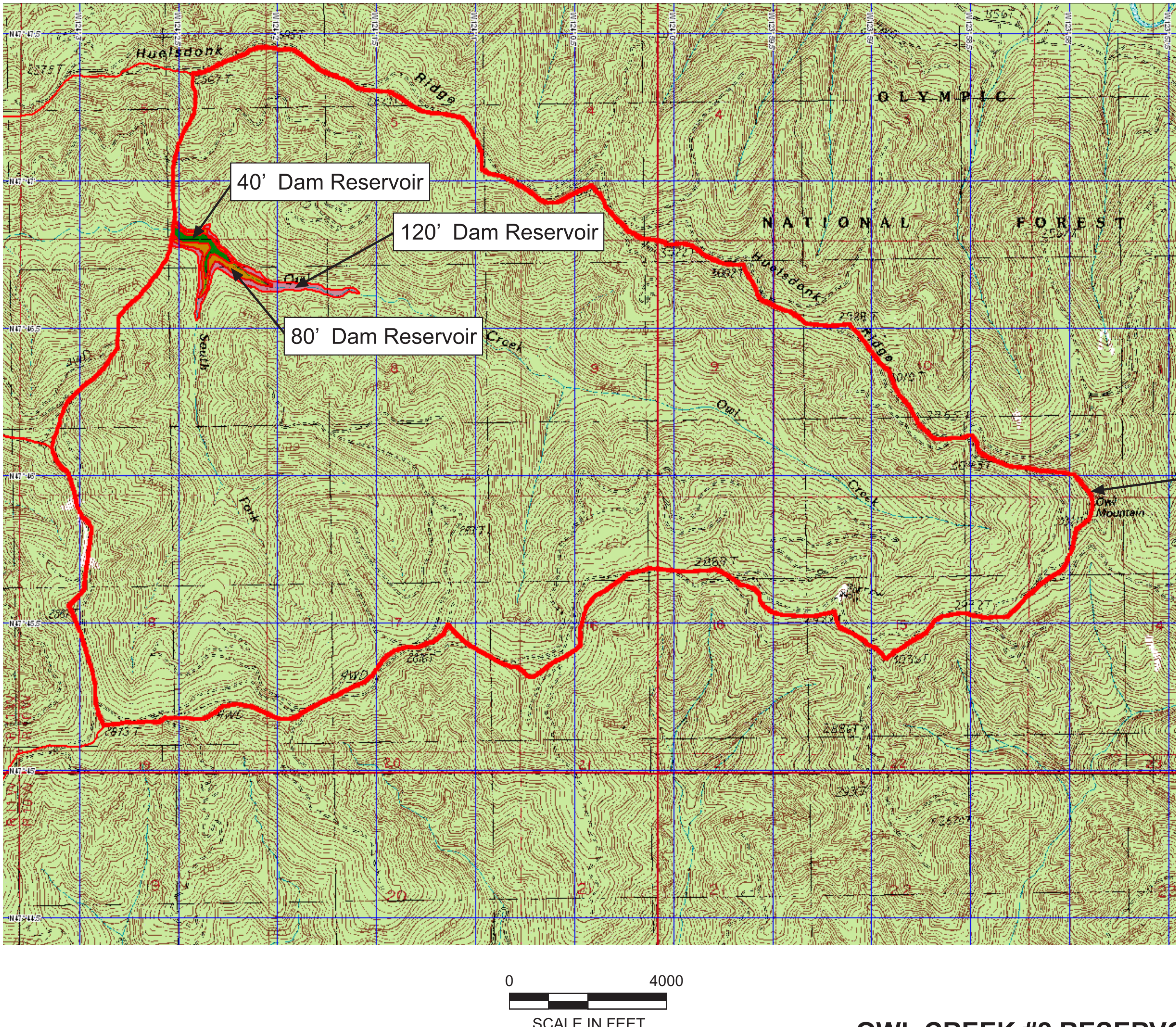


FIGURE **5-9**

OWL CREEK #2 RESERVOIR CATCHMENT

CLALLAM/WRIA 20 WATERSHED PLAN/WA

043113010023 00fg05.fh11 | Mod: 06/16/05 | AMP

Golder Associates

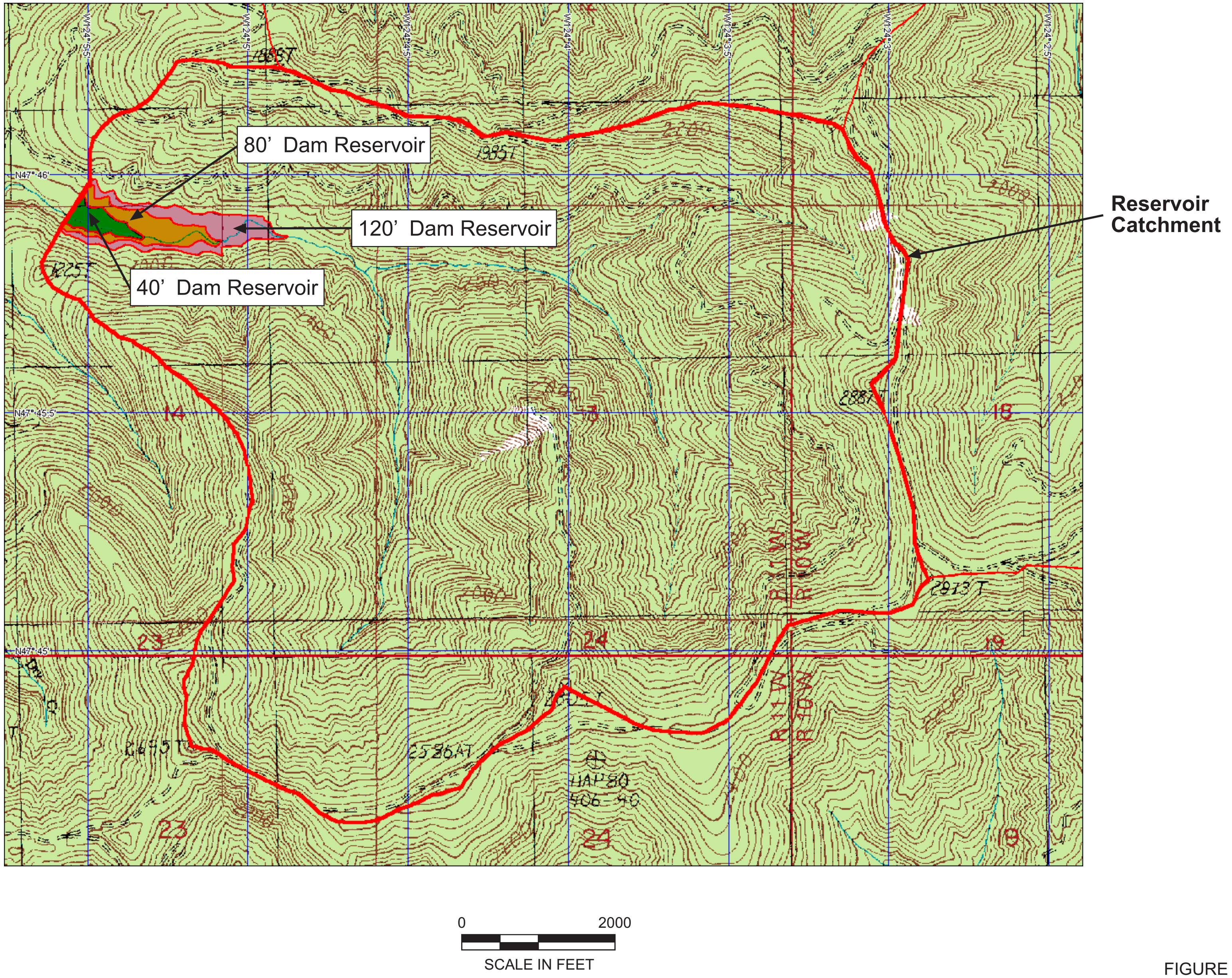


FIGURE **5-10**

MAPLE CREEK #1 RESERVOIR CATCHMENT

CLALLAM/WRIA 20 WATERSHED PLAN/WA

043113010023OOfg02.fh11 | Mod: 06/16/05 | AMP

Golder Associates

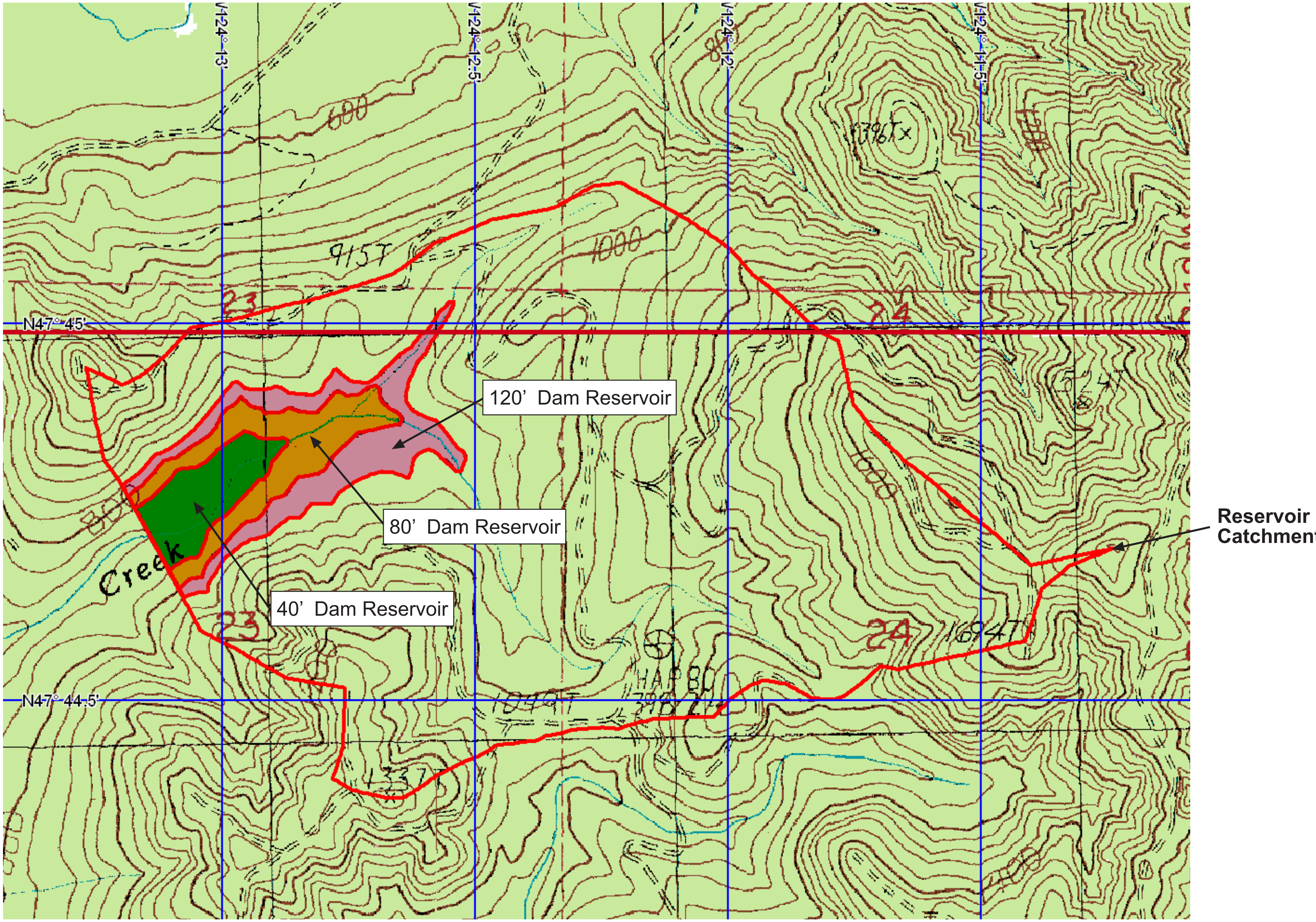


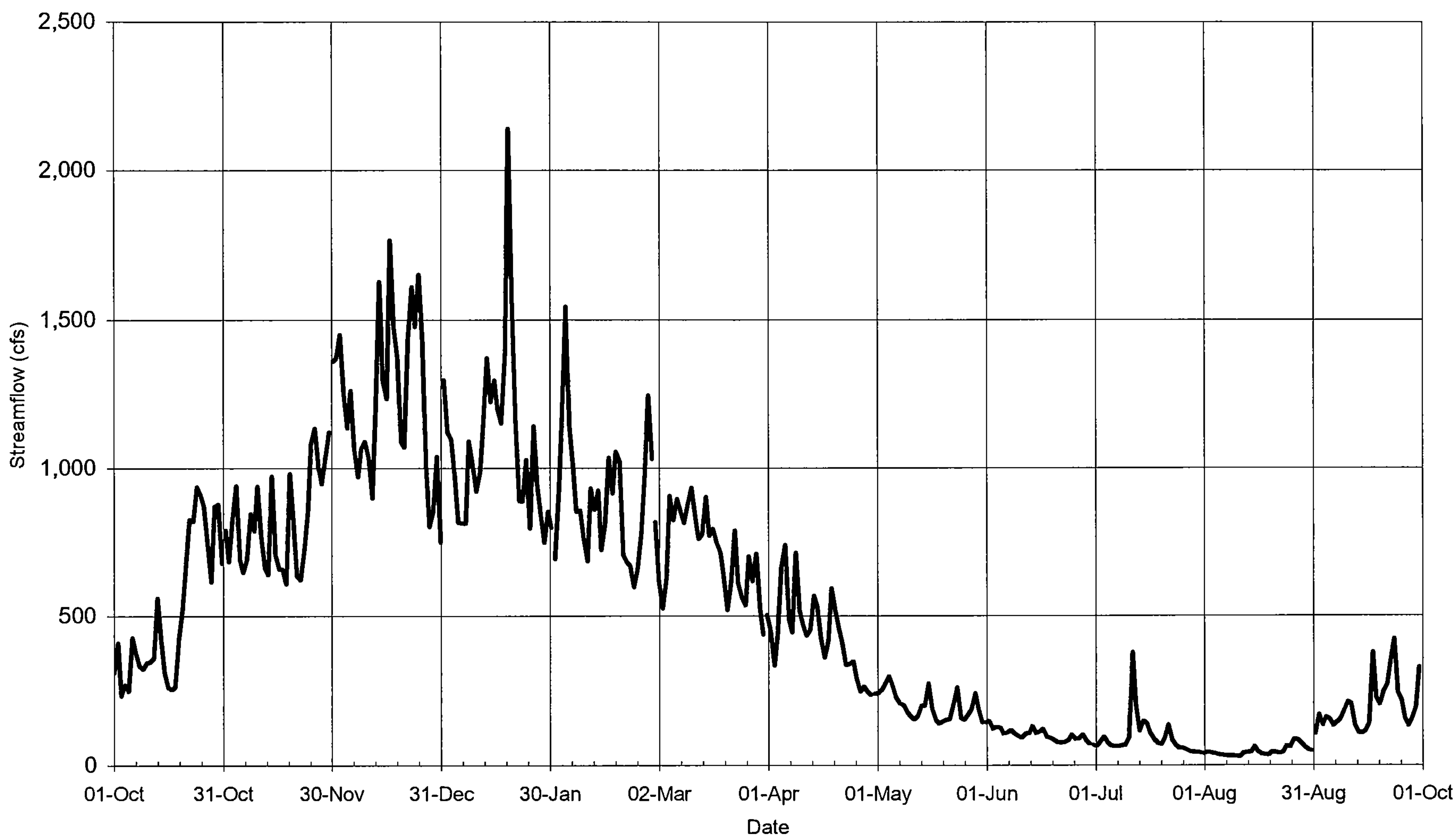
FIGURE **5-11**

