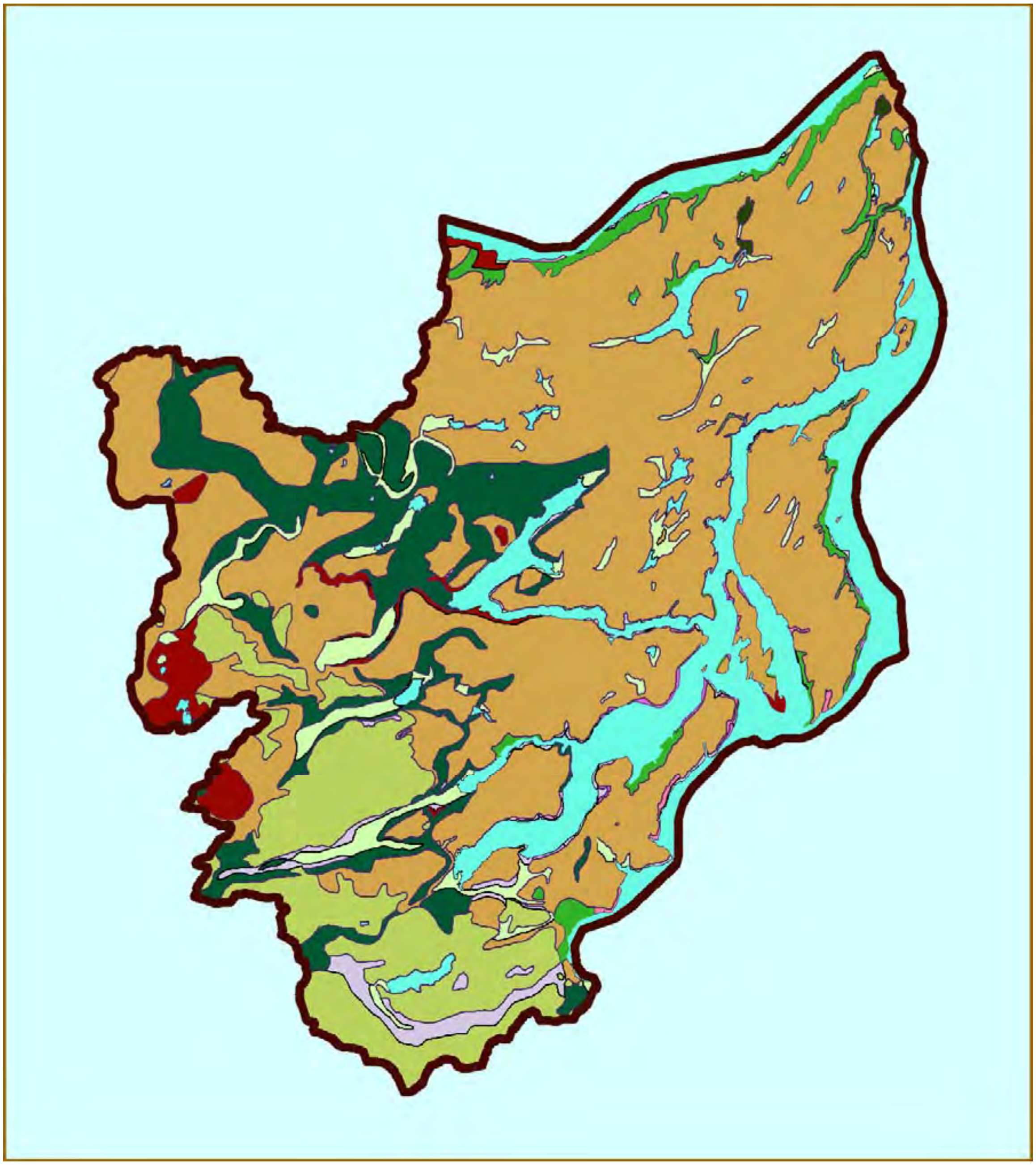

Final WRIA 14 / Kennedy-Goldsborough Watershed Phase II Hydrogeologic Investigation

NORTHWEST Land & Water, INC.
Consulting in Hydrogeology

Submitted to the WRIA 14 Planning Unit December 31, 2005
Prepared under Grants G0300042 & G0000107

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December 31, 2005

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1.0 Executive Summary

➲ *Section 7.0 presents recommendations for monitoring, future groundwater development, and quantifying pumping impacts.*

As part of ongoing regional watershed planning efforts, several hydrogeologic investigations have been conducted in Water Resource Inventory Area (WRIA) 14, the Kennedy-Goldsborough watershed. This Phase II investigation expands on earlier work near Shelton, Washington, and focuses on water resources within a 10-square-mile area. It entailed three major tasks that not only improved our understanding of the study area's hydrogeology but also yielded data for future studies:

- Refining the preliminary conceptual model of the focus area's hydrogeology.
- Monitoring water levels to assess aquifer responses to natural and induced stresses.
- Collecting water samples and analyzing them for chemical parameters and environmental isotopes. The isotope samples provided information about the age and flow patterns of groundwater in the focus area.

All Washington Department of Ecology (Ecology) well records from within the focus area were incorporated into a project database; this data was supplemented with information from *Water Supply Bulletin 29* (Molenaar and Noble, 1970). In addition, many wells were surveyed in the field to obtain accurate location and elevation information. Drillers' well logs were analyzed to identify the hydrogeologic contacts corresponding to the tops and bottoms of key aquifers and aquitards. Hydrogeologic and water level information was added to the project database and linked to *Viewlog*, a software application used to develop a three-dimensional conceptual model.

1.1 Hydrostratigraphy

A set of seven cross-sections was used to refine our understanding of the focus area's hydrostratigraphy. Four of these sections were developed for this Phase II investigation; the other three were modified from Phase I work based on newly acquired data.

In general, the hydrogeology of this area is characterized by a complex, alternating sequence of sediments deposited by glaciers, streams, and lakes. Six units (A through F) were identified during Phase I investigations. Of these, three units—A, D, and F—typically form the aquifers that supply water for drinking and other purposes. Units B, C, and E usually form aquitards, which impede the flow of groundwater.

All six units appear in the focus area, in varying thicknesses and at varying depths. However, the thickness of hydrogeologic units in glacial environments can change radically within relatively small lateral distances. This condition was observed for Unit D, which thins from more than 100 to 0 feet within one-quarter mile. The cross-sections also indicate that the texture of the hydrostratigraphic units is inconsistent, another characteristic of glaciation in this area. For example, some wells appear to be completed in permeable strata within Unit B, which is generally considered to be poorly permeable.

Unit F is of particular interest. It contains an uppermost aquifer, known as the Sea Level Aquifer, along with a deeper aquifer. Because these aquifers may be less hydraulically connected to surface water bodies, they are more attractive for future groundwater development than shallower units. In parts of the focus area, however, Unit F occurs near land surface instead of at depth. This unit is typically separated from land surface by some or all of Units A, B, C, D, and E—a sequence that includes some thick, low-permeability units. However, it is directly overlain by Unit A in the lower Goldsborough Creek / downtown Shelton and Johns Creek vicinity, near where these creeks discharge into Oakland Bay. Receding glaciers probably removed Units B, C, D, and E in this area.

1.2 Water Level Monitoring & Analysis

Monitoring for this project entailed two main components. One was obtaining "snapshots" of water-level conditions in 32 wells during fall 2004 and spring 2005. These wells were completed in Unit D and F. The other monitoring component involved measuring water levels in four wells (the Dittmer, Hiapark, Maple Glen, and City of Shelton (COS) test wells) over a 6-month period. The goal was to assess how nearby pumping and natural stresses affect groundwater levels.

1.2.1 Fall & Spring Snapshots

Water-level elevation maps ("snapshot" maps) were prepared for three aquifers—Unit D, Unit F, and the very deep part of Unit F. The fall and spring maps were then compared to assess seasonal patterns in the groundwater flow system.

The water-level contour maps all indicate that groundwater flows toward Oakland Bay. It is likely that some groundwater in the deeper part of Unit F discharges to the bay. Groundwater flow in the focus area also has a strong downward component.

1.2.2 Long-Term Monitoring

Hydrographs were prepared for the long-term monitoring wells. The water level trends were compared to possible "stressors"—pumping from nearby COS and Port of Shelton (POS) wells, precipitation, marine tides, and barometric pressure. In addition, Johns Creek stage data was compiled and compared to water levels in the Dittmer well, which is located nearby.

The Dittmer well is completed in Unit D, which appears to be semiconfined at this location based on barometric data. This well responded strongly to tidal fluctuations but not to short-term pumping at the POS well. Water levels in the Dittmer well changed in response to precipitation after about 3 weeks.

The Maple Glen well is completed in Unit A, which appears unconfined at this location based on barometric data. This shallow well showed no response to tidal fluctuations or to pumping at the COS wells. Water levels in the Maple Glen well responded to precipitation after only 1 day—just as expected for a shallow, unconfined aquifer.

The Hiapark well appears to be completed in a confined portion of Unit D, based on barometric data. This well showed no response to tidal fluctuations or to pumping at the POS well. However water levels fluctuated constantly, in response to an intermittent stress from a nearby small water system well. Although water levels in the Hiapark well changed after precipitation, the response was very dampened.

The COS test well is completed in the very deep portion of Unit F, which appears to be a confined portion based on barometric data. This well showed a strong response to tidal fluctuations, a small response to pumping COS Well 1, and no response to pumping COS Well 3.

Note that a lack of response to pumping does not necessarily indicate a lack of hydraulic connection. Additional monitoring, testing, and/or analyses are required in some cases to verify the responses described above.

1.3 Water Chemistry

Water samples were analyzed for routine constituents and for stable isotopes of oxygen and hydrogen. These samples were collected from Johns Creek and from wells that are completed in various aquifers. Five groundwater samples were also analyzed for carbon-14 and tritium to provide information about their age.

The results show that the samples all have similar chemical characteristics; consequently, using routine chemistry to differentiate groundwater by aquifer is difficult. The isotopic signatures of the Johns Creek samples are relatively heavy compared to those of the deep groundwater samples. This indicates that Johns Creek water likely originates primarily from local, low-elevation precipitation. A secondary component of Johns Creek is groundwater discharge from shallow aquifers.

Most groundwater samples from the deep Unit F had a light isotopic signature. This suggests that, unlike the Johns Creek water, groundwater in Unit F originates at a higher elevation outside the study areas. The isotopic signature of water from some Unit F wells was similar to signatures in Unit D wells, indicating local mixing between aquifers.

Tritium was detected in all five sampled wells. Carbon-14 ages ranged from about 100 to almost 3,000 years old. These data corroborate the stable isotope results, which show that in some areas groundwaters from Unit D and F are mixing. The relatively old carbon-14 ages also support the notion that some recharge to the groundwater system occurs well outside the study area.

1.4 Hydraulic Continuity & Relative Risk

Using the results of the hydrostratigraphy, water level, and hydrogeochemistry work, five areas were examined to assess their potential for hydraulic continuity. A relative risk was assigned for each area based on the potential effects of developing groundwater in Unit F.

The area offering the lowest potential risk to surface (fresh) water is the Oakland Bay vicinity. Areas of moderate potential risk include the COS Wells 1 and 3, and lower Goldsborough Creek / downtown Shelton vicinities. The Johns Creek vicinity offers the highest potential for hydraulic continuity.

2.0 Introduction

This document summarizes the results of a hydrogeologic investigation conducted in WRIA 14, the Kennedy-Goldsborough watershed, as part of ongoing regional watershed planning efforts. This investigation expands on a previous study—a preliminary (Phase I) hydrogeologic characterization conducted by Northwest Land & Water (NLW) in fall 2004 for a 60-square-mile area near Shelton, Washington. The Phase II study described in this report characterizes water resources within a "focus area" of about 10 square miles. **Figure 2-1** shows the extent of WRIA 14, along with both the Phase I and II study area boundaries.

This work satisfies the requirements of Step B of *Instream Flow Grant #G0300042* and *Watershed Base Grant #G0000107*. Both grants were awarded to Mason County by Ecology to characterize the WRIA's hydrogeologic conditions, particularly the interactions between surface water and groundwater. The study results will provide information planners can use to make decisions about groundwater withdrawals and their potential effects on surface water.

2.1 Purpose

Adequate supplies of good-quality water are essential to WRIA 14's economic and environmental viability. People, fish, and wildlife depend on the availability of water in certain quantities for a variety of uses such as drinking, industrial processing, or—in the case of salmon—spawning and other life stages. The Shelton area features not only potentially developable land but also salmon streams. Land development could require new groundwater supplies in the future; new supplies must be developed in way that minimizes or prevents impacts to streams.

The ultimate goal of hydrogeologic characterization work in WRIA 14, therefore, has been to provide a sound scientific basis for making decisions about water resources. One major goal of this Phase II investigation has been to characterize the hydrogeology of the focus area in more detail than previous studies. Another has been to characterize groundwater flow patterns and aquifer hydraulic properties using data collected specifically for this investigation. The Phase II investigations and data-collection activities were designed to address knowledge gaps about:

- Aquifers that lie below sea level
- Relationships between aquifers and streams
- Aquifer responses to induced stresses such as pumping and natural stresses such as seasonal climate variations
- Areas where future withdrawals would have minimal impacts on instream flows

2.2 Scope of Phase II Investigations

Work for this project was outlined in *Scope of Work: WRIA 14 / Kennedy-Goldsborough Watershed Preliminary Hydrogeologic Characterization for Instream Flow Grant* (NLW and PTCS, 2004b), which was finalized and submitted to the WRIA 14 Planning Unit in May 2004. It entailed three major components that not only improved our understanding of the study area's hydrogeology but also yielded data that could be used in future studies:

- Refining the preliminary conceptual model of the focus area's hydrogeology.
- Monitoring water levels in wells to assess aquifer responses to natural and induced stresses.
- Collecting water samples and analyzing them for various chemical parameters and envi-

ronmental isotopes. These samples provided information about the age and flow patterns of groundwater in the focus area.

Section 3.0 of this report describes the methods and results of the detailed hydrogeologic characterization. Section 4.0 discusses the water level monitoring and Section 5.0 presents the chemistry results. Section 6.0 synthesizes all the results and discusses hydraulic continuity. Section 7.0 presents recommendations for future work.

2.3 Phase I & II Study Areas

Located in the southeastern corner of the Olympic Peninsula, the Phase I study area is bounded to the northwest and southeast by narrow arms of Puget Sound (**Figure 2-1**). It covers about 60 square miles in the Kennedy-Goldsborough watershed and contains all or part of several smaller watersheds in WRIA 14:

- The north portion of Goldsborough Creek
- Shelton Creek
- Johns Creek
- Cranberry Creek
- The lower portion of Deer Creek

The focus area delineated for Phase II, shown in more detail on **Figure 2-2**, includes Johns and Shelton Creeks. Some work was conducted in the downtown Shelton area, outside the focus area boundary. This area was included after the Phase II boundary was established because the Planning Unit recognized that it may supply part of Shelton's water in the future.

2.4 Warranty

This work was requested by the WRIA 14 Planning Unit and completed by the NLW team. It was performed, and this draft report was prepared, in accordance with hydrogeologic practices generally accepted at this time, in this area, for the exclusive use of the WRIA 14 Planning Unit, for specific application to the study area. No other warranty, express, or implied, is made.

3.0 Hydrostratigraphy

The study areas for the Phase I and II hydrogeologic investigations are covered by a complex sequence of interbedded glacial and nonglacial deposits. These unconsolidated sediments overlie bedrock, which crops out at land surface in some places—specifically, in the southwest corner of the study area—but occurs at great depth in other places.

This section summarizes the local and regional hydrostratigraphy based on the work presented in *Draft WRIA 14 / Kennedy-Goldsborough Watershed, Preliminary Hydrogeologic Characterization and Work Plan* (NLW and PTCS, 2004a) for the Phase I study. It also presents new findings for the Phase II focus area.

3.1 Regional Context & Classification

In general, the upper glacial sediments correspond to Vashon events and the deeper sediments correspond to pre-Vashon events. The Vashon glacial deposits can be grouped into four distinct units (from highest to lowest in the sequence):

- Coarse-grained recessional outwash
- Till and compacted deposits
- Fine-grained lacustrine deposits
- Coarse-grained advance outwash

The lower, pre-Vashon deposits consist of clay and silt alternating with layers of sand and gravel and local till. These units likely originated during more than one glacial event—they are separated by nonglacial deposits. The uppermost nonglacial unit is commonly referred to as the Kitsap formation or, more recently, as Qps (pre-Vashon sand). The sand and gravel of the upper pre-Vashon glacial deposits correspond to what is commonly referred to as the Sea Level Aquifer. Few wells tap the units that underlie the Sea Level Aquifer, and little is known about these deep aquifers.

Note that the glacial stratigraphy of south Puget Sound has been classified under several different nomenclature systems. Two of these systems are referenced in this report. The U.S. Geological Survey (USGS) nomenclature, which has been used widely for many years, is most recently reported in *Professional Paper 1424-C* (Jones, 1999). In 2003, the Washington Department of Natural Resources (WDNR) published a map of the Shelton Quadrangle (Schasse et al., 2003). This map uses different nomenclature from that of the USGS. The descriptions that follow reference both classification systems.

3.2 Hydrogeologic Units

Because the study area lies at the southern extent of continental glaciation in the Puget Sound region, it was often occupied by the terminus—or endpoint—of each advancing or retreating glacier. In areas that lie far from termini, glaciers leave a distinctive sequence of advance, till, and recessional deposits. On the other hand, in areas near the glacier's terminus, this "classic" sequence is far less obvious because advancing and retreating events leave a less predictable mixture of layered sands, gravels, silt, clay, and till. Other processes can cause units to be locally discontinuous or to vary widely in thickness over small lateral distances. Such processes include the scouring of waterfalls and the deposition of sediments in deep glacial lakes.

These variations are apparent beneath the study area, where hydrogeologic units sometimes pinch out completely or change dramatically in thickness. For example, one unit comprises till and compacted or cemented sand, gravel, and silt. In some areas, it attains thicknesses of more than 100 feet. Stratigraphically, this unit correlates to Vashon till. However, Vashon till does not generally attain such thicknesses, so these sediments are likely a combination of till and other "hard" or cemented deposits.

Sediments may also contain relatively small-scale lateral variations that are related to historic seismic events. Through detailed mapping, the Squaxin Island Tribe has identified what appears to be faults in outcrops along the lower reach of Johns Creek. Faults may control groundwater flow from shallow aquifers to creeks, which in turn may promote the formation of habitat for fish. Other researchers have recently identified surficial faults and folds near Olympia that may be related to the Olympia "structure," a north-west trending bedrock fault or fold that extends beneath the Shelton area (Pratt, personal communication, 12/13/05).

Identifying units that correlate to distinct glacial events is difficult in the Phase I and II study areas. Consequently, hydrogeologic units were classified based on their water-bearing potential and relative depth rather than on the formally accepted nomenclature for Puget Sound glacial stratigraphy. Six units—A, B, C, D, E, and F—were identified. They are described below and summarized in **Table 3-1**. The composition of Units A through F alternates between high- and low-permeability materials.

3.2.1 Unit A

Unit A, the uppermost aquifer, consists of sand and/or gravel, with local zones of less permeable clay, silt, and fine sand. It ranges from 0 to about 120 feet in thickness. Locally, Unit A pinches out where the underlying unit is exposed at land surface.

Under the USGS nomenclature (Jones, 1999), some or all of Unit A may be classified as Quaternary Vashon recessional outwash (Qvr). Under the WDNR nomenclature (Schasse et al., 2003), it may be classified as Quaternary glacial outwash (Qgo).

Many wells are completed in Unit A, which yields significant quantities of water in areas where it is sufficiently thick and saturated. Locally, groundwater in this unit may interact with surface water in creeks; Unit A may discharge to creeks as baseflow or it may receive recharge via creek bed seepage.

3.2.2 Unit B

Unit B, the uppermost aquitard, contains till and other "hard" sediments. Generally poorly sorted and described in well logs as "till," "hardpan," or "cemented," this unit locally contains zones of sand and/or gravel that yield water to wells. It ranges from 0 to 170 feet in thickness. Unit B occurs throughout most of the study area. However, it pinches out locally and it is not apparent from driller's logs.

Under the USGS nomenclature (Jones, 1999), some or all of Unit B may be classified as Quaternary Vashon recessional till (Qvt). Under the WDNR nomenclature (Schasse et al., 2003), it may be classified as Quaternary glacial till (Qgt).

Unit B typically does not yield significant quantities of water to wells.

3.2.3 Unit C

Unit C, the intermediate aquitard, is fine-grained and low in permeability. Ranging from 0 to 180 feet in thickness, this unit contains deposits of clay and silt with some sand. Although Unit C underlies part of the study area, it is absent beneath much of it.

Under the USGS nomenclature (Jones, 1999), some or all of Unit C may be classified as Quaternary Vashon lacustrine deposits (Qvl). Under the WDNR nomenclature (Schasse et al., 2003), it may be classified as a fine-grained part of Quaternary Vashon advance outwash (Qga).

Unit C typically does not yield significant quantities of water to wells.

3.2.4 Unit D

Unit D, the intermediate aquifer, consists of sand and/or gravel with local zones of clay, silt, and fine sand, which are lower in permeability. It ranges from 0 to 255 feet in thickness. Unit D occurs throughout most of the study area; however, it appears to thin and pinch out in the eastern part.

Under the USGS nomenclature (Jones, 1999), some or all of Unit A may be classified as Quaternary Vashon advance outwash (Qva). Under the WDNR nomenclature (Schasse et al., 2003), it may be classified as Quaternary Vashon advance outwash (Qga).

Many of the study area wells are completed in Unit D, which yields significant quantities of water in areas where it is sufficiently thick and saturated.

3.2.5 Unit E

Unit E, the deepest identified aquitard, consists predominantly of fine sand and silty sand with local gravel zones and occasional peat or wood. It is generally believed to be nonglacial in origin. The data available for characterizing this unit is limited to logs for deeper wells, which indicate that Unit E is laterally extensive beneath the study area.

Under the USGS nomenclature (Jones, 1999), some or all of Unit E may be classified as Quaternary Kitsap formation or Olympia beds (Qk). Under the WDNR nomenclature (Schasse et al., 2003), it may be classified as Quaternary pre-Fraser deposits (Qpf and Qps), which are nonglacial and pre-Vashon in origin.

Unit E typically does not yield significant quantities of water to wells.

3.2.6 Unit F

Unit F, the deepest identified unit, comprises a thick sequence of undifferentiated glacial deposits—till, outwash, lacustrine—as well as nonglacial deposits. It occurs throughout the study area, ranging in thickness from 0 (where it meets the bedrock in the southwest) to approximately 1,000 feet in the northeast.

The uppermost part of this unit may contain saturated sand and/or gravel that has been classified as the Sea Level Aquifer (Qc) under the USGS nomenclature (Jones, 1999). A glacial till locally overlies this aquifer (note: where this till is present it has been mapped in the overlying Unit E). This Sea Level Aquifer overlies Quaternary undifferentiated deposits (Qu). Under the WDNR nomenclature, the upper portion of Unit F has been classified as Quaternary pre-Vashon gravel (Qpg).

Many wells are completed in Unit F, which yields significant quantities of water in areas where a highly permeable layer is sufficiently thick.

3.2.7 Bedrock

Bedrock—that is, consolidated volcanic and sedimentary rock—underlies the unconsolidated sediments, effectively forming a hydraulic boundary. The bedrock surface is defined as the "top of basement" (Jones, 1999). Bedrock is exposed at land surface in the southwestern corner of the study area, where at least two wells are known to penetrate these materials. The bedrock surface is based on three data sources:

- Well logs
- Surface exposures
- Information from Jones (1999)

Elevations from these three sources were added to the project database and used to generate the bedrock surface.

3.3 Focus Area Hydrostratigraphy

This section presents the work involved in refining the conceptual hydrogeologic model of the Phase II focus area. Note that three cross-sections were originally prepared as part of the Phase I investigation; four additional sections were prepared for this investigation. As a consequence of acquiring new subsurface information, the three Phase I sections required modification. Phase II entailed reviewing data from water well reports, well logs, and reports (published and unpublished). This new this new information was then incorporated into a conceptual model.

3.3.1 Methodology

3.3.1.1 Data Sources

Digital elevation data was obtained from the University of Washington's Geospatial Database. The grid consists of square cells that measure 30 meters per side. Geographic Information Systems (GIS) coverages of the area's surficial geology and hydrography came from WDNR. About 75 wells were considered in the Phase I investigation; these wells were selected because they were the deepest from each square-mile section of the study area. About 264 wells within the focus area were added to the database for Phase II work, increasing the total to 339. These wells are listed in **Appendix A**. Wells that were monitored or used in cross-sections are identified by a "field name," which reflects the current owner if different from the name on the well log. Data was compiled from three sources:

- The well database available from the Ecology Web site (Ecology, 2003)
- Consultant reports (Hart Crowser, 1979; Parametrix, 2002).
- *Water Supply Bulletin 29*, a report authored and published by WDNR (Molenaar and Noble, 1970)

3.3.1.2 Well Log Analysis

All the wells from Ecology's database within the focus area were included in the Phase II database. Ecology identifies well locations to the nearest quarter-quarter section, an area typically covering about 40 acres. Wells were assumed to be centered within this area, and the digital elevation at this central point was assumed to be the wellhead elevation. Many wells were surveyed to obtain accurate location and elevation information[1]. In some cases, unsurveyed wells were located a known distance from surveyed ones. Their locations in the database were modified based on those of the nearby surveyed wells.