NOLAN CREEK #1 RESERVOIR CATCHMENT

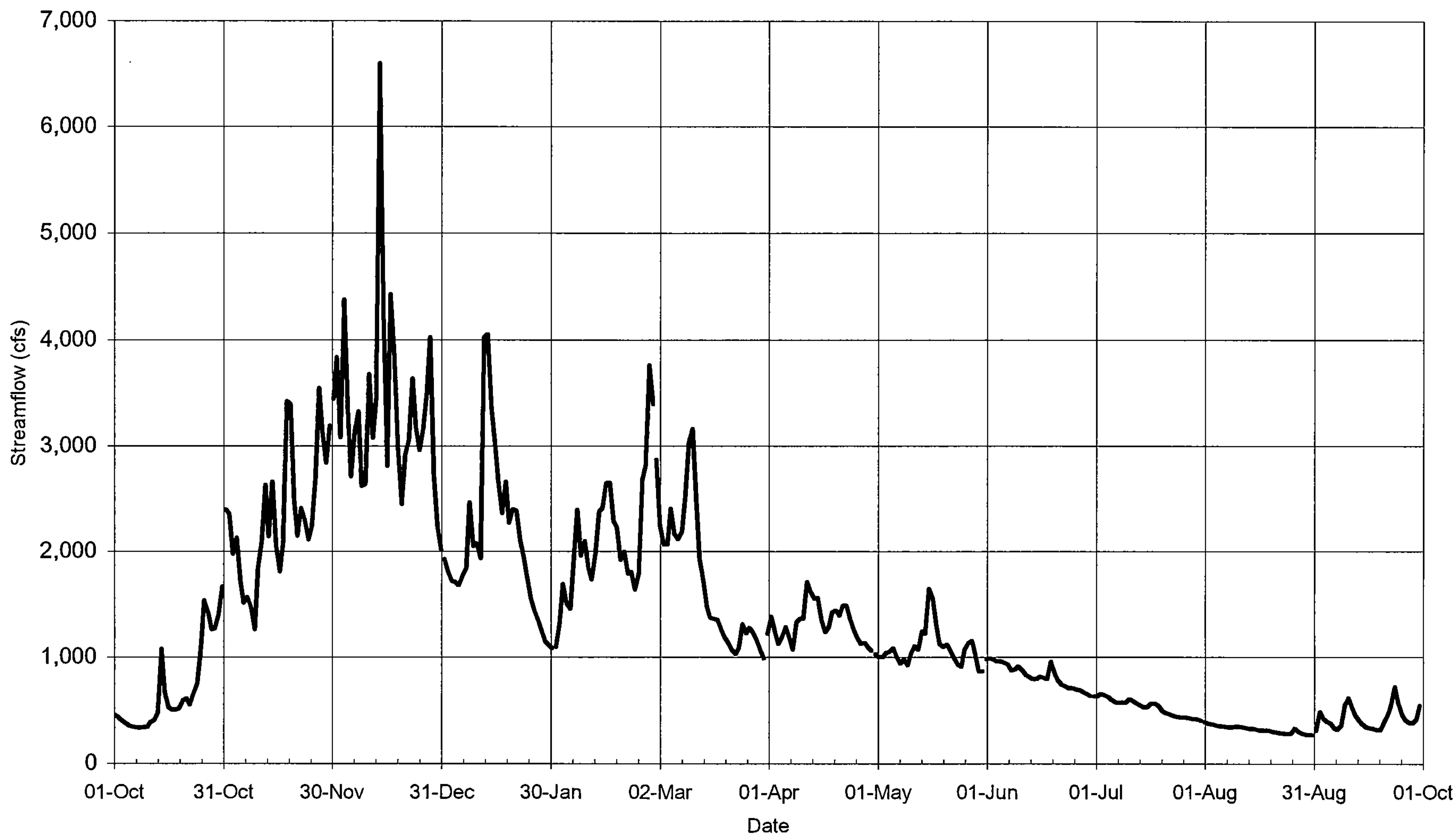
CLALLAM/WRIA 20 WATERSHED PLAN/WA

APPENDIX 2-A

HYDROGRAPHS



Golder Associates	TITLE **Mean Daily Streamflow-Dickey River at La Push**		
WRIA 20 Multi-Purpose Storage Assessment	DRAWN MPK	DATE Jun-05	JOB NO. 043-1130-100.001
	CHECKED DB	SCALE na	DWG. NO. na
	REVIEWED DB	FILE NO. river hydrographs	FIGURE NO. **2-A-1**



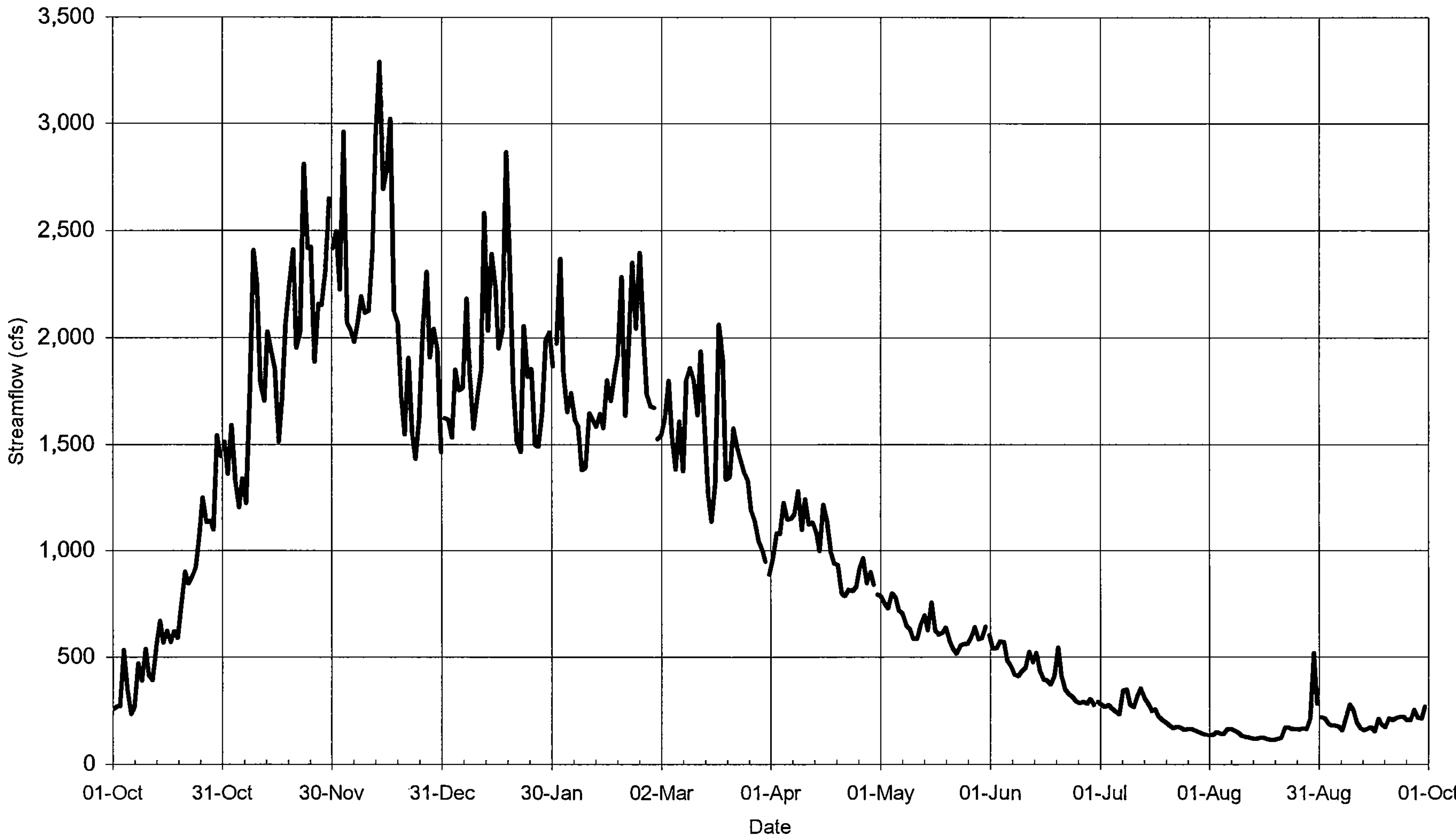
Golder Associates

WRIA 20 Multi-Purpose Storage Assessment

TITLE