The drillers' log for each well was printed and compiled into a notebook for reference. Well logs were analyzed and simplified to reflect the texture, cementation, and other characteristics of materials observed during drilling. Materials were classified as:

- Sand and gravel
- Silty sand
- Till and cemented or "hard" deposits
- Sandy clay
- Clay and gravel
- Clay
- Bedrock

[1] *These wells were selected for surveying because they were included in the sampling or monitoring network. The location information for these wells reflects the survey data; as such, it generally differs from the digital elevation obtained from the GIS coverage for that location.*

From these classifications, hydrogeologic contacts corresponding to the tops and bottoms of key aquifers and aquitards were identified. This information, along with screen interval and water level, was entered into an *Access* database and linked to the software application *Viewlog*, as described below.

3.3.1.3 Cross-Section Development

Cross-sections were prepared using *Viewlog*, which allows users to store and examine well log data. More importantly, it allows them to specify hydrogeologic contacts and other information so *Viewlog* can construct a three-dimensional model of the subsurface. *Viewlog* uses the hydrogeologic contacts identified during the well log analysis to create a series of surfaces that correspond to the key hydrogeologic units, extrapolating between data points. Users can import GIS and other digital data. *Viewlog* is dynamically linked to an *Access* database that has been developed to manage all the hydraulic and hydrogeologic data for WRIA 14. For this project, digital elevation, geologic, and hydrographic data were imported and integrated into the model.

Note that the cross-sections were prepared to identify key hydrostratigraphic units. The actual geology of the area is more complex; however, this scope of work did not include field investigation and mapping. The Squaxin Island Tribe has collected some detailed geologic field data. Section 7 includes recommendations to synthesize the Tribe's data with the project conceptual model.

3.3.2 Interpretation

Figure 3-1 shows the well locations and cross-section alignments, which illustrate the subsurface relationships between key hydrogeologic units. **Figures 3-2 through 3-8** correspond to cross-sections A-A′ through G-G′. The wells along each section are identified by the borehole identification (BHID) number used in the project database. The BHID corresponds to Ecology's internal tracking number, or "well log ID." Wells from sources other than Ecology were assigned a BHID. The cross-sections show land-surface elevation based on the digital elevation data along the trace of the section. In some cases, the surveyed wells plot above or below the land surface profile.

3.3.2.1 Alignments

Cross-sections A-A′, B-B′, and C-C′ show the hydrostratigraphy beneath the Phase I study area but also cover the Phase II focus area (**Figure 3-1**). Sections D-D′, E-E′, F-F′, and G-G′ show hydrostratigraphic details beneath the focus area. D-D′ trends roughly southwest-northeast through the northern half of the focus area. E-E′ traverses the southeast boundary of the focus area, almost paralleling Oakland Bay. F-F′ trends north-south through the eastern part of the focus area, along Shelton Creek, and extends north to the Phase II study area boundary. G-G′ trends along Johns Creek, into Oakland Bay. Cross-sections E-E′ and F-F′ intersect in the downtown Shelton vicinity, near the area where Shelton Creek meets Oakland Bay.

3.3.3.2 Notable Features

As discussed previously, the thickness of hydrogeologic units in glacial areas such as this can change radically within relatively small lateral distances. This condition is salient on G-G′ (**Figure 3-8**), where Unit D thins from more than 100 to 0 feet between the northern and southern parts of the section. The cross-sections also show the texture of stratigraphic units as inconsistent, reflecting the terminus nature of glaciation in this area. For example, some wells appear to be completed in permeable strata within Unit B, which is considered to be poorly permeable.

Sections E-E′, F-F′, and G-G′ (**Figures 3-6, 3-7, and 3-8**) show one of the most notable features in the area—the occurrence of Unit F near land surface. Unit F commonly lies at great depth beneath some or all of Units A, B, C, D, and E. It is commonly separated from land surface by thick, low-permeability units. Consequently, this unit is of interest because it may offer the most attractive option for development in areas where pumping from shallower aquifers could impact surface water.

However, this normally deep unit occurs close to land surface at wells in near downtown Shelton and Johns Creek vicinity, near the area where these creeks discharge into Oakland Bay. In this area, Unit F is directly overlain by Unit A. (Conversely, at wells located on the uplands or near creeks located far from Oakland Bay, Unit F lies at significant depth.) It is likely that during the last period of glaciation, Units B, C, D, and E were removed as the glacier receded but left outwash deposits along Shelton and Johns Creeks.

4.0 Water Level Monitoring & Analysis

Monitoring entailed two main components:

- Obtaining "snapshots" of water level conditions in select wells during fall 2004 and spring 2005 for the intermediate, deep, and very deep aquifers (Unit D and an upper and lower aquifer in Unit F)
- Measuring water levels in four wells over a long period to assess how nearby pumping and natural stresses affect groundwater levels

In addition, water levels were monitored in several wells during an infiltration test conducted as part of another study. **Figure 2-2** shows the locations of all the wells used in these analyses.

4.1 Methodology

All water level data for this project is maintained in an *Access* database and dynamically linked to *Viewlog*.

4.1.1 Well Selection & Field Inventory

After the hydrostratigraphy was refined, wells were selected for water level monitoring. First, *Viewlog* was used to identify wells completed in various aquifers in both the focus area and beyond. A list of potential candidates was then developed. Each candidate well was visited in fall 2004 to verify its existence, locate it, obtain access from the owner, and determine whether the water level in the well could be measured manually. Letters were presented to well owners to obtain permission to measure water levels; a sample of such a letter is included in **Appendix B**. Wherever possible, water level measurements were taken during this field inventory.

In addition, wells that could be outfitted with long-term monitoring equipment were noted. A major goal of this inventory was to identify unused wells that would provide nonpumping (static) water levels, which best reflect natural groundwater conditions.

Based on this work, a well network was finalized for the water-level snapshot measurements. These wells are listed on **Table 4-1**, which also includes information about their completion. Four additional wells were selected for long-term monitoring. Information about these wells is summarized in **Table 4-2**—their depth, general location, completion unit[2], and the presence of any nearby pumping wells.

4.1.2 Well Location Survey

Wells included in the monitoring network were surveyed to verify their location, land surface elevation, and measuring point elevation. Work was conducted by the Squaxin Island Tribe using a hand-held GPS unit. The accuracy of this survey is believed to be about 3 feet horizontal and 4 feet vertical.

4.1.3 Fall & Spring Snapshots

During the initial field inventory, water levels were measured in wells for which owners had granted access. Measurements were made using an electric water-level sounder; date and time were recorded. The data set obtained during this inventory was used to construct a series of maps showing the fall 2004 water-level snapshot. During late spring and early summer 2005, water levels in these wells were remeasured and used to construct the spring 2005 snapshot maps.

The water-level elevation maps (the "snapshot" maps) were prepared for three aquifers—Unit D

[2] *This term refers to the hydrostratigraphic unit in which the well is screened.*

(intermediate), Unit F (deep), and the very deep part of Unit F (very deep). Water-level elevations were calculated by subtracting the depth to water from the surveyed measuring point elevation for each well. For unsurveyed wells, the measuring point elevation was assumed to be the land surface elevation indicated on the digital elevation map.

The fall and spring maps were compared to assess seasonal patterns in the groundwater flow system. Results of this analysis are discussed in Section 4.2.1.

4.1.4 Long-Term Monitoring

Between January and March 2005, four wells were equipped with pressure transducers and electronic dataloggers for continuous, long-term monitoring (**Table 4-2; Figure 2-2**). In addition, a transducer and datalogger were configured to monitor barometric pressure at the same time interval used for the monitoring the wells.

The pressure transducers were the nonvented, vibrating-wire type manufactured by Geokon, Inc. Nonvented transducers provide better long-term data, since they are not prone to condensation in the vent tube; however, they sense changes in barometric pressure, which must be considered when interpreting the data, as discussed in Section 4.1.5.2.

Water levels were generally measured at 15-minute intervals, but data was downloaded from the single-channel dataloggers approximately every 6 to 8 weeks and stored in an *Excel* spreadsheet.

4.1.5 Data Compilation & Analytical Methods for Aquifer Stressors

Water levels in aquifers may be affected by a variety of forces, or “stressors,” including pumping from nearby wells, changes in barometric pressure, and changes in precipitation. If the aquifer is in hydraulic continuity with nearby creeks, water levels can also respond to changes in stage. Likewise, aquifers in nearshore areas may respond to fluctuations in daily tides. Each stressor must be quantified to accurately interpret the trends observed in water level data.

4.1.5.1 Pumping Data

Pumping data was obtained for the most significant water supply wells in the focus area: COS Wells 1 and 3, and Port of Shelton (POS) Johns Prairie (JP) Wells 1 and 2. Both the COS and POS place a high priority on reliably delivering water to customers. Therefore, pumping individual wells for extended periods was not possible during the high water-demand season. COS pumping data was collected for 5 weeks during April and May. POS pumping data was collected for a 3-week period in late May and early April. Pumping data is maintained in *Excel* spreadsheets.

COS Wells. Prior to this investigation, the COS wells were equipped with instantaneous and totalizer flow meters. Although these meters produce a milliamp (mA) signal, they were not configured to record digital flow data. Instead, pumping data was monitored visually and recorded. As part of this study, HOBO® dataloggers were purchased and installed in the existing flow meters for COS Wells 1 and 3. COS modified its meters so the datalogger could read and record the 4- to 20-mA digital signal. The dataloggers were used to record continuous COS data. A calibration equation was developed at the beginning of the monitoring period by correlating mA data collected at known pumping rates. Data collected during the remainder of the pumping period was converted from mA to gallons per minute (gpm) using this equation. Pumping data is maintained in *Excel* spreadsheets. NLW worked with COS well operations to control pumping from Wells 1 and 3. Typical operations allow both wells to pump simultaneously or individually. In an effort to differentiate effects on water level changes in nearby wells, NLW requested that Wells 1 and 3 be pumped individually for a period of weeks.

POS Wells. Because the POS flow meters do not produce a digital signal, a magnetic recording device was used to measure the flow rate of water moving from the pump column through the pipe. This device was rented and temporarily strapped to the pipe's exterior. This work was subcontracted to a local engineering firm that owns and operates an external magnetic flow meter. NLW worked with the POS to control pumping from JP Wells 1 and 2.

4.1.5.2 Barometric Pressure

Barometric pressure must be recorded whenever nonvented transducers are used to measure water levels in wells. For this study, a barometer station was established in the Hiapark pump house. It consists of a 2.5-psi, vibrating-wire pressure transducer that measures changes in barometric pressure rather than absolute values. Data was stored and collected using a single-channel Geokon datalogger. Barometric and water-level measurements were synchronized at about 15-minutes intervals. Water level data collected at each well was "corrected" by removing changes in barometric pressure. Barometric pressure was plotted on each hydrograph, where it could be compared to trends in these "corrected" water levels.

Changes in barometric pressure produce different responses in confined and unconfined aquifers. In unconfined aquifers, water levels in wells do not respond to barometric pressure, which acts equally on the water level in the well and the water level in the aquifer. Confined aquifers, on the other hand, respond inversely to changes in barometric pressure. In such aquifers, barometric pressure acts directly on the water level in the well, which is open to the atmosphere—but not on water level in the aquifer. When barometric pressure increases, for example, it exerts a downward force on the water in the well. In a confined aquifer, this force moves water from the high-pressure area in the well to the lower pressure of the adjacent aquifer.

A parameter known as barometric efficiency can be calculated for wells that respond to changes in barometric pressure. Barometric efficiency is a measure of the degree of this response. Theoretically, unconfined aquifers have a barometric efficiency of zero and confined aquifers have a barometric efficiency of 100 percent.

4.1.5.3 Precipitation

Precipitation changes can strongly affect water levels, particularly those in shallow aquifers. Hourly rainfall data for Shelton Airport was obtained from the Western Regional Climate Center or the Desert Research Institute[3]. This data is stored in the project database and converted to daily precipitation values. The daily values were plotted for comparison to water-level hydrographs.

4.1.5.4 Marine Tides

Marine tides were extrapolated for Shelton using Seattle tidal observations for Station ID 9447130 and a formula from the Steve Gill of the National Oceanic and Atmospheric Administration (NOAA; Steve Gill, personal communication, 2005). The Seattle tidal data was obtained from the NOAA website[4]. The tide at Shelton lags about 1.5 hours behind Seattle and has a diurnal range of about 14.2 feet, in contrast to Seattle's 11.4 feet. To estimate Shelton tides, the time of tides observed in Seattle was shifted by 1.5 hours and the amplitude was multiplied by a factor of 1.254. All the observed and extrapolated tidal data are maintained in an *Excel* workbook. The extrapolated Shelton tide levels were plotted for comparison to groundwater level hydrographs.

[3] *http:// www.wrcc.dri.edu*

[4] *http://tidesandcurrents.noaa.gov/data_res.html*

4.1.5.5 Johns Creek Stage Data

The Squaxin Island Tribe collects and maintains stage data for Johns Creek. This data was provided to NLW and stored in an *Excel* workbook. The Johns Creek stage data was plotted and compared to groundwater level in the Dittmer well, which is located nearby and completed in Unit D. Because no other wells near Johns Creek are completed in shallow aquifers, the relationship between stage and groundwater levels could not be assessed elsewhere.

4.1.6 Water-Reuse Infiltration Test

At the request of the Planning Unit, NLW monitored POS Well JP2 during an infiltration test that was conducted for the reclaimed water reuse and storage project (Cosmopolitan, 2005). Data was collected using a vented, vibrating-wire pressure transducer manufactured by Geokon. Testing occurred on August 10, 2005, and entailed pumping water from POS JP1 into a trench for 4 hours at a rate of 115 gpm. This trench was located about 1,500 feet west of Well JP2.

4.2 Results

Figures 4-1 through 4-6 show groundwater level contours and flow directions for various hydrogeologic units. **Figures 4-7 through 4-16** present 6-month hydrographs—which may also show barometric pressure, rainfall, and pumping data—for the Dittmer, Hiapark, Shelton Test, and Maple Glen wells. **Figure 4-17** compares the long-term monitoring data to marine tidal levels for Shelton.

4.2.1 Groundwater Flow Patterns

Figures 4-1 and 4-2 show water-level contours for Unit D in fall 2004 and spring 2005, respectively. **Figures 4-3 and 4-4** show contours for the upper part of Unit F for fall and spring. **Figures 4-5 and 4-6** are maps for the deeper part of Unit F for fall and spring.

4.2.1.1 Horizontal Flow within Aquifers

The contour maps all indicate that groundwater flows toward Oakland Bay. It is likely that some groundwater in the deeper part of Unit F discharges to the bay and the more distant and larger marine water bodies of Puget Sound.

Unit D. Groundwater in Unit D appears to flow southeast toward Oakland Bay. Most water levels in this aquifer range from about 150 to 250 feet above mean sea level (msl), except near Oakland Bay, where they are lower. Flow patterns along Johns Creek are controlled by the creek's lowermost canyon reach. Near Oakland Bay, Unit D appears to plunge downward and pinch out.

Upper Unit F. Groundwater in the upper part of Unit F appears to flow southeast toward Oakland Bay. However, the contour maps also show a groundwater divide beneath the upper reach of Johns Creek. In this area, groundwater in upper Unit F likely flows to the Skokomish River basin. Water levels range between about 50 to 150 feet msl. Additional water level information is needed to clarify the pattern and location of this divide.

Deep Unit F. Groundwater in the very deep part of Unit F appears to flow southeast toward Oakland Bay. Water levels are less than about 50 feet msl.

4.2.1.2 Flow between Aquifers

In addition to the lateral component described above, groundwater flow in the focus area also has a strong downward component. Water levels are typically 50 to 100 feet higher in Unit D than in the upper part of Unit F, resulting in significant hydraulic head differences. Consequently, groundwater flows downward from high- to low-elevation aquifers where Unit E (an aquitard) is relatively permeable, thin, and/or absent. Note that Unit D water levels can vary by 10 to 40 feet over distances of one-quarter mile, and wells in this unit are screened over a range of elevations. This variation may be due to the presence of multiple permeable zones, possibly separated by thin layers of till deposited by rapidly advancing and retreating glaciers over a relatively short time.

Too few wells are completed in Unit F to clearly identify vertical flow patterns between its upper and deeper horizons. At the Shelton test well location, there appears to be a downward gradient. Conversely, at the Bayshore Golf Course well, the gradient may change from upward to downward depending on season and tide. At this location, the water level in the upper Unit F is above land surface. Nonpumping water levels in the Bayshore well are above land surface, indicating the potential for upward groundwater flow from the upper part of Unit F to Johns Creek and/or Oakland Bay.

Unit A appears to be an important source of water for domestic wells, based on the hydrogeologic cross-sections and the large number of shallow wells included in the project database (**Appendix A**). The cross-sections indicate that Unit A is laterally discontinuous. Water-level contour maps could not be prepared for this unit; however, the water level in the Stonebriar 1 well, which is completed in Unit A near Johns Creek, was compared to water levels in nearby, deeper wells. This comparison indicates a potential for downward groundwater flow from Unit A to Unit D in arras where Units B and C are permeable or absent.

4.2.2 Long-Term Trends

Long-term water-level trends were assessed in four wells: the Dittmer, Maple Glen, Hiapark, and COS test wells (**Table 4-2; Figure 2-2**). Long-term barometric pressure trends were included on one or more hydrograph for each well.

In addition, the Squaxin Island Tribe monitored water levels in the Sheldrup well during June 2005. This shallow well is located near the Oakland Bay. NLW analyzed 5 days of data collected from this well as part of this investigation.

4.2.2.1 Barometric Pressure

Generally, barometric pressure changed within a range equal to 1 foot of water. Increases or decreases occurred over periods of hours to days. For example, barometric pressure generally increased from May 11 to 18 and then decreased until May 25. However, superimposed on these trends are smaller-magnitude trends that last for about 12 hours and present as diurnal changes. These smaller fluctuations are likely due to local thermal variation. In contrast, trends lasting more than 1 day are generally due to regional weather patterns.

4.2.2.2 Dittmer

The Dittmer well is 105 feet deep and completed in Unit D. It was selected for long-term monitoring because of its proximity to the POS wells and Johns Creek.

When monitoring started in mid-February, water levels in the Dittmer well were relatively high and rising (**Figure 4-7**). They continued to rise until late April and began to decline the first week of May, continuing a general declining trend until the end of August. Water levels fluctuated up and down throughout the monitoring period; however, a marked change occurred about the first week of May, when the daily or multi-day fluctuations increased from about 0.25 to about 0.75 feet in magnitude. These late spring and summer fluctuations span a few days to 2 weeks and suggest a change in the pumping regimes of nearby wells. The water level trends observed in the Dittmer well after late spring suggest that this pumping (or other stress) is somewhat irregular. Note this change corresponds roughly to a higher seasonal water use such as irrigation.

Water levels were higher at the beginning of the monitoring period than at the end. Long-term seasonal trends cannot be discerned because monitoring lasted for only about 7 months. Continued monitoring during the next year would provide the data needed to establish seasonal trends in response to climate variation.

Barometric Effects: The diurnal variations observed in the Dittmer well do not correlate to barometric pressure trends (**Figure 4-7**). However, during April, when water levels are relatively stable (flat), subtle changes inversely correlate to barometric pressure. The correlation is slight but consistent with the response of a semi-confined aquifer.

Precipitation: The water level rise noted during spring is likely a response to precipitation in March and April (**Figure 4-7**). Similarly, the rise in late May and early June likely reflects the late rain events of mid to late May, indicating that precipitation directly affects water levels after a lag time of about 3 weeks. However, if the water level rise in mid-July is due to precipitation in early July, the lag time would be less than 1 week.

Marine Tidal: Water levels correlated directly to the extrapolated tide levels in Shelton (**Figure 4-17**). The amplitude of change in the Dittmer water level is about 2 to 3 percent of the tidal amplitude. This response is somewhat surprising because the Dittmer well is completed in Unit D, well above land surface. It indicates that stress is transferred to groundwater in Unit D from the underlying units. As cross-section G-G′ indicates, the Dittmer well is completed in Unit D and separated from Unit F (the "Sea Level Aquifer") by about 40 feet of Unit E, which consists of low-permeability clay, clay and gravel, and sometimes hardpan.

The observed tidal effect may be due to either water movement through underlying Unit E into Unit D or to the movement of a pressure pulse. Because groundwater moves relatively slowly, a measurable lag, or shift, would likely be observed in the timing of "peaks" and "valleys" between the Dittmer well and marine tide. The absence of such a lag suggests that the change in water level is due to propagation of a pressure pulse moving from Unit F, through Unit E, and into Unit D. As tide level changes, the changes in loading on the underlying sediments result in pore water pressure changes. These pressure changes propagate upward through Unit E and into Unit D. The details of this mechanism require additional data analysis beyond the project scope.

Johns Creek Stage: The precipitation data suggests that groundwater discharge is the primary source of flow in Johns Creek. As expected, stage levels correlate closely to precipitation. If streamflow were due primarily to runoff, creek stage would mimic precipitation—with no lag time. However, **Figure 4-7** shows stage continuing to rise for a while after the rain stops, suggesting that precipitation is stored in the vadose zone and released slowly. This lag in the stage peaks presents as attenuated versions of the precipitation peaks. Likewise, the water-level hydrograph represents a highly dampened response to precipitation, stage, or both.

The relationship between Johns Creek stage and marine tidal fluctuations, shown in **Appendix C**, further supports a hydraulic connection with the aquifer. Creek stage periodically rises and falls. This pattern correlates with the tidal fluctuations, suggesting that the tidal response observed in the Dittmer well may propagate to Johns Creek. However, the magnitude of the stage rise and fall is small—on the order of 0.02 feet—and further analysis is warranted to clarify these relationships.

Pumping at JP2: **Figure 4-8** shows the pumping rate for POS JP2, which typically operates at 100 to 200 gpm. This well lies within approximately 1,050 feet of the Dittmer well and pumps from the highly permeable parts of Unit F. No pumping effects were observed at Dittmer while JP2 was pumped.

Water Reuse Infiltration Test: The hydrograph in **Appendix D** shows water levels for JP2 and the Dittmer well during this infiltration test. It indicates no response at either well. Groundwater levels in Unit A rose 0.2 feet about 40 feet from the trench (Cosmopolitan, 2005).

Water Levels at POS Well JP1 while Pumping at JP2: Well JP1 was pumped at about 220 gpm from May 25 to 30 and then allowed to recover afterward. The hydrograph in **Appendix E** shows water levels in JP1 during the pumping period. Note that the vertical scale of this graph (44 to 54 feet) was selected to show recovery data; however, the pumping water levels fall outside this scale. During the recovery period, water levels indicate the influence of marine tides. The aquifer response in JP1 is not apparent from this graph. To improve this analysis, barometric and tidal effects could be removed for the period from June 2 to 6.

4.2.2.3 Maple Glen

The Maple Glen well is 46 feet deep and completed in Unit A. It was selected for long-term monitoring because it lies near the COS supply wells and might show a response to pumping. Its response would indicate the degree of hydraulic connection between Unit F and shallow Units A or B in that area.

When monitoring started in early February, water levels in the well were moderately high but declining (**Figure 4-9**). This declining trend continued, except for brief rises, until late March, when water levels rose significantly and abruptly and then began to steadily decline, interrupted by brief, abrupt rises. Water level continued to decline throughout the remainder of the monitoring period. Except for a few very small, abrupt water level rises, this decline was smooth and steady from June to September.

Water levels were higher at the beginning of the monitoring period than at the end. Long-term seasonal trends cannot be discerned because monitoring lasted for only about 7 months. Continued monitoring during the next year would provide the data necessary to establish seasonal and multi-season trends in response to climate variation.

Barometric Effects: No barometric effects are apparent in the water level data, suggesting that this well is completed within an unconfined aquifer (**Figure 4-9**). No driller's log is available for the Maple Glen well; the hydrostratigraphy is inferred from adjacent wells, as shown on cross-section F-F′ (**Figure 3-6**).

Precipitation: The abrupt rises observed in the Maple Glen water levels occur almost simultaneously with precipitation events (**Figure 4-9**). The lag between the peak precipitation and the corresponding water level rise is about 1 day. For each rainfall event, groundwater level rises abruptly, similar to the precipitation trend, but the falling limb is more gradual. This pattern would occur if the infiltrating water starts as saturated flow in the beginning of the event but transitions to unsaturated flow after the rain stops. The deposits in the interval between land surface and the bottom of the Maple Glen appear to be highly permeable. This observation is based on the abrupt water-level rise and fall, and the similarity to the precipitation trend.

Marine Tidal: The Maple Glen well does not appear to respond to marine tides (**Figure 4-17**). Based on logs for nearby wells (cross-section F-F′, **Figure 3-6)**, this well bottoms out in Unit A and is separated from Unit F (the Sea Level Aquifer) by about 136 feet. The thicknesses of the underlying units are uncertain because Unit B pinches out north of the Maple Glen well and Units C and D pinch out to the south. However, the tidal water level changes in Unit F do not appear to propagate through overlying units to Unit A. As the barometric and precipitation data indicate, the Maple Glen well is completed in an unconfined aquifer. Unconfined aquifers have significantly higher storage coefficients than confined ones; thus, they may not show measurable water level responses to small and short duration changes in pressure. Therefore, water level changes in Unit F would not propagate to observable changes in unconfined Unit A.

Pumping at COS Wells 1 and 3: **Figure 4-10** shows water levels in the Maple Glen well, along with the pumping rate for COS Wells 1 and 3, over a 6-week period. During this period, the pumping wells turn on and off, but are mostly on, pumping between 900 and 1200 gpm. During nonpumping periods, a well is generally off and infrequently turned on briefly. During the first 8 days, both wells were pumping. During the next 20 days, only COS Well 3 was pumping and Well 1 was generally off. During the following 10 days, COS Well 1 was pumping, while COS Well 3 was generally off.