Mean Daily Streamflow-Sol Duc River near Quillayute

DRAWN MPK	DATE Jun-05	JOB NO. 043-1130-100.001
CHECKED DB	SCALE na	DWG. NO. na
REVIEWED DB	FILE NO. river hydrographs	FIGURE NO. **2-A-2**



Golder Associates	TITLE **Mean Daily Streamflow-Calawah River near Forks**		
WRIA 20 Multi-Purpose Storage Assessment	DRAWN MPK	DATE Jun-05	JOB NO. 043-1130-100.001
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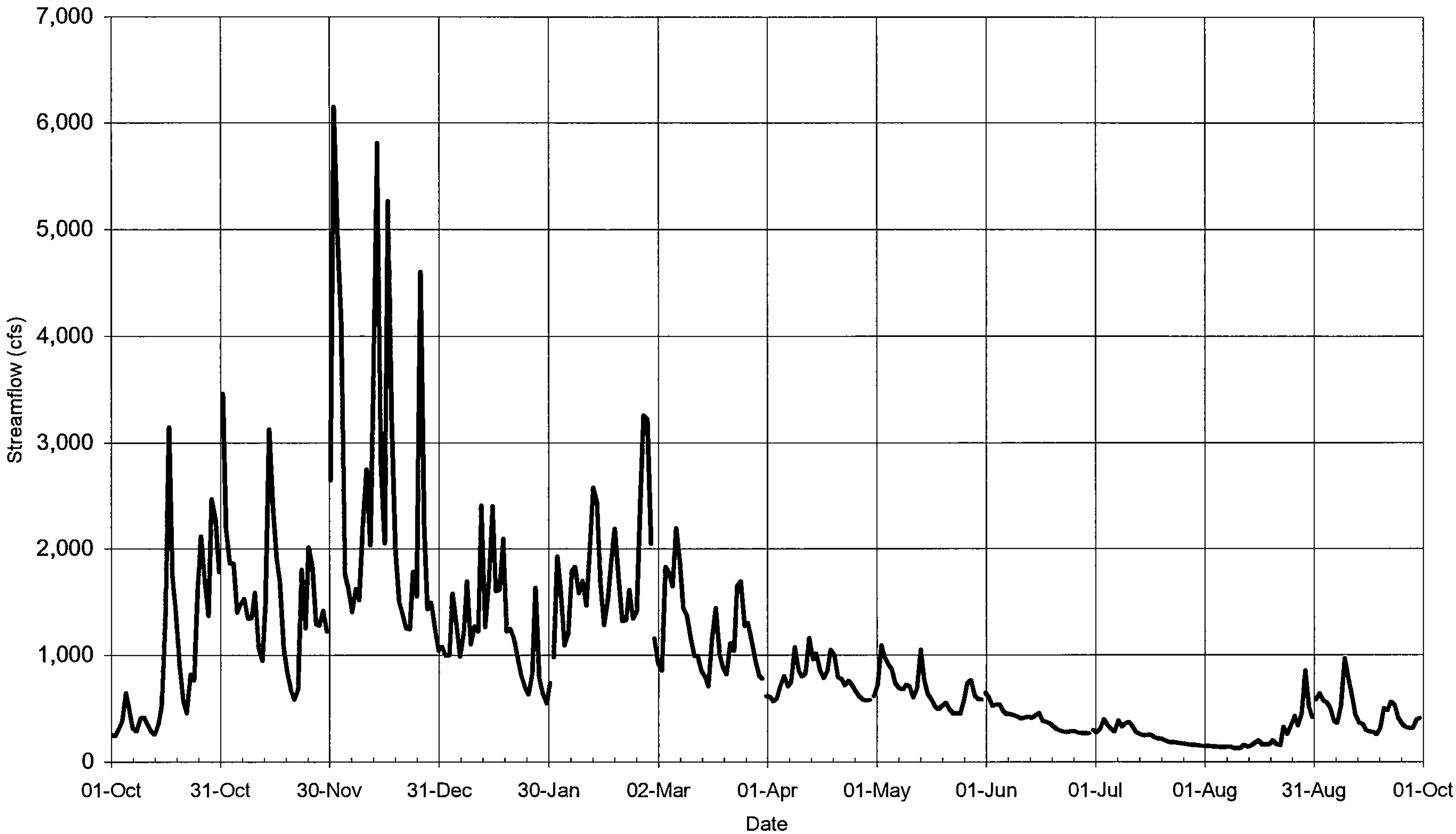
	REVIEWED DB	FILE NO. river hydrographs	FIGURE NO. **2-A-3**