Figure 4-10 shows no discernible change in Maple Glen water levels when COS Well 1 was shut off or when COS Well 3 was shut off and COS Well 1 was turned back on again. This suggests that Unit A in the Maple Glen vicinity is unaffected by pumping at the COS wells when these wells are pumped alternately on/off for periods of weeks. This indicates either a relatively weak hydraulic connection between Units F and A, or a substantially dampened connection. However, the abrupt water level change that correlates to a strong precipitation event occurs just after Well 3 was shut off and Well 1 turned on. Additional monitoring is needed to confirm that pumping does not affect water levels at Maple Glen.

4.2.2.4 Hiapark

The Hiapark well is 79 feet deep and completed in Unit D. It was selected for long-term monitoring because it is located near the COS supply wells; consequently, it might show the effects (if any) of COS pumping. The Hiapark well response would also indicate the degree of hydraulic connection between Unit F and Unit D.

Over the monitoring period, water levels in the Hiapark well (**Figure 4-11**) bounce up and down, by about 0.5 feet, but form a very distinct trend. This bouncing indicates a response to an intermittent stress—a stress that cycles on and off, or changes from strong to weak frequently—most likely, a nearby pumping well. When monitoring begins in early February, water levels in the Hiapark well were relatively high but declining. They continued to decline until late March, rose from late March to late April, and then began a steady decline that lasted through the monitoring period. Small water-level fluctuations occur during the entire monitoring period.

Water levels were higher at the beginning of the monitoring period than at the end. Long-term seasonal trends cannot be discerned because monitoring lasted for only about 7 months. Continued monitoring during the next year would provide the data necessary to establish seasonal and multi-season trends in response to climate variation.

Barometric Effects: **Figures 4-11 and 4-12** show barometric pressure and water level data at the same scale. Although the bouncing water levels make for a difficult comparison with barometric pressure, in general, the water level trend moves inversely to the barometric pressure trend. The period from April 7 to 15 is best for making comparisons because the water level trend is flat. During this period, water level declines when barometric pressure increases—a typical response for a confined aquifer (Section 4.1.5.2). Water levels change by as much as 50 percent of the change in barometric pressure, indicating a barometric efficiency of about 50 percent. For example, a low point barometric pressure starts on April 12 at 8:50 and increases until April 14 at 10:20, when it peaks. Conversely, the Hiapark water level trend starts at a peak on April 12 at 8:50 but declines to a low point on April 14 at 10:20. The change in barometric pressure 0.62 feet, and the corresponding change in the Hiapark water level is about 0.3 feet. During other periods, barometric efficiency appears to range from about 30 to 50 percent, suggesting that the aquifer is semiconfined. The drillers' log indicates that till overlies the aquifer and that groundwater level is about 15 feet below the top of the sand and gravel in which the well is completed.

Precipitation: The Hiapark well's response to precipitation is dampened significantly, making it difficult to identify individual rain events; however, during periods of sustained precipitation, water levels show an increasing trend (**Figure 4-11**). Similarly, during periods of little precipitation, water levels decline. Shortly after a significant precipitation event that began on March 26, 2005, water levels in the Hiapark well began to rise and continued this trend until April 22. Water levels began to decrease until about May 12 and then stabilized, corresponding to a 2-week period of significant rainfall. A declining trend began again in early June and continued through the end of the monitoring period, corresponding to a period of very little precipitation. The hydrographs show that a few small precipitation events may correspond to observed water level trends. For example, rain falling on about July 7 likely corresponds to a small water level rise on July 8. The strongly dampened water level response to precipitation indicates that low permeability deposits overlie the Unit D aquifer in the vicinity of Hiapark.

Marine Tidal: Marine tides do not appear to affect Hiapark water levels (**Figure 4-17**). The bottom of the Hiapark well sits at an elevation of 165 feet msl. Although no logs are available for nearby deep wells to shed light on the local subsurface stratigraphy, the *Viewlog* model indicates more than 100 feet between the bottom of Hiapark well and the top of Unit F. Units D and E overlie these deposits. Because the Hiapark well is completed in a confined to semiconfined aquifer, water levels would likely respond to relatively small changes in pressure. The lack of response to tidal changes suggests that the pressure pulse does not propagate through the units separating Hiapark well from Unit F.

Pumping at COS Wells 1 and 3: **Figure 4-13** shows water levels in the Hiapark well, along with pumping at COS Wells 1 and 3, during a 6-week period. During pumping periods, the COS wells may turn on and off, but they are mostly on. During nonpumping periods, these wells are generally off but may be turned on infrequently for a brief time. For first 8 days of monitoring, both wells were pumping; over the next 20 days, only COS Well 3 was pumping, while COS Well 1 was generally off. During the following 10 days, COS Well 1 was pumping, while COS Well 3 was generally off. Note that the datalogger was removed from the Hiapark well to monitor a POS well during the last 10 days of pumping. **Figure 4-13** shows no discernible response in the Hiapark well when COS Well 1 was shut off. This suggests that Unit D in the Hiapark vicinity is not strongly affected by COS Well 1 pumping. The declining water-level trend observed during the pumping period may be attributed to low or no precipitation. Further monitoring is needed to confirm the effects of COS pumping on Hiapark water levels.

4.2.2.5 COS Test Well

The COS test well is 752 feet deep and is completed in the very deep portion of Unit F. It was selected for long-term monitoring because of its proximity to COS pumping wells and its potential to provide information on the extent of pumping-induced drawdown in this deep unit.

Water levels in the test well fluctuate up and down regularly by about 0.5 feet, but follow a distinct trend (**Figure 4-14**). This behavior indicates a response to an intermittent stress—one that cycles on and off, or changes from strong and weak, on a regular basis. When monitoring started in mid February, water levels were relatively high and steady. Periods of logarithmic water level rise and decline (characterized by large rate of change grading into smaller rate of change and then eventually to a rate of change of almost zero) are punctuated by steady periods (rate of change of zero). This pattern is superimposed onto a general decreasing trend from June through the rest of the pumping period.

Water levels were higher at the beginning of the monitoring period than at the end. Long-term seasonal trends cannot be discerned because monitoring lasted for only about 7 months. Continued monitoring during the next year would provide the data necessary to establish seasonal and multi-season trends in response to climate variation.

Barometric Effects: Water levels in the test well respond to changes in barometric pressure (**Figure 4-15**). However, barometric effects are difficult to distinguish from the strong tidal response. On April 1, water levels rise when barometric pressure declines and decline when barometric pressure rises. Because the tidal response is superimposed on this trend, the barometric pressure trends (peaks and troughs) must be extrapolated to show water level changes that range from about 60 to 80 percent of the corresponding barometric pressure changes. This barometric efficiency (60 to 80 percent) is typical of confined aquifers.

Precipitation: Water levels in the test well do not respond to precipitation (**Figure 4-14**. This lack of response reflects the local hydrogeologic conditions: Up to 200 feet of deposits separate the top of Unit F (where the test well is completed) from incident precipitation. The lack of response does not indicate that Unit F is not recharged by precipitation; rather, the recharge is stored within overlying deposits, which dampen the pulsing nature of infiltration.

Marine Tidal: Water levels in the test well respond strongly to tidal fluctuations (**Figure 4-17**). The bottom of the well is open to low permeability material (cross-section F-F′, **Figure 3-7**) more than 500 feet from sea level. Despite this distance, the pressure pulse from changing tides propagates quickly and abruptly through this thick sequence of deposits.

Pumping at COS Wells 1 and 3: **Figure 4-16** shows water levels in the test well, along with pumping at COS Wells 1 and 3, during a 6-week period. During pumping periods, the COS wells may turn on and off, but they are mostly on. Likewise, during nonpumping times, the wells are generally off and infrequently turned on for a brief time. For first 8 days of monitoring, both wells were pumping. Over the next 20 days, only COS Well 3 was pumping, while COS Well 1 was generally off. During the following 10 days, COS Well 1 was pumping, while COS Well 3 was generally off. Water levels in the test well rose after COS Well 1 stopped pumping (**Figure 4-16**) and declined when pumping resumed. In fact, the water level was about 1 foot lower than it had been when both COS Well 1 and COS Well 3 were pumping. When only one well is pumping, its daily withdrawals are likely larger than if both wells are pumping. Therefore, water level drawdown would be larger in the test well when COS Well 1 is pumping.

During pumping periods, a well turns on and off several times daily. Water levels in the test well were examined closely to identify immediate changes that may correlate to pumping start and stop times. This analysis shows no immediate response when COS Well 1 or 3 starts or stops. Both pumping wells are completed in Unit F (cross-section F-F′, **Figure 3-7**). Although the respective depths of these wells are 745 and 278 feet, both are screened at about sea level. COS Well 1 was backfilled and currently draws water from about the same depth as COS Well 3.

Because COS Well 3 could not be shut down after both wells had been pumping, its effect on the test well is uncertain. Further monitoring is needed to confirm the effects of COS pumping at the test well site. Ideally, both wells would be pumped before shutting off COS Well 3.

4.2.2.6 Sheldrup Well

The Sheldrup well is 50 feet deep. **Appendix F** presents 5 days of water level data provided by the Squaxin Island Tribe, along with marine tide at Shelton. The water levels show a weak, inconsistent response to tidal fluctuations—not a strong response, as expected for Unit F, which is overlain by a thick clay layer (Unit E) in the Dittmer, Hiapark, and the COS test well vicinities. The response may occur because Unit F is overlain by till at the Sheldrup well. This till may be porous enough to store water and accommodate upward flow. If so, tidal fluctuations would not cause pore pressures to increase as they would in a confined aquifer.

5.0 Geochemistry

Water samples were collected and analyzed for routine chemistry, stable isotopes, radiocarbon, and tritium. **Figure 2-2** shows geochemistry sample locations. The purpose of this work was to provide information about the source and age of groundwater recharge, as well as the degree of mixing between aquifers and their continuity with Johns Creek. Surface water samples were collected during the end of the low-flow period to ensure that they represent baseflow conditions, when groundwater discharge is highest.

In addition to the data acquired via sampling, nitrate records were obtained from Washington Department of Health (WDOH) for all Group A and B wells in WRIA 14. This data was brought into a GIS project for analysis.

5.1 Background Theory

This section provides some background on how major and minor ions, stable isotopes, tritium, and carbon-14 are used to characterize water quality.

5.1.1 Inorganic Major & Minor Ions

Inorganic constituents can be useful for identifying geochemical "signatures," or unique water types. Data from many samples can be plotted on a single trilinear diagram, or Piper plot. The trilinear diagram features two ternary plots for cations and anions. Those points are then projected onto a diamond-shaped plot that summarizes both anions and cations. **Figure 5-1** shows a trilinear diagram, along with the two ternary plots. Waters that plot in the same vicinity have similar chemistries. The ternary plots only show concentration as a percentage of the total but do not indicate absolute concentration. Therefore, circles are used on trilinear diagrams to indicate concentration; the radius is proportional to the total dissolved solids TDS). The trilinear diagram shows geochemical signatures for wells with similar chemical characteristics.

5.1.2 Stable Isotopes

Oxygen and hydrogen stable isotopes provide information about the source of groundwater and define its isotopic signature. Stable isotopes are reported using the δ (delta) notation in units of permil relative to standard mean ocean water (SMOW). The results are typically plotted with the meteoric water line—a line along which all global precipitation generally falls (Craig, 1961). Samples that plot along or near this line originate from precipitation. They have not been affected or modified by processes that have changed its isotopic signature, such as evaporation or geothermal activity. Relatively light isotopic signatures have large negative values, containing significantly less oxygen-18 relative to SMOW; they characterize high-elevation precipitation. Conversely, relatively heavy isotopic signatures have smaller negative values, containing slightly less oxygen-18 relative to SMOW; they characterize low-elevation precipitation.

5.1.3 Tritium

Tritium is a radioactive form of hydrogen that occurs naturally in the atmosphere and acts as a groundwater tracer. Because it decays over time, becoming smaller in concentration, tritium also provides information on the age of the groundwater. It can reveal whether groundwater is older or younger than about 50 years. If more than 1 tritium unit (TU) is detected in a sample, it contains water that was recharged after the early 1950s, when atomic bomb testing began and released large amounts of tritium globally into the atmosphere.

Tritium concentrations in groundwater also increased because precipitation, which originates in the atmosphere, provides a major source of recharge to aquifers. Currently, atmospheric tritium in the Pacific Northwest is reported to range from 4 to 6 TU (IAEA, 1992). Except for a few years before bomb-testing began, groundwater recharged before bomb-testing no longer contains detectable tritium since about four half-lives have passed since then.

Because of the variability of the historic tritium record, this method does not provide absolute or precise dates.

5.1.4 Carbon-14

Carbon-14, a radioactive isotope of carbon, is used to date water that is less than about 35,000 years old. Analytical results for dissolved inorganic carbon-14 in groundwater are reported in years before present (BP) and units of fraction modern carbon (Fmdn). A value of Fmdn 1.0 reflects current conditions and an age of 0 years. An Fmdn of 0.5 is half of the current carbon-14 value—that is, the amount remaining after half the original amount of dissolved inorganic carbon has decayed. A value of Fmdn 0.5 equals about 5,568 years, the half-life of carbon-14.

Actual ages of water may differ from the dates reported by laboratories because the water may have reacted with carbon-bearing minerals or "dead" carbon (containing no carbon-14) from decayed organic matter. Lab dates can be corrected to account for chemical reactions occurring along the groundwater flow path that may affect the carbon chemistry and thus the carbon-14 age. These corrections are complex and involve a significant amount of work. However, if carbon-related reactions did not significantly change the water chemistry, laboratory dates provide a useful age estimates for groundwater.

5.2 Sampling & Laboratory Analysis

The following samples were collected for analysis:

- **Routine constituents**: Ten groundwater samples and three Johns Creek samples (upgradient, downgradient, and an intervening tributary location).
- **Stable isotopes of oxygen-18, and deuterium**: Ten groundwater samples and seven surface water samples at three locations along Johns Creek and two along Goldsborough Creek. At two of the Johns Creek locations, samples were collected during two separate low-flow periods—September 2004 and August 2005.
- **Carbon-14 and tritium**: Five groundwater samples.

Routine constituents were field-filtered and analyzed by Analytical Resources, Inc. Stable isotopes were collected without head space to avoid any changes to the isotopic signature of the sample. These samples were submitted to Zymax, Inc. Radiocarbon samples were collected in polyethylene bottles, treated with sodium hydroxide, and analyzed by Beta Analytic, Inc. Tritium was collected in polyethylene bottles and analyzed by the University of Miami. No glow-in-the-dark watches or other items were worn during collection of the tritium samples.

Laboratory data were added to the project water-quality database. For major ions, an ion balance was calculated as a quality assurance measure. Routine constituents were plotted on a trilinear diagram as described in Section 5.1.1. Stable isotopes were plotted on a graph with the meteoric water line.

5.3 Results

Table 5-1 summarizes the results for all the samples collected during this investigation.

5.3.1 Routine Constituents

Figure 5-1, a trilinear diagram, plots the routine chemistry for all the wells and surface water samples. It indicates that all the samples have similar water chemistry except for Artesian Well at Pumphouse (AWP) and COS Well 1, where sodium percentage and TDS are higher than for the other samples. The higher sodium may be a result of cation exchange, a relatively slow but common reaction that occurs between groundwater and clay. Groundwater takes two sodium ions (each with a charge of +1) from the clay and replaces them with one calcium or magnesium (charge of +2). Typically, groundwater with a long residence time—in other words, old groundwater—has more sodium than young groundwater. At first glance, it is surprising that the chemical conditions for COS Wells 1 and 3 are distinct, since they are both completed within the upper part of Unit F. However, COS 1, which is completed in the top of this unit, may receive water from overlying clayey deposits. AWP also has high chloride, which—along with the sodium—could originate from seawater intrusion.

The tight data cluster indicates that the groundwater and surface water share very similar chemical characteristics. Consequently, differentiating groundwater by aquifer is difficult based on these chemical parameters.

5.3.2 Nitrate

5.3.2.1 Sampling Results

Table 5-1 indicates that nitrate was detected in two surface water samples and six groundwater samples, in low concentrations. However, nitrate is a common result of land use activities from fertilizers and/or septic discharge. Its presence indicates recharge from shallow groundwater.

Nitrate was detected in the Johns Creek tributary and the downgradient Johns Creek sample, but not in the upgradient one. Nitrate concentrations are higher in the tributary, which mixes with upgradient creek water, than in the downgradient sample.

Nitrate was detected in several deep wells—COS 3, Bayshore Golf Course, Oak Park, and Sheldrup—along with wells completed in the upper part of Unit F. However, it was not detected in COS Well 1, Bob Barnes, and AWP, which are completed in the deeper part of Unit F. Nitrate was also detected in the SV Pullin and Verdonk wells, which are both completed in Unit D, but not in Stonebriar, a relatively shallow well completed in Unit A.

5.3.2.2 WDOH Data

Figure 5-2 shows the distribution of nitrate for Group A and B wells in the Phase II focus area. The number of wells represented on this plot is significantly greater than the number of plotted points. Several wells may plot at the same point because they are located only to the nearest quarter-quarter section. No wells on record with WDOH in the vicinity of Johns Creek have nitrate concentrations exceeding 5 mg-N/l. In general, for most the Group A and B wells in the focus area, nitrate is 0.5 mg-N/l or less.

5.3.3 Stable Isotopes

Figure 5-3 shows stable isotope data plotted for ten groundwater and seven surface water samples, along with the meteoric water line.

5.3.3.1 Johns Creek Water

The isotopic signatures of the Johns Creek samples are relatively heavy compared to those of the deep groundwater samples. Johns Creek water likely originates primarily from local, low-elevation precipitation; a secondary component is groundwater discharge from shallow aquifers that have a slightly heavier isotopic signature. The tributary's signature is heavier than that of Johns Creek at Oak Park, suggesting that the Oak Park groundwater originates from local precipitation and that the tributary contains groundwater recharge from a higher elevation. However, the tributary more likely represents a mixture of shallow, heavy water with deeper, lighter water. Johns Creek at Highway 3 appears to contain a mixture of the Oak Park and tributary waters.

Samples collected in September 2004 and August 2005 for Johns Creek at Highway 3 and Johns Creek at Oak Park were similar between years, indicating that the data is reliable. The 2005 Johns Creek at Oak Park sample had a heavier delta O-18 value, suggesting evaporation, which is not surprising given the wetlands in the upper part of the Johns Creek.

5.3.2.2 Goldsborough Creek

The Squaxin Island Tribe measured Goldsborough Creek flow in July 2004 and found substantial gains between the Highway 101 trestle and the creek's mouth in downtown Shelton (Konovsky, 2005). The gains amounted to about 8 cfs—about 25 percent of the average flow in this reach. To better understand the source of this inflow, samples were collected at both creek locations and analyzed for stable isotopes. The results were then compared to the isotopic signature for AWP, which yields water from the deep Unit F aquifer. Groundwater potentially flows upward from this deep aquifer under strong gradients.

The isotopic signatures of the two creek samples are similar. They are lighter than the Johns Creek samples and heavier than the AWP sample. This suggests that Goldsborough Creek receives flow from a large groundwater component that originates outside the focus area at higher elevations. The similarity of the two samples also suggests that same water source feeds Goldsborough Creek between its mouth and the trestle. If deep groundwater inflow were significant along this reach, the isotopic signature of the downgradient creek sample would reflect the signatures of both the trestle and AWP samples. However, the results show this mixing is not occurring, although further work is required to confirm this finding.

5.3.2.3 Groundwater

Three groundwater samples from deep Unit F have a light isotopic signature:

- COS Well 3, located on the Shelton upland
- AWP, located in downtown Shelton near the mouth of Goldsborough Creek
- Bob Barnes, located in the lower Johns Creek area.

These results suggest that groundwater in Unit F originates at a higher elevation, at a distance from the study area. This water differs from water in Johns Creek, which originates from local precipitation. Other results indicate local mixing between aquifers. The isotopic signature of water in some Unit F wells—Sheldrup, Bayshore GC, Oak Park, and COS 1—is mixed. It is also similar to water in Unit A and D wells (Stonebriar, SV Pullin, and Verdonk).

As discussed in Section 4.2.1, groundwater moves from the west and/or northwest, where surface elevations are higher. The deep groundwater system is likely recharged in these higher-elevation areas, outside of the study area.

5.3.4 Radiocarbon & Tritium

Tritium was detected in all five sampled wells. In the absence of other data, these detections might mean that the water is younger than 50 years old. However, carbon-14 dates these samples in the 100- to 3,000-year range, indicating that young and old waters are mixing. This corroborates the stable isotope results, which show mixing of groundwaters from Units D and F. One example of this mixing occurs at the Sheldrup well, which has a C-14 age of 2,560 years, along with detectable tritium, stable isotopes, and nitrates. The relatively old carbon-14 ages also support the notion that some recharge to the groundwater system occurs outside the study area.

6.0 Flow Patterns & Hydraulic Continuity

Minimum instream flows for the Kennedy-Goldsborough watershed are specified in *Chapter 173-514* of the *Washington Administrative Code (WAC)*. Seasonal closures apply to streams in the Shelton vicinity. These flow requirements and stream closures could limit water-right allocations in areas where streams are hydraulically connected to aquifers. Consequently, one important goal of this work was to identify areas where pumping groundwater would have minimal impacts to streams because hydrogeologic conditions favor a low degree of hydraulic continuity.

6.1 Background Theory

Pumping is most likely to affect surface water in areas where streams intersect permeable aquifers and where aquifers are not isolated by till or other sediments that function as aquitards. When a well pumps, local hydraulic conditions change. The water level drops in the well, increasing the groundwater gradient—and therefore flow—toward it. Initially, the pumped water is captured from nearby areas in the aquifer. As pumping continues, however, the well may capture water from areas that lie increasingly farther away. The size of this radial "zone of influence" depends on several factors, including the well's pumping rate and the aquifer's properties (transmissivity, degree of confinement, etc.).

In areas where surface water and groundwater are hydraulically connected, impacts to lakes, streams, or wetlands increase with proximity to the pumping well. Wells that are pumped for long periods may affect flow in these features as they capture surface water directly or as they intercept groundwater flowing to them. Under certain conditions, the pumping wells may intercept groundwater flow to marine waters, changing the position of the freshwater-saltwater interface.

Pumping wells within the study area ultimately capture water that flows to, or occupies, local creeks and lakes (such as Shelton Creek, Johns Creek, and Island Lake) or marine waters (such as Oakland Bay and more distant points in Puget Sound). A number of factors influence the degree to which a pumping well will impact streamflow:

- Its depth (deeper has less impact)
- Its distance to the stream (farther has less impact)
- Its location in the basin (closer to the outlet of the basin has less impact)

Additionally, poorly permeable, continuous layers overlying an aquifer will dampen the effect of a pumping well on a creek. These layers will also drive impacts farther downgradient—potentially to marine waters in Oakland Bay.

6.2 Assessment of Potential Impacts

So, how will a water supply well impact nearby surface water, especially where fish require inflows of high-quality, cold groundwater to sustain a healthy habitat? This investigation has identified several key relationships that provide information about the hydraulic connection not only between aquifers but also between aquifers and surface water, particularly Johns Creek. It may help guide where and how water development might occur in the future.

6.2.1 Evidence of Hydraulic Continuity

6.2.1.1 Hydrogeologic & Hydraulic Evidence

As is typical of glaciofluvial-lacustrine deposits in south Puget Sound, the hydrogeologic units within the focus area can be mapped between wells but not over distances of miles (**Figures 3-2 through 3-8**). This lateral discontinuity promotes hydraulic continuity between aquifers and surface water features. Hydrogeologic data indicate that—at least in localized areas—the aquitards separating aquifers are competent and would impede vertical hydraulic connections. In the lower Goldsborough Creek / downtown Shelton area, where Units B, C, D, and E have been removed and Unit A overlies Unit F directly, there is likely hydraulic continuity between Unit F and the shallow system. However, this condition likely only spans a short reach in the most downgradient portion of Shelton Creek. Other parts of the focus area are overlain by thin or permeable aquitards. Locally, near the marine shoreline of Oakland Bay, numerous artesian wells are completed in Unit F, indicating a vertically upward flow component and the presence of one or more aquitards.

In general, the water level data indicate a downward gradient; areas where aquitards are permeable or absent would be characterized by some degree of hydraulic continuity.

6.2.1.2 Chemical Evidence

The stable isotope results indicate mixing in some areas, a characteristic of hydraulic continuity. In some places, groundwater from Units D and F has similar isotopic signatures; in others, groundwater from Unit F is distinct. The occurrence of tritium in waters with an old carbon-14 age also indicates mixing between Units D and F, and perhaps between Units A and D. Except for along the marine coastline, the prevailing downward gradient is the likely means by which mixing occurs.

A temperature study was conducted for the Squaxin Island Tribe using Forward Looking Infrared (FLIR; Watershed Sciences, 2004). Stream temperatures were measured from a helicopter flying along the length of Johns Creek; **Figure 6-1** shows temperatures along the Johns Creek thalweg. Abrupt temperature drops occur along Johns Creek at spring locations where groundwater discharges upward through the creek bed. The relatively heavy isotopic signature of the creek water suggests that the springs contribute water from shallow sources that are recharged from local precipitation. However, isotopic signature of the Johns Creek tributary is heavier than that of the creek's upper reach, indicating that the tributary captures groundwater originating from higher-elevation precipitation.

6.2.3 High- & Low-Risk Areas

Table 6-1 synthesizes the results of the hydrostratigraphy refinement, the water level analysis, and the hydrogeochemistry assessment, summarizing information that is relevant to groundwater flow and hydraulic continuity. Six different areas were evaluated. For each area, **Table 6-1** assigns a relative risk based on the potential effect of developing groundwater in Unit F. These relative risk assignments assume that "groundwater development" represents substantial rates / volumes of pumped water, either from a single large capacity well, or from many small-capacity wells.