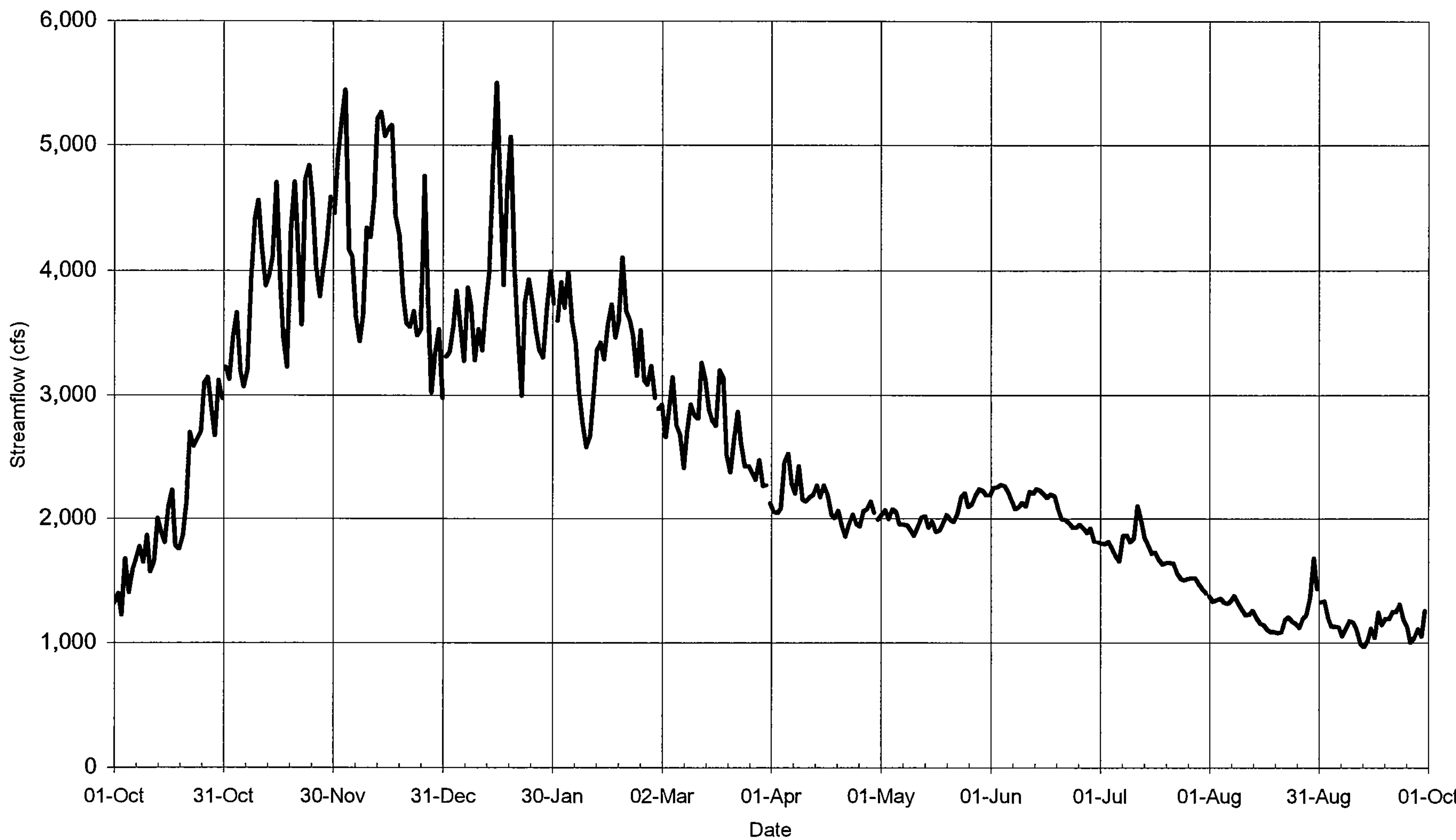
Golder Associates

WRIA 20 Multi-Purpose Storage Assessment

TITLE

Mean Daily Streamflow-Bogacheil River near Forks

DRAWN MPK	DATE Jun-05	JOB NO. 043-1130-100.001
CHECKED DB	SCALE na	DWG. NO. na
REVIEWED DB	FILE NO. river hydrographs	FIGURE NO. **2-A-4**



Golder Associates

WRIA 20 Multi-Purpose Storage Assessment

TITLE

Mean Daily Streamflow-Hoh River at Highway 101

DRAWN MPK	DATE Jun-05	JOB NO. 043-1130-100.001
CHECKED DB	SCALE na	DWG. NO. na
REVIEWED DB	FILE NO. river hydrographs	FIGURE NO. **2-A-5**

APPENDIX 3-A

BIG RIVER SITE PHOTOS
(SELECTED SITES, PROVIDED BY MAKAH TRIBE)

Example of flat gradient lake influence

APPENDIX **A-1**
BIG RIVER AT ~ RM 0.0

Example of flat gradient water and fine grained sediments.

APPENDIX **A-2**
BIG RIVER AT ~ RM 1.8

Gauging station on bridge.

Example of gravel sediments.

APPENDIX **A-3**
BIG RIVER AT STREAM GAUGE SITE AT RM 4.7

View looking at bridge crossing.

APPENDIX **A-4**

BIG RIVER AT STREAM GAUGE SITE AT RM 4.7

Example of bank erosion.

APPENDIX **A-5**

BIG RIVER AT FRED CROSS PROPERTY IN 2004
HOKO OZETTE ROAD CROSSING AT ~ RM 7.9

Example of eroding banks.

Example of eroding banks.

APPENDIX **A-6**

BIG RIVER AT FRED CROSS PROPERTY IN MARCH 2005
HOKO OZETTE ROAD CROSSING AT ~ RM 7.9

Example of eroding banks.

Note woody debris buried in banks.

APPENDIX **A-7**

BIG RIVER AT FRED CROSS PROPERTY IN MARCH 2005
HOKO OZETTE ROAD CROSSING AT ~ RM 7.9

Example of bank armoring.

APPENDIX **A-8**

BIG RIVER AT FRED CROSS PROPERTY IN MARCH 2005
HOKO OZETTE ROAD CROSSING AT ~ RM 7.9

APPENDIX 3-B

"COMPLETION REPORT BY STREAM CLEARANCE UNIT ON OZETTE AND BIG RIVERS", APRIL, 1953, ROBERT KRAMER (SELECTED MAP AND PHOTOS FROM BIG RIVER)

COMPLETION REPORT

BY

STREAM CLEARANCE UNIT

ON

OZETTE AND BIG RIVERS

APRIL, 1953

Robert Kramer, Supervisor
Stream Clearance Projects
Stream Improvement Division
Department of Fisheries

BIG RIVER

Clearance operations began on Big River following the completion of work on the Ozette River. Big River is the largest and most important tributary of the Ozette system. The stream drains an area of 24 square miles. It flows through a low, rather flat valley for a distance of eight miles. Seven miles of stream area was surveyed by walking. Many log jams were found, most of them being partial blocks to migration.

Stream clearance started on November 1, 1952, at the bridge crossing about six miles upstream from the mouth. About three and one-half miles of stream area was cleared of logs and debris. Work was greatly hampered by weather conditions during December. Heavy rains in the area caused Big River to rise considerably, making clearance work quite hazardous. The county road, the only available road in the whole area, was at times covered with flood waters. Operations ceased on December 19, 1952, when it became quite evident that the weather conditions would greatly curtail activities.

Big River has almost a continuous bed of gravel from the bridge at the seven mile point downstream to about one mile from its mouth. This lower mile area is quite heavily choked with large logs and debris. The area is also low and swampy with a mud bottom. Clearance equipment is not large enough to handle the heavy watersoaked logs. Weather conditions also prevented entrance into this area. In the lower mile area, migration is possible only during high water stages. The heavy logging debris presents a definite barrier to salmon during low water stages.

Moving upstream to the one and a-half mile point, several large trees were felled across the stream by the Ozette Timber Company. They have promised to remove all trees and debris in this area this coming summer when they are operating in the area.

Stream clearance is complete from the two mile point upstream to the six mile point at the bridge crossing. Several log jams still exist above the bridge. These are small jams and should be removed. No survey was made past the seven mile point. There is a falls fifty feet high about eight miles upstream, located in Sections 15 and 16, Township 31 North, Range 14 West, W. M. Exact location is not known as it is very near the section line.

Some clearing, for agricultural purposes, exists along the banks of the river. Erosion is quite evident along the cleared area, being aided by periods of heavy run-off.

Considerable amounts of debris remain near the stream banks due to past logging operations. A more thorough check should be made of logging operations working in this section of the country.

Big River supports quite a large run of silver salmon. Dogs and humpies also spawn in this stream, but they are of a definite minority. Observations indicated that silvers predominate by a large majority.

Additional clearance work is necessary on Big River to insure adequate fish passage. Clearance operations have made three and a half miles of good to excellent stream area available.

Trout Creek, tributary of Big River, is of some importance as salmon were observed spawning in the lower mile area. The creek drains a low swampy area, with intermittent gravel areas extending into the upper reaches. Survey was made only for a mile of stream area.

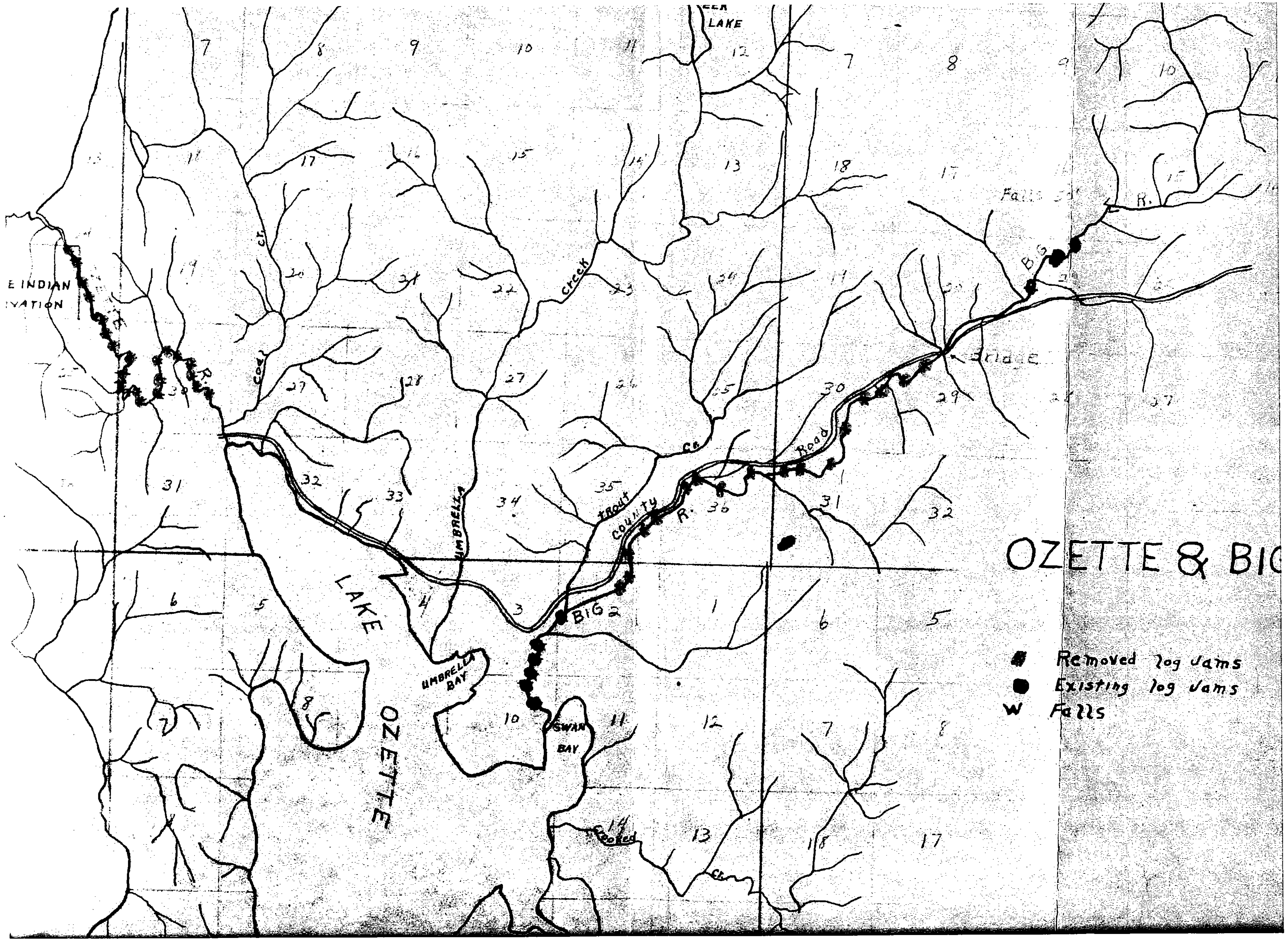
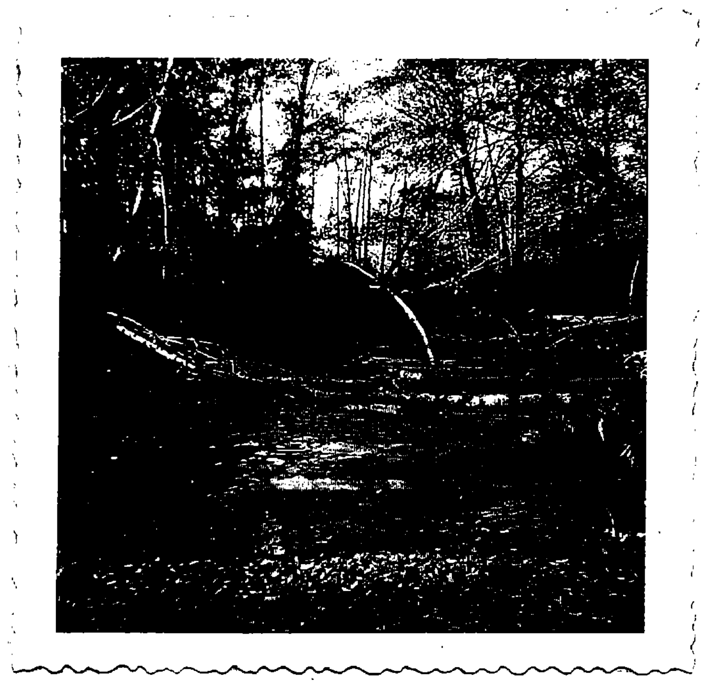

OZETTE & BIG
LAKE
OZETTE
UMBRELLA BAY
SWAN BAY
UMBRELLA
Creek
Trout
County Road
BIG
R.
Coal Cr.
Crooked
Bridge
Falls
LAKE
Removed log jams
Existing log jams
W Falls

FIGURE 4



Logs and debris being removed from Big R. about 4 miles from mouth.

FIGURE 5

Log jam above bridge crossing on Big R. Not removed.

APPENDIX 3-C

EXCERPT FROM PHINNEY AND BUCKNELL, 1975. "A CATALOG OF WASHINGTON STREAMS AND SALMON UTILIZATION, VOLUME 2, COASTAL", WASHINGTON STATE DEPARTMENT OF FISHERIES, 1975

OZETTE RIVER

This section covers the Ozette River, Ozette Lake and its 12 tributaries as well as several lesser tributaries to the Pacific Ocean including Seafield and Cedar creeks. Streams in this area have a total length of over 80 miles.

Stream Discussion

The primary streams discussed in this section include Ozette River, Coal Creek, Umbrella Creek, Big River, Crooked Creek and Siwash Creek. Ozette Lake is 7,787 acres in area and has a depth of over 300 feet. It is the third largest natural lake in the State of Washington. Ozette River drains Ozette Lake in a northwesterly direction and enters the Pacific Ocean near Cape Alava. Most of the tributaries to Lake Ozette drain from the hills to the north and west of the lake. All of the surrounding land outside the boundaries of the Olympic National Park and Ozette Indian Reservation are in timber production. The Olympic National Park encompasses all of the beach stretch in this area and borders Lake Ozette and Ozette River. The Ozette Indian Reservation is located on a portion of Ozette River.

Big River is the largest tributary to Ozette Lake. This stream originates in the hills north of Lake Ozette and flows southwesterly to its confluence with the lake. The streambed has an average width ranging from 10 yards in its lower reaches to 5 yards near the upper limit of salmon use. The streambed materials are predominantly sand with some gravel in the lower 5 miles while gravel and sand predominate in the remainder of the stream. The river has a moderate gradient throughout. Stream bank cover is generally good and is provided by deciduous vegetation. Tributaries to Big River range from 1 to 5 yards in width at lower reaches. These streams contain suitable gravel for spawning material.

Other tributaries to Lake Ozette range from 1 to 7 yards in width. These streams generally have a moderate gradient throughout. Bottom material consists primarily of sand and gravel with suitable spawning material found in various reaches. Stream bank cover is generally adequate on these tributaries with the exception of certain areas which have been recently clear-cut logged.

Salmon Utilization

The Ozette River system supports runs of sockeye, chinook, coho and chum salmon. Major spawning areas have not been identified for all species or all areas. Chum and chinook spawning reportedly occurs in Ozette River downstream from Lake Ozette and in Big River. Sockeye spawning is known to occur in Big River and Siwash Creek and undoubtedly occurs in other accessible streams. All accessible tributaries support runs of coho salmon. Big River and Umbrella and Crooked creeks appear to be the major coho production areas in the drainage. Salmon presently utilize at least 52 miles of stream in this section.

Limiting Factors

Factors limiting salmon production in the Ozette River section include warm summer water temperatures in Ozette River and certain tributaries which have been extensively logged. Logging and road construction have occurred in recent years throughout the basin and have resulted in denuding of stream banks and siltation of streambeds. A falls on Big River at mile 10.9 is a total barrier to further upstream migration of coho. A falls on South Fork Crooked and debris jams on many smaller streams hinder salmon migration.

Beneficial Developments

No project has been undertaken in this area to benefit salmon production.

Habitat Needs

Additional protection of the salmon production habitat is required in this area during road construction and logging activities. No major improvement projects are presently recommended.