Figure 6-2 shows the relative risk to surface (fresh) water associated with developing groundwater in Unit F in selected areas. Note that relative risk was only assessed for areas that have been considered for groundwater development; undesignated areas (shown as blank or white) are not necessarily free of risk.

- Area of lowest potential risk: Oakland Bay vicinity

- Areas of moderate potential risk: COS Well 1 and 3, and lower Goldsborough Creek / downtown Shelton
- Areas of high potential risk: Johns Creek vicinity

Note that these risk assignments are qualitative; they are based on available information and the analyses conducted to date. As new information becomes available, they may change. Additional monitoring and analysis targeting specific areas would be required to better our understanding of potential continuity-related impact from developing groundwater in Unit F.

7.0 Recommendations

Based on the results of these Phase II investigations, NLW has developed a set of recommendations to support ongoing watershed planning efforts. The recommendations that follow describe additional work (specifically, monitoring), approaches for future groundwater development, and methods for quantifying potential impacts.

7.1 Additional Monitoring & Data Analysis

NLW recommends an area-wide program for monitoring pumpage, groundwater levels, and streamflows. This information will help planners identify optimal locations for groundwater development and optimal seasons for withdrawing water from a regionally intertied system. It may become increasingly important to protect creek habitat as water demands increase and climate conditions change.

- Monitoring should continue at the groundwater level stations for at least 1 year from when it started. Barometric pressure should also continue to be monitored.
- Water-level trends should be reanalyzed after a full year of data collection. Small, yet discernable variations in water levels may reveal important relationships that are not documented in this report. Also, seasonal relationships will be more evident after 1 or more years of data collection.
- Although water samples were collected from AWP for tritium and C-14, they were not submitted to a lab. However, given the stable isotope results for this well and lower Goldsborough Creek, NLW recommends submitting these samples for analysis. The results would not only help investigators identify the origins of water in this area but also its potential for providing industrial or municipal supplies.
- Samples should be collected from shallow and deep aquifers along Goldsborough Creek and analyzed for isotopes to better understand the relationship between creek water, local precipitation, and groundwater from underlying aquifers.
- The major water suppliers, including the City and Port, should electronically monitor water production (instantaneous rates and cumulative volumes), along with water levels. COS Wells 1 and 3 are currently configured to accommodate this type of monitoring.
- Monitoring should continue at the Johns Creek stream gauges (JOH2 and the new gauge at Highway 3.
- A more detailed conceptual model should be developed for the Johns Prairie / Johns Creek area to help planners better understand the relationships between pumping, reclaimed water storage, groundwater levels, and flows. The model should integrate geologic and other data from the Squaxin Island Tribe's hydrogeologists and water-reuse consultants. It should also be tailored to meet water management objectives in this area. One possible management scenario, for example, would involve replacing withdrawals for industrial and/or irrigation with reclaimed water. The model could be used to help answer questions about how much reclaimed water could be stored in the subsurface. Work for this conceptual model should include one or more of the following tasks:
  - Constructing multiple hydrogeologic cross sections.
  - Performing a correlation analysis between withdrawals from the Port of Shelton wells and water levels in the Dittmer well.
  - Drilling permanent monitoring wells since long-term monitoring is likely not possible at the Dittmer well.

- Establishing new stage gauges on Johns Creek.

In addition, selected data collected as part of this study could be analyzed further. The goal of these additional analyses would be to assess trends and provide additional information about the subsurface hydraulics in the Johns Prairie / Johns Creek area.

- Pumping data should be analyzed for COS Wells 2R and 3, which were pumped simultaneously for short periods on August 17, 2005. These two supply wells are located within 100 feet of each other. The pumping data should be compared to water levels in the Hiapark and COS test well to assess the response of the overlying Unit D and underlying deep zones in Unit F. This analysis would provide a baseline for evaluating the effects of withdrawals in future years, especially if total pumpage from Wells 2R and 3 increases. In particular, it could provide insights about how withdrawals may affect regional water levels in overlying aquifers. Understanding these impacts is critical to making informed decisions about continued development of water at the Well 2R/3 site in the future.

7.2 Future Groundwater Development

7.2.1 Needs & Supply Analysis

Before developing additional groundwater supplies, the Planning Unit should conduct a comprehensive needs analysis and identify potential sources in the Shelton vicinity. Key questions include:

- Where will water be needed for people? In other words, where can growth occur under current zoning—and where is it most likely to occur?
- What nearby sources and infrastructure are available to meet demands in each of these areas?
- Are streamflows in each of these areas sufficient to sustain desired fish populations? How would future water development impact streamflows?

Once the Planning Unit understands all the possible scenarios, it can target areas for monitoring, data collection, and analysis (including appropriate models that quantify rates and impacts) in support of specific water projects. This approach will focus future efforts and resources in the most efficient manner possible.

7.2.2 Possible Locations for Groundwater Development

The Planning Unit should consider developing any new groundwater supplies in deep Unit F aquifers, at locations far from Johns Creek. This approach would best protect instream flows in the creek while allowing water providers to meet future demands in the Shelton vicinity. Potential sites for further assessment or exploration should include:

- **The lower Goldsborough Creek / downtown Shelton area**. Historic supply wells should be inventoried to identify any that could serve as municipal and / or industrial supply sources. As part of a feasibility study, their potential impacts to Shelton and Goldsborough Creeks should also be assessed. This study should include (but not be limited to) three wells that were part of this Phase II study: AWP, the Ninth Street Well, and the Green Diamond Resource Company (Simpson Timber) well, formerly "Rayonier Well 6." Although these wells were tested for some geochemical parameters under this study, further investigation would be required to assess their physical configuration, location relative to conveyance infrastructure, and yield. A pumping test lasting at least 24 hours would provide information about potential production rates, potential impacts to surface water, and possible marine water intrusion. During this test, samples could be collected for analysis of drinking water constituents and stable isotopes, C-14, and tritium (which could be used to identify the source of this water).

- **Shelton Test Well area**. This well is another potential supply source. Downhole geophysical logging could be conducted to identify any permeable aquifers adjacent to the 12-inch casing. If the results are promising, the well could be exposed to permeable zones and tested to estimate yield and evaluate drinking water quality and other geochemical parameters.
- **Oakland Bay**. The area around downtown Shelton and southeast of Bayshore may be favorable for future water development. This recommendation is based primarily on geography, not on detailed monitoring or geochemistry. It is likely that groundwater withdrawn here would otherwise discharge to Oakland Bay and possibly to more distant locations in Puget Sound. If this area is considered, it should be evaluated in more detail. Water level monitoring should be coordinated with local gravel pit operations.

7.3 Quantifying Potential Impacts

7.3.1 Water Use Analysis

Because protecting flows and preserving fish habitat is a priority, water use in the Johns Creek sub-basin will need to be quantified—especially in light of future changes in land use, water use, and climate. When used in conjunction with information about hydraulic continuity, this data will help planners decide how to supply water to people in this sub-basin in the future without impacting flows in Johns Creek.

NLW recommends conducting a detailed inventory of active wells in the Johns Creek area. For each well, the pumping rate and type of water use—domestic single family, industrial, irrigation, etc.—should be documented. If long-term pumping records are available in the Dittmer well / Johns Creek vicinity for spring and summer 2005, they should be compared to the hydrograph for the Dittmer well.

7.3.2 Groundwater Flow Modeling

If the Planning Unit decides to quantify how pumping will impact creek flows, a groundwater flow model could be developed using the data generated during this Phase II investigation. The first step of this process would involve constructing layers from the cross sections. Layer properties would then be estimated through both analytical and numerical methods; the numerical methods would entail simulating the test data collected during this study. Note that aquifer parameters can be evaluated at both the municipal supply wells (COS and POS) and instrumented monitoring wells using the pumping, barometric, and tidal time-series data.

Models predict how groundwater withdrawals will impact the aquifer system and surface water flows over time. They can also be used to assess the benefits of artificial recharge or to estimate the position of the freshwater / marine water boundary as nearby wells are pumped. Because of the costs involved, modeling should be conducted only after the Planning Unit identifies specific goals.

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Table 3-1: Summary of Hydrogeologic Units in the Phase I / II Study Areas

Unit	Aquifer	Description	"Old" Nomenclature[1]	"New" Nomenclature[2]
A	Uppermost Aquifer	Sand and/or gravel; local zones of clay, silt, and fine sand	Qvr	Qgo
B	Uppermost Aquitard	Till and other "hard" sediments with local zones of sand or gravel	Qvt	Qgt
C	Intermediate Aquitard	Clay and silt with some sand	Qvl	Qgf
D	Intermediate Aquifer	Sand and gravel	Qva	Qga
E	Deep Aquitard	Sand and silty sand with local gravel zones; may also include peat or wood	Kitsap Formation	Qpf, Qps
F	Deep Aquifer	Alternating layers of sand and gravel, and clay	Sea Level Aquifer[3]	Qpg[4]

[1] Jones, 1999
[2] Schasse et al,, 2003
[3] Upper sand and gravel portion only
[4] Upper sand and gravel portion only

Table 4-1: Summary of Wells in Monitoring Network with Fall 2004 & Spring 2005 Snapshot Water-Level Data

Borehole ID (BHID)	Well Name	Measuring Point Elevation (feet)	Wellhead Elevation (feet)	Depth to Water (feet)	Water Level Elevation (feet)	Monitoring Round
7	Artesian Well at Pumphouse	8	8.2	-1.0	9.0	NLW Spring 05
				-1.0	9.0	NLW Fall 04
9	Bayshore	46	42.8	3.1	42.9	NLW Fall 04
				2.8	43.2	NLW Spring 05
11	Johnson	204	199.6	71.9	132.1	NLW Spring 05
				74.3	129.7	NLW Fall 04
12	Moores	241	236.7	37.3	203.7	NLW Spring 05
				47.2	193.8	NLW Fall 04
14	POS JP1	212	211.0	108.8	103.2	NLW Spring 05
				91.2	120.8	NLW Fall 04
15	Rainbow L.	197	191.6	41.0	156.0	NLW Fall 04
				25.8	171.2	NLW Spring 05
16	POS Sanderson 1	301	296.1	48.0	253.0	NLW Spring 05
17	Cherry Park	255	251.2	24.9	230.1	NLW Spring 05
19	Maple Glen	208	206.7	15.6	192.4	NLW Spring 05
24	J.R. Kirk 2?	215	211.0	23.2	191.8	NLW Spring 05
33201	Bayshore GC	25	21.3	-22.3	47.3	NLW Fall 04
				-9.0	34.0	NLW Spring 05
34034	COS Well 3	224	221.2	120.0	104.0	NLW Fall 04
				113.6	110.4	NLW Spring 05
34035	COS Test Well	232	229.0	181.6	50.4	NLW Fall 04
				180.9	51.1	NLW Spring 05
39114	POS JP2	210	208.8	108.5	101.5	NLW Fall 04
				88.9	121.1	NLW Spring 05
40183	Sheldrup	63	59.7	4.0	59.0	NLW Fall 04
				3.8	59.2	NLW Spring 05
40820	Tom Brady	215	211.8	23.9	191.1	NLW Spring 05
42314	Dittmer	209	207.9	71.7	137.3	NLW Fall 04
				69.9	139.1	NLW Spring 05
42518	Hiapark	244	244.1	36.2	207.8	NLW Fall 04
				32.4	211.6	NLW Spring 05
42812	S&K	226	222.3	107.5	118.5	NLW Spring 05
43391	D and D	207	206.8	29.3	177.7	NLW Spring 05
				30.5	176.5	NLW Fall 04
49357	Stonebriar	221	218.4	8.4	212.6	NLW Fall 04
				7.0	214.0	NLW Spring 05
50781	Dayton Trails #2	379	377.6	89.3	289.7	NLW Fall 04
				80.9	298.1	NLW Spring 05
52047	Bolender	360	357.4	133.6	226.4	NLW Fall 04
55713	A. Thompson	340	336.3	39.0	301.0	NLW Spring 05
				39.5	300.5	NLW Fall 04

Table 4-1: Summary of Wells in Monitoring Network with Fall 2004 & Spring 2005 Snapshot Water-Level Data

Borehole ID (BHID)	Well Name	Measuring Point Elevation (feet)	Wellhead Elevation (feet)	Depth to Water (feet)	Water Level Elevation (feet)	Monitoring Round
56393	Juno Ct.	239	235.3	102.5	136.5	NLW Spring 05
				106.1	132.9	NLW Fall 04
274274	COS Well 1	217	217.3	170.0	47.0	NLW Fall 04
				165.6	51.4	NLW Spring 05
274276	COS Well 2	227	222.4	124.5	102.5	NLW Fall 04
				124.4	102.6	NLW Fall 04
275074	Rayonier 275074	11	11.2	-20.0	31.0	NLW Fall 04
276702	POS Sanderson 2	312	305.7	56.2	255.8	NLW Fall 04
				50.6	261.4	NLW Spring 05
277469	Rayonier Well 6	62	59.1	0.3	61.7	NLW Fall 04
				0.0	62.0	NLW Spring 05
335699	Vern Sratton	322	319.2	201.5	120.5	NLW Fall 04
				200.8	121.2	NLW Spring 05
356369	Manke Family Resources	178	175.3	60.1	117.9	NLW Spring 05
				61.5	116.5	NLW Fall 04