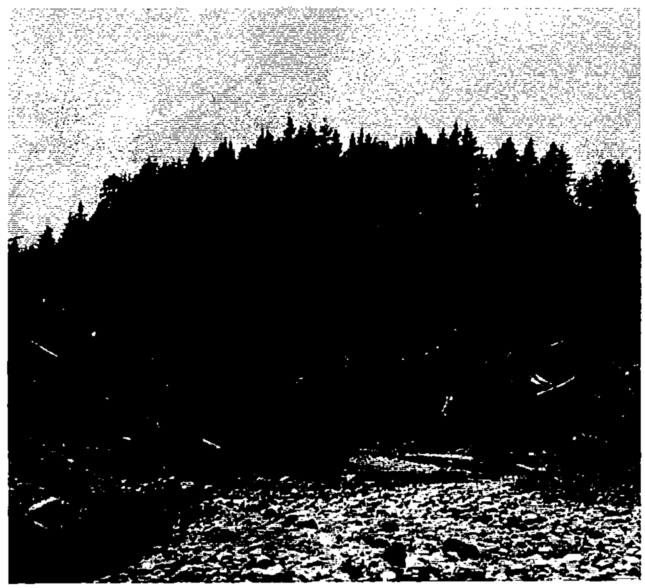
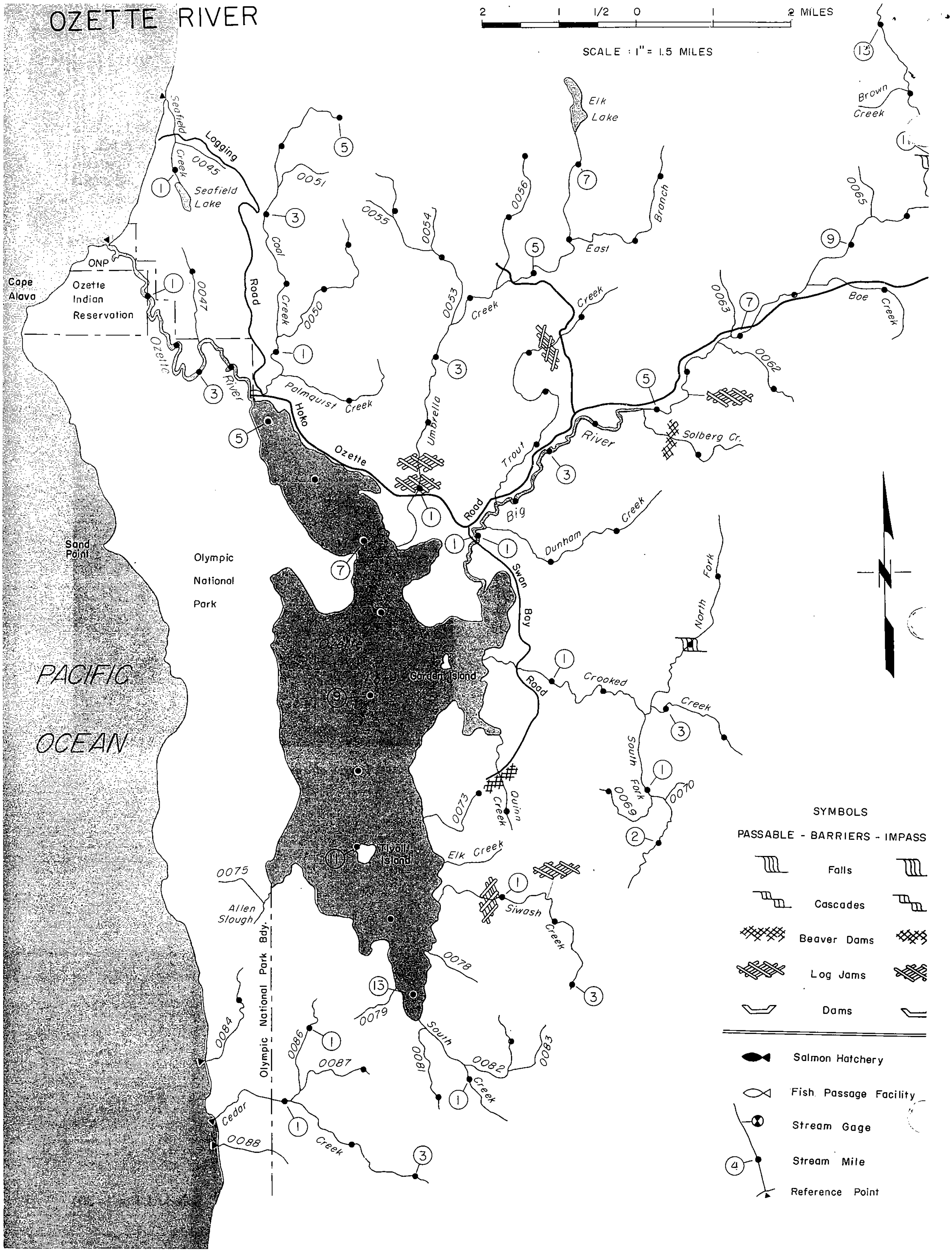


PHOTO 20-9. Logged off area along Umbrella Creek.


OZETTE RIVER
2 1 1/2 0 1 2 MILES
SCALE : 1" = 1.5 MILES
PACIFIC OCEAN
Cape Alava
ONP
Ozette Indian Reservation
Sand Point
Olympic National Park
Olympic National Park Bdy.
Seafield Creek
Logging Road
0045
Seafield Lake
0047
Ozette River
Coal Creek
0051
0050
0055
0054
0053
Palmquist Creek
Hoko Ozette Road
Umbrella Creek
0056
Elk Lake
East Branch
Creek
Trout Creek
Big River
0063
0062
0065
Brown Creek
Boe Creek
Solberg Cr.
Dunham Creek
North Fork
Swan Bay Road
Crooked Creek
South Fork
0069
0070
Garden Island
Tivoli Island
0073
Quinn Creek
Elk Creek
0075
Allen Slough
Siwash Creek
0078
0079
0084
0086
0087
South Creek
0081
0082
0083
Cedar Creek
0088
SYMBOLS
PASSABLE - BARRIERS - IMPASS
Falls
Cascades
Beaver Dams
Log Jams
Dams
Salmon Hatchery
Fish Passage Facility
Stream Gage
Stream Mile
Reference Point

APPENDIX 3-D

CONSERVATION PROGRAM FACT SHEETS

CONSERVATION RESERVE PROGRAM

Farm Service Agency
Online

Fact Sheet

USDA United States Department of Agriculture

Electronic Edition

August 2004 (revised 08/11/04)

Conservation Reserve Program Sign-up 29
August 30 to September 24, 2004

Overview

USDA's Farm Service Agency (FSA) will hold a Conservation Reserve Program (CRP) general sign-up from August 30 to September 24, 2004.

CRP is a voluntary program available to agricultural producers to help them safeguard environmentally sensitive land. Producers enrolled in CRP plant long-term, resource-conserving covers to improve the quality of water, control soil erosion, and enhance wildlife habitat. In return, FSA provides participants with rental payments and cost-share assistance. Contract duration is between 10 and 15 years.

FSA administers CRP, while other USDA agencies and partners provide technical support. More detailed information on CRP is available in the FSA fact sheet "Conservation Reserve Program."

Submitting CRP Offers

Land that is not currently enrolled in CRP may be offered for enrollment during CRP sign-up 29.

In addition, CRP participants with contracts expiring on September 30, 2004, or September 30, 2005, may submit offers during CRP sign-up 29.

To submit CRP offers, producers must visit their local FSA offices. FSA will accept offers only during the sign-up period (August 30 to September 24, 2004). To find your local FSA office, visit FSA's Web site at: http://oip.usda.gov/scripts/ndisapi.dll/oip_agency/index?state=us&agency=fsa

NOTE: CRP sign-up 29 does not apply to participation in CRP continuous sign-up, in which land devoted to certain conservation practices may be enrolled at any time. Further information on CRP continuous sign-up is available in the FSA fact sheet "Conservation Reserve Program Continuous Sign-up."

Eligible Producers

To be eligible for CRP enrollment, a producer must have owned or operated the land for at least 12 months prior to close of the CRP sign-up period, unless:

- The new owner acquired the land due to the previous owner's death;
- The ownership change occurred due to foreclosure where the owner exercised a timely right or redemption in accordance with state law; or
- The circumstances of the acquisition present adequate assurance to FSA that the new owner did not acquire the land for the purpose of placing it in CRP.

Eligible Land

To be eligible for placement in CRP, land must be either:

- Cropland (including field margins) that is planted or considered planted to an agricultural commodity 4 of the previous 6 crop years from 1996 to 2001, and which is physically and legally capable of being planted in a normal manner to an agricultural commodity;
- Certain marginal pastureland that is enrolled in the Water Bank Program; or
- Certain land devoted to hardwood trees that was under CRP contract which expired on September 30, 2001, or earlier.

Additional Cropland Requirements

In addition to the eligible land requirements, cropland must meet one of the following criteria:

- Have a weighted average erosion index of 8 or higher;
- Be expiring CRP acreage; or
- Be located in a national or state CRP conservation priority area.

CRP Payments

FSA provides CRP sign-up 29 participants with annual rental payments, including certain incentive payments, and cost-share assistance:

- ***Rental Payments***
  In return for establishing long-term, resource-conserving covers, FSA provides rental payments to participants. FSA bases rental rates on the relative productivity of the soils within each county and the average

dryland cash rent or cash-rent equivalent. The maximum CRP rental rate for each offer is calculated in advance of enrollment. Producers may offer land at that rate or offer a lower rental rate to increase the likelihood that their offer will be accepted.