Table 4-2: Wells Selected for Long-Term Monitoring

Name	BHID*	Well Depth (feet)	Wellhead Eleveation (feet)	Well Bottom Elevation (feet)	Completion Unit	Comments
Near COS Pumping Wells						
Maple Glen	19	46	206.7	160.7	A	Shallow depth well near COS pumping
Hiapark	42518	79	244.1	165.1	D	Intermediate depth well near COS pumping
COS Test Well	34035	752	229.0	-523.0	F, very deep	Deep well near COS pumping
Near POS Pumping Wells						
Dittmer	42314	105	207.9	102.9	D	Intermediate depth well between Johns Creek and POS well

* - Borehole ID

Table 5-1: Summary of Analytical Results, WRIA 14 Phase II Hydrogeologic Investigation

	Units	Johns Creek at HWY 3 (Sept '04)	Johns Creek at HWY 3 (Aug '05)	Johns Creek at Oak Park (Sept '04)	Johns Creek at Oak Park (Aug '05)	Johns Creek Trib (Fall '04)	Goldsborough Creek nr Trestle (Aug '05)	Goldsborough Creek at 1st St (Aug '05)	Bayshore Golf Course	Bob Barnes	COS Well 1	COS Well 3	Oak Park #2	Sheldrup WDFW2	Stonebriar #1	SV Pullin	Verdonk	Artesian Well at Pumphouse
		Surface Water							Groundwater -- Hydrogeologic Unit									
									F	F	F(d)	F	F	F	A	D	D	F(d)
Field Parameters																		
Temperature, 0 F	0 F	13.8		17		9			9.6	9.6	10.3	10	9.8	8.6	8.6	16.5	9.4	11.2
Specific Conductance @ 25C	umhos/cm								109	98	123	111	113	107	78	158	90	205
pH field	std. units					7.02			7.73	8.52	8.64	8.16	8.33	8.09	6.94	7.98	6.93	8.64
Dissolved Oxyger	mg/L	8		7		8			0.5	0.5	0.5	3	2	1.5	4.5	3.5	5.5	1.5
Inorganics																		
Total Dissolved Solid	mg/L	61		62		49.5			76.5	63.5	86	91	80	70	57	90	63	144
Sulfate, Dissolvec	mg/L	2.5		2.6		2.1			2		3	3.2	2U	2U	1U	2.5	2U	4.3
pH lab	std. units	7.62		7.47		6.84							7.95	7.93	7.03			8.56
Nitrite as Nitroger	mg/L as N	0.01U		0.01U		0.01U			0.01U	0.01U	0.01U	0.01U	0.01U	0.01U	0.191	0.01U	0.01U	0.01U
Nitrate+Nitrite as Nitroger	mg/L as N	0.231		0.01U		0.422			0.017	0.01U	0.01U	0.208	0.064	0.032	0.191	1.37	0.157	0.01U
Nitrate as Nitroger	mg/L as N	0.231		0.01U		0.422			0.017	0.01U	0.01U	0.208	0.064	0.032	0.01U	1.37	0.157	0.01U
Chloride	mg/L	2.5		2.5		2			1.8		2.3	2.1	1.9	1.6	1.8	2.3	1.9	12.3
Carbonate as CaCO3	mg/L	1U		1U		1U			1U	1U	6.4		1U	1U	1U	1U	1U	5.8
Bicarbonate As CaCO3	mg/L	35.7		40.8		25.9			57.3	53.4	60	55.3	58.1	59.5	37.7	75.5	48.9	83.1
Alkalinity (as CaCO3	mg/L	35.7		40.8		25.9			57.3	53.4	66.4	55.3	58.1	59.5	39.7	75.5	48.9	88.9
Isotopes																		
Tritium	TU								3.05	0.47			3.26	2.03	2.63			
Oxygen-18	permil	-8.9	-8.7	-8.4	-7.9	-8.9	-9.4	-9.3	-10	-9.9	-9	-10.2	-9.4	-9.4	-9.5	-9.1	-9.4	-10
Deuterium	permil	-60	-62	-58	-59	-63	-64	-65	-66	-73	-65	-73	-64	-68	-65	-66	-67	-73
Carbon-14	Years BP								1690	2870			1510	2560	130			
Carbon-13	permil								-18.8	-18.5			-17.3	-19.1	-19.8			
Metals																		
Sodium, Dissolvec	mg/L	3.3		3.6		3.4			3.4		9.9	4	3.4	3.8	3.2	4.3	3.3	18.7
Silicon	mg/L	8.56		10		7.52			8.7		9.64	9.18	8.66	8.74	10.1	8.14	9.97	7.59
Potassium, Dissolvec	mg/L	0.5U		0.5U		0.5U			0.5U		0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U
Magnesium, Dissolvec	mg/L	3.36		3.74		2.57			5.28		1.7	3.55	4.01	4.53	4.24	6.46	4.88	1.9
Iron, Dissolvec	mg/L	0.05U		0.05U		0.05U			0.05U		0.05U	0.05U		0.05U	0.05U	0.05U	0.05U	0.05U
Calcium, Dissolvec	mg/L	8		8.65		6.14			12.3		16.9	15.3	14.7	14.2	8.71	19.8	10.3	24.3

Notes:

F(d) = Deep portion of Unit F

Table 6-1. Hydraulic Continuity Relative Risk Matrix for Potential Impacts

	Area					
	Johns Prairie / Lower Johns Creek	**Oak Park / Mid Johns Creek**	**COS Well 3 / Island Lake**	**COS Test Well / COS Well 1 / Maple Glen**	**Lower Goldsborough Creek/Downtown Shelton**	**Oakland Bay**
Hydrostratigraphy	Top of Unit F occurs relatively near to creek bed in lower Johns Creek, indicating potential for hydraulic continuity. Temperature data indicate groundwater discharge to Johns Creek. This may occur where top of Unit F is near creekbed.	Relatively thick layers of sediments separate Unit F from middle part of Johns Creek, thus minimizing potential hydraulic continuity. However, locally, Units B and C are thin or absent, thus allowing potential hydraulic continuity.	Island Lake appears perched on Unit B till. If pumping effects reach Units A, B, and C, then leakage through the lake bed and Unit B could buffer some of the hydraulic effects of pumping from COS Well 3.	Shelton TW is very deep, overlain by multiple fine-grained layers. It is, therefore, less connected to shallow groundwater and surface water.	Unit F contains multiple fine-grained layers above productive zones, dampening effect of pumping on overying units and surface water. Baseflow in Goldsborough Creek is larger than Johns Creek. Occurs at outlet of creek basins.	Does not discharge to significant creeks. Groundwater discharges to marine water.
Water Level	Tidal effect observed in Unit D (Dittmer) and Johns Creek stage may indicate hydraulic continuity or propagation of pressure pulse. No visual response between POS JP pumping wells, Dittmer, and Creek stage.	*No long-term water level monitoring conducted in this area.* Water level contour maps suggest that Unit D may be discharging to Johns Creek. Hydraulic connection between Units F and D is uncertain	No apparent water level response in Unit D (Hiapark) due to pumping Unit F (COS Wells 1 or 3)	Deep Unit F (COS Test Well) responds to pumping from upper Unit F (COS Well 1)	Flowing artesian wells occur here, indicating upward gradient, suggesting potential for hydraulic continuity.	*No long-term water level monitoring conducted in this area*
Geochemistry	Unit D and/or Unit F aquifers hydraulically connected to shallow groundwater (stable isotopes indicated "mixed"). Deep Unit F aquifer (Bob Barnes) is predominately old, but Unit F well water is mixed with some young water (tritium in Bob Barnes).	Unit A (Stonebriar 1) well is predictably young water and Unit F (Oak Park #2) aquifer is a mix of young (presence of tritium) and old (radio carbon age 1510 years) suggesting a connection to downward moving shallow groundwater.	Upper Unit F (COS Well 3) not strongly connected to shallow groundwater (based on stable isotopes), however detectable nitrate indicates connection with shallower groundwater	Upper Unit F in continuity with overlying units based on stable isotopes of COS Well 1	Deep Unit F shows less mixing with shallower groundwater (stable isotope data for Artesian@pumphouse). Lower Goldsborough Creek stable isotope data indicate minimal mixing with deep artesian groundwater.	For nearest sampled upland Unit F well, Bob Barnes, stable isotopes and tritium indicate deep groundwater with minimal mixing with shallow groundwater
Relative Risk *	***High***	***High***	***Moderate***	***Moderate***	***Moderate***	***Low***

Notes:

This assessment is qualitative and based on available information. Assessment may change with additional information. Further refinement requires further monitoring and/or modeling in specific areas.

* Relative risk of potential impacts to surface water as a result of developing a substantial groundwater supply in Unit F

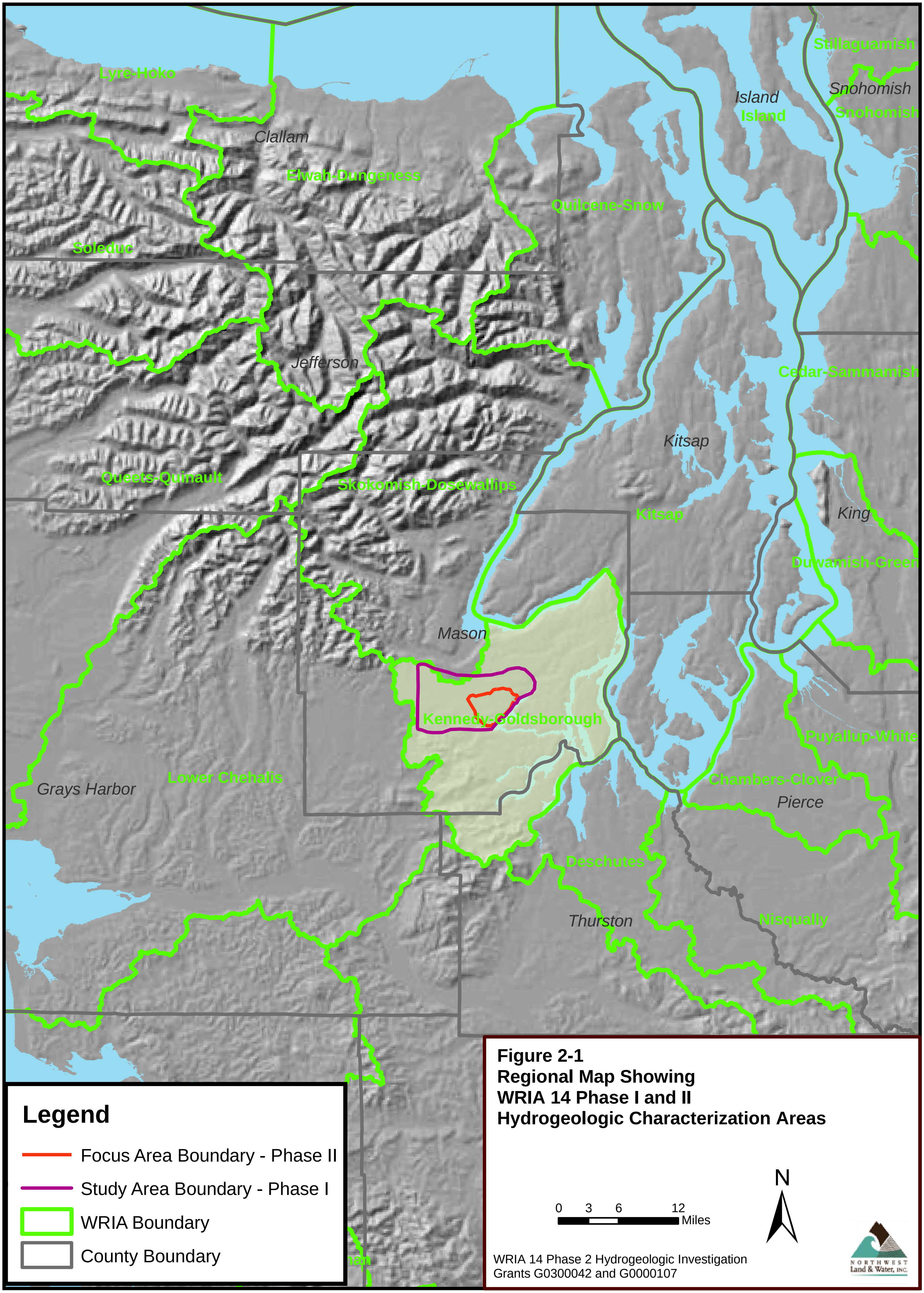