- ***Maintenance Incentive Payments***
  CRP annual rental payments may include an additional amount up to $5 per acre per year as an incentive to perform certain maintenance obligations.

- ***Cost-share Assistance***
  FSA provides cost-share assistance to participants who establish approved cover on eligible cropland. The cost-share assistance can be an amount not more than 50 percent of the participants' costs in establishing approved practices.

Ranking CRP Offers

Offers for CRP sign-up 29 will be ranked according to the Environmental Benefits Index (EBI).

FSA collects data for each of the EBI factors based on the relative environmental benefits for the land offered. Each eligible offer is ranked in comparison to all other offers and selections made from that ranking. Decisions on the EBI cutoff will be made after the sign-up ends. Those who have met previous sign-up EBI thresholds are not guaranteed a contract under this sign-up. Producers can consult with local USDA experts on steps producers can take to maximize EBI points and increase the likelihood that their offer will be accepted.

Producers can enroll the most environmentally sensitive land in CRP's continuous sign-up program. Under the continuous sign-up, relatively small amounts of land serving much larger areas, such as filter strips, riparian buffers and grass waterways, can be enrolled at any time.

More information on EBI for CRP sign-up 29 is available in the FSA fact sheet, "Conservation Reserve Program Sign-up 29, Environmental Benefits Index."

For More Information

For more information on CRP, contact your local FSA office or visit FSA's Web site at: www.fsa.usda.gov

Farm Service Agency *Online*

Fact Sheet

Electronic Edition

USDA United States Department of Agriculture

April 2003

Conservation Reserve Program

Overview

USDA Farm Service Agency's (FSA) Conservation Reserve Program (CRP) is a voluntary program available to agricultural producers to help them safeguard environmentally sensitive land. Producers enrolled in CRP plant long-term, resource-conserving covers to improve the quality of water, control soil erosion, and enhance wildlife habitat. In return, FSA provides participants with rental payments and cost-share assistance. Contract duration is between 10 and 15 years.

The Food Security Act of 1985, as amended, authorized CRP. The program is also governed by regulations published in 7 CFR, part 1410. The program is implemented by FSA on behalf of USDA's Commodity Credit Corporation.

Benefits

CRP protects millions of acres of American topsoil from erosion and is designed to safeguard the Nation's natural resources. By reducing water runoff and sedimentation, CRP protects groundwater and helps improve the condition of lakes, rivers, ponds, and streams. Acreage enrolled in the CRP is planted to resource-conserving vegetative covers, making the program a major contributor to increased wildlife populations in many parts of the country.

CRP Administration

FSA administers CRP, while technical support functions are provided by:

- USDA's Natural Resources Conservation Service (NRCS);
- USDA's Cooperative State Research, Education, and Extension Service;
- State forestry agencies;
- Local soil and water conservation districts; and
- Private sector providers of technical assistance.

CRP General Sign-up

Producers can offer land for CRP general sign-up enrollment only during designated sign-up periods. For information on upcoming sign-ups, contact your local FSA office. To find your local office, visit FSA's Web site at: http://oip.usda.gov/scripts/ndisapi.dll/oip_agency/index?state=us&agency=fsa

CRP Continuous Sign-up

Environmentally desirable land devoted to certain conservation practices may be enrolled at any time under CRP continuous sign-up. Certain eligibility requirements still apply, but offers are not subject to competitive bidding. Further information on CRP continuous sign-up is available in the FSA fact sheet "Conservation Reserve Program Continuous Sign-up."

Eligible Producers

To be eligible for CRP enrollment, a producer must have owned or operated the land for at least 12 months prior to close of the CRP sign-up period, unless:

- The new owner acquired the land due to the previous owner's death;
- The ownership change occurred due to foreclosure where the owner exercised a timely right or redemption in accordance with state law; or
- The circumstances of the acquisition present adequate assurance to FSA that the new owner did not acquire the land for the purpose of placing it in CRP.

Eligible Land

To be eligible for placement in CRP, land must be either:

- Cropland (including field margins) that is planted or considered planted to an agricultural commodity 4 of the previous 6 crop years from 1996 to 2001, and which is physically and legally capable of being planted in a normal manner to an agricultural commodity; or
- Certain marginal pastureland that is enrolled in the Water Bank Program or suitable for use as a riparian buffer or for similar water quality purposes.

Additional Cropland Requirements

In addition to the eligible land requirements, cropland must meet one of the following criteria:

- Have a weighted average erosion index of 8 or higher;
- Be expiring CRP acreage; or
- Be located in a national or state CRP conservation priority area.

CRP Payments

FSA provides CRP participants with annual rental payments, including certain incentive payments, and cost-share assistance:

- ***Rental Payments***

  In return for establishing long-term, resource-conserving covers, FSA provides annual rental payments to participants. FSA bases rental rates on the relative productivity of the soils within each county and the average dryland cash rent or cash-rent equivalent. The maximum CRP rental rate for each offer is calculated in advance of enrollment. Producers may offer land at that rate or offer a lower rental rate to increase the likelihood that their offer will be accepted.

- ***Maintenance Incentive Payments***

  CRP annual rental payments may include an additional amount up to $5 per acre per year as an incentive to perform certain maintenance obligations.

- ***Cost-share Assistance***

  FSA provides cost-share assistance to participants who establish approved cover on eligible cropland. The cost-share assistance can be an amount not more than 50 percent of the participants' costs in establishing approved practices.

- ***Other Incentives***

  FSA may offer additional financial incentives of up to 20 percent of the annual payment for certain continuous sign-up practices.

Ranking CRP Offers

Offers for CRP contracts are ranked according to the Environmental Benefits Index (EBI). FSA collects data for each of the EBI factors based on the relative environmental benefits for the land offered. Each eligible offer is ranked in comparison to all other offers and selections made from that ranking. FSA uses the following EBI factors to assess the environmental benefits for the land offered:

- Wildlife habitat benefits resulting from covers on contract acreage;
- Water quality benefits from reduced erosion, runoff, and leaching;
- On-farm benefits from reduced erosion;
- Benefits that will likely endure beyond the contract period;
- Air quality benefits from reduced wind erosion; and
- Cost.

For More Information

For more information on CRP, contact your local FSA office or visit FSA's Web site at: http://www.fsa.usda.gov/dafp/cepd/crp.htm

CONSERVATION RESERVE ENHANCEMENT PROGRAM

Farm Service Agency
Online

Fact Sheet

Electronic Edition

USDA United States Department of Agriculture

May 2003

Conservation Reserve Enhancement Program

Overview

The Conservation Reserve Enhancement Program (CREP) is a voluntary land retirement program that helps agricultural producers protect environmentally sensitive land, decrease erosion, restore wildlife habitat, and safeguard ground and surface water.

The program is a partnership among producers; tribal, state, and federal governments; and, in some cases, private groups. CREP is an offshoot of the country's largest private-lands environmental improvement program -- the Conservation Reserve Program (CRP).

Like CRP, CREP is administered by USDA's Farm Service Agency (FSA). By combining CRP resources with state, tribal, and private programs, CREP provides farmers and ranchers with a sound financial package for conserving and enhancing the natural resources of farms.

CREP addresses high-priority conservation issues of both local and national significance, such as impacts to water supplies, loss of critical habitat for threatened and endangered wildlife species, soil erosion, and reduced habitat for fish populations such as salmon. CREP is a community-based, results-oriented effort centered around local participation and leadership.

Eligibility

A specific CREP project begins when a state, Indian tribe, local government, or local nongovernment entity identifies an agriculture-related environmental issue of state or national significance. These parties and FSA then develop a project proposal to address particular environmental issues and goals.

Enrollment in a state is limited to specific geographic areas and practices. To determine if your state and county are involved in CREP and if your land qualifies, contact your local county FSA office.

Like CRP, CREP contracts require a 10- to 15-year commitment to keep lands out of agricultural production. CREP provides payments to participants who offer eligible land. A federal annual rental rate, including an FSA state committee-determined maintenance incentive payment, is offered, plus cost-share of up to 50 percent of the eligible costs to install the practice. Further, the program generally offers a sign-up incentive for participants to install specific practices.

FSA uses CRP funding to pay a percentage of the program's cost, while state, tribal governments, or other non-federal sources provide the balance of the funds. States and private groups involved in the effort may also provide technical support and other in-kind services.

Benefits

For the landowner, CREP is not just a cost-effective way to address rural environmental problems and meet regulatory requirements; it can provide a viable option to supplement farm income as well.

CREP is convenient for producers because it is based on the familiar, highly successful CRP model. Land must be owned or leased for at least one year prior to enrollment to be eligible, and must be physically and legally capable of being cropped in a normal manner.

Land must also meet cropping history and other eligibility requirements. Enrollment can be on a continuous basis, permitting farmers and ranchers to join the program at any time rather than waiting for specific sign-up periods.

CREP supports increased conservation practices such as filter strips and forested buffers. These conservation practices help protect streams, lakes, and rivers from sedimentation and agricultural runoff.

CREP also helps landowners develop and restore wetlands through the planting of appropriate groundcover. Restoring water regimes helps protect national treasures like the Chesapeake Bay, Mammoth Cave, and the Florida Everglades. By maintaining clear goals and requiring annual monitoring, CREP helps participants measure progress and ensure success.

For More Information

For more information on CREP, contact your local FSA office or Soil and Water Conservation District office. Additional information is also available on FSA's Web site at: http://www.fsa.usda.gov

Farm Service Agency *Online*

Fact Sheet

USDA United States Department of Agriculture

Electronic Edition

October 1998

Conservation Reserve Program

Washington State Enhancement Program

Background

USDA's Farm Service Agency (FSA), Commodity Credit Corporation (CCC), and the State of Washington have agreed to implement a voluntary Conservation Reserve Enhancement Program (CREP) to improve the water quality of streams providing habitat for salmon species listed under the Federal Endangered Species Act.

The project area includes all streams in Washington crossing agricultural lands providing spawning habitat for the endangered salmon species.

Program Authorities

The Washington State Enhancement Program is authorized to enroll up to 100,000 acres to be devoted to riparian buffers planted to trees.

Program Responsibilities

CCC will pay applicable land rental costs, 50 percent of the cost of establishing conservation practices, an annual maintenance incentive, and a portion of the costs of providing technical assistance.

The State of Washington will pay 37.5 percent of the cost of establishing conservation practices, all the costs of the annual monitoring program, and a portion of the technical assistance costs.

Payments and Incentives

Annual rental payments will be based on the soil rental rate, as calculated by FSA.

For installing the riparian buffer, producers will receive each year an incentive payment 50 percent above the annual per acre rental rate.

Additionally, producers will receive a 10-percent incentive payment for lands protected as agricultural lands under the Washington Growth Management Act.

Eligible Practices

The eligible CRP practice will be CP 22 (Riparian Buffer Area)

Producers may also offer eligible acreage for general or continuous CRP signup.

Eligibility

In addition to offering acreage along salmon streams, the application must satisfy the basic eligibility criteria for CRP.

Land must be cropland that has been cropped 2 out of the past 5 years that is physically and legally capable of being cropped. Marginal pastureland is also eligible to be enrolled provided that it is suitable for use as a riparian buffer planted to trees.

Producers are eligible if the land has been owned or operated for at least one year prior to enrollment. Land with an existing CRP contract or an approved offer with a contract pending is not eligible for CREP until that contract expires.

CREP enrollment will be on a continuous basis beginning January 1, 1999. Producers can sign up at the local USDA Service Center.

Information about CREP is available at State FSA offices and the FSA website at www.fsa.usda.gov/dafp/cepd/crpinfo.htm

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USDA NEWS RELEASE

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Release No. 0431.98

Backgrounder

Washington Conservation Reserve Enhancement Program

Questions and Answers

What is the Conservation Reserve Enhancement Program?

The Conservation Reserve Enhancement Program (CREP) is a joint federal and state land retirement conservation program that targets significant environmental effects related to agriculture. It is a voluntary program that uses financial incentives to encourage farmers and ranchers to enroll in the Conservation Reserve Program (CRP) in contracts of 10 to 15 years duration to remove lands from agricultural production.

What is the Washington State CREP?

The Washington CREP, developed to assist in the restoration of habitats for salmon listed under the Federal Endangered Species Act, will restore freshwater riparian habitat along as many as 3,000 miles of salmon streams throughout Washington State. It is a federal and state agreement to retire environmentally sensitive agricultural land through the Conservation Reserve Program.

What are the goals of the Washington State CREP?

Washington State and USDA have jointly developed several goals for the program, including –

Reducing water temperature to natural ambient conditions

Reducing sediment and nutrient pollution from agricultural lands adjacent to the streams by more than 50 percent

Stabilizing streambanks along critical salmon streams

Restoring stream hydraulic and geomorphic conditions on 3,000 miles of streams

Washington State will conduct monitoring throughout the project to evaluate and record progress in achieving these goals.

What areas in Washington State are included in the program?

The project area consists of all streams in Washington across agricultural crop and marginal pasture lands that provide spawning habitat for salmon species that have been listed under the Federal Endangered Species Act. It is estimated that there are several thousand miles of such streams. The program provides for enrollment of up to 100,000 acres that will generally consist of riparian buffers up to 150 feet in width.

What are the benefits of the Washington State CREP?

CREP will provide a number of significant environmental benefits to Washington State and to its salmon. The establishment of forested riparian buffers will help restructure streams and increase the availability of insects and other salmon food. Trees along streams will provide shade and reduce the rate of solar water heating. And riparian buffers will reduce pollution and improve stream water quality.

What is the cost?

For enrollment of 100,000 acres, the total financial obligation will be approximately $250 million over 15 years, with $210 million coming from the USDA, and the balance from the State and producers.

Which conservation practice will be used?

Riparian buffers, an area of trees and/or shrubs adjacent to and up-gradient from water bodies, will be planted.

Who can signup for the Washington State CREP and when?

Enrollment for the Washington State CREP will be on a continuous basis beginning this winter. In addition to offering acreage along salmon spawning streams, the applicant must satisfy the basic eligibility criteria for CRP. Land must be either cropland or marginal pasture land. Cropland must have been planted to crops two of the past five years and be physically and legally capable of being cropped. Marginal pasture land can be enrolled provided it is suitable for use as a riparian buffer planted to trees. Producers are eligible if the land has been owned or operated for at least one year prior to enrollment. Lands that have an existing CRP contract or an approved offer with a contract pending are not eligible for CREP until that contract expires.

What are the payments under CREP?

There are three types of payments for which participants in the Washington State CREP will be eligible: annual rental payments, financial assistance in the installation of the conservation practices, and annual maintenance payments.

The annual rental payment will be based on the soil rental rate, as calculated by USDA's Farm Service Agency. Producers will receive an incentive payment above the mean annual per acre rental rate of 50 percent for the installation of the riparian buffer. Additionally, producers will receive a 10 percent incentive payment for lands protected as agricultural lands under the Washington Growth Management Act. USDA's Commodity Credit Corporation will pay 50 percent of the cost of installing conservation practices (installing new vegetation, fencing, etc.) and the State will pay 37.5 percent of the cost of the conservation practices. Participants will receive $5 per acre for an annual maintenance incentive payment.

Where can people get more information about the Washington CREP?

They should contact their local USDA Service Center, Soil and Water Conservation District, or the State of Washington's Conservation Commission. Information can also be obtained from the FSA web site at

#

October 19, 1998

Return to Release Index

APPENDIX 4-A

CITY OF FORKS FIELD VISIT NOTES

May 21, 2005

Tim White of Golder Associates, Inc. makes a field visit to Forks, WA. The goal of the field visit is to identify types of glacial geology and locate any outcrops of bedrock.

Tim visits approximately two dozen locations, most located along roads in the area and notes the geology (till, bedrock, outwash, etc). Of interest is the till cap on the Quillayute Prairie. It is unclear if the whole thickness of the Prairie is comprised of till, but it is present at least at the top one-third of the hill. The till is extremely well consolidated (it would be difficult to dig with a shovel) and extends at least to the southern edge of the Quillayute Prairie. The conceptual model of the Quillayute Prairie may be one of a former till plain eroded from the south by the Sol Duc River.

May 22, 2005

Tim meets Dave Zellar (City of Forks Public Works Director) to measure the water levels in the City's wells. Tim also measures the water level in the monitoring wells at the treatment plant. Dave takes Tim to the Forks Municipal Airport to measure the static water level on the oil exploration hole next to the runway. The depth of the well is unknown and Dave has never seen a borehole log for it. The static water level of the well is much deeper than the City's wells (~277 feet bgs) and methane gas (?) bubbled out of the well as the valve was opened.

Dave then takes Tim to the Quillayute Airport to measure the static water level in the well that NOAA uses for their work. Dave and Tim then return to City Hall to identify any other materials that may be of use to the study. Dave will gather pumping records, well videos and any other well info that might be useful.

Following his meeting with Dave Zellar, Tim hikes to the elongate hill north of the City and finds a view of a scarp on the west end of the hill overlooking the Quillayute River. The vegetation has been removed by erosion and there does not appear to be any exposed bedrock on the hill.

May 24, 2005

Tim White returns to Forks in order to conduct short pumping tests on the City's wells in order to determine the specific capacity of the wells, estimate aquifer parameters and determine if there is any influence between the City's wells. A pressure transducer was installed in Well 1 to measure water levels throughout the pumping tests. Short (30-minute) pumping tests were conducted in Wells 2, 3, and 4 in order to determine specific capacity of each of the wells. A 1-hour pumping test was conducted in Well 5 in order to determine specific capacity and if there was any drawdown in the Tillicum Park Wells (Wells 1, 2, and 3). Following the specific capacity tests, Well 3 was pumped for approximately 17 hours in order to determine aquifer response.

May 25, 2005

Tim White shuts off the pump in Well 3 and measures recovery of the well from the overnight pumping test. Following approximately two hours of recovery, Tim drives out to the airport to canvas well owners and measure water levels in several wells in order to determine flow direction. Tim meets with Jack Hines, Greg Senderhauf and Candy Hendrickson and measures water levels in three wells. In the afternoon, Tim returns to Forks to meet with Dave Zellar in order to measure water levels in two domestic wells (Jerry King and David Haight). Following this, Tim measures the water levels in the City's wells and returns to the Quillayute Airport to measure more wells.

Tim meets Oscar Fields and measures the water level in his well. There is no log for the well but he thinks that it is about 100 to 110 feet deep. Oscar then takes Tim to an old well used by the base. The pump base is still attached to the wellhead, but the water level cannot be measured in it. The airline is too heavy to be lifted and moved in order to sound the water level. Mr. Fields takes Tim to see the outfall from the storm drain draining runoff from the airport. The outfall from the pipe has excavated an approximately 40-50 foot cliff exposing the till which comprises Quillayute Prairie.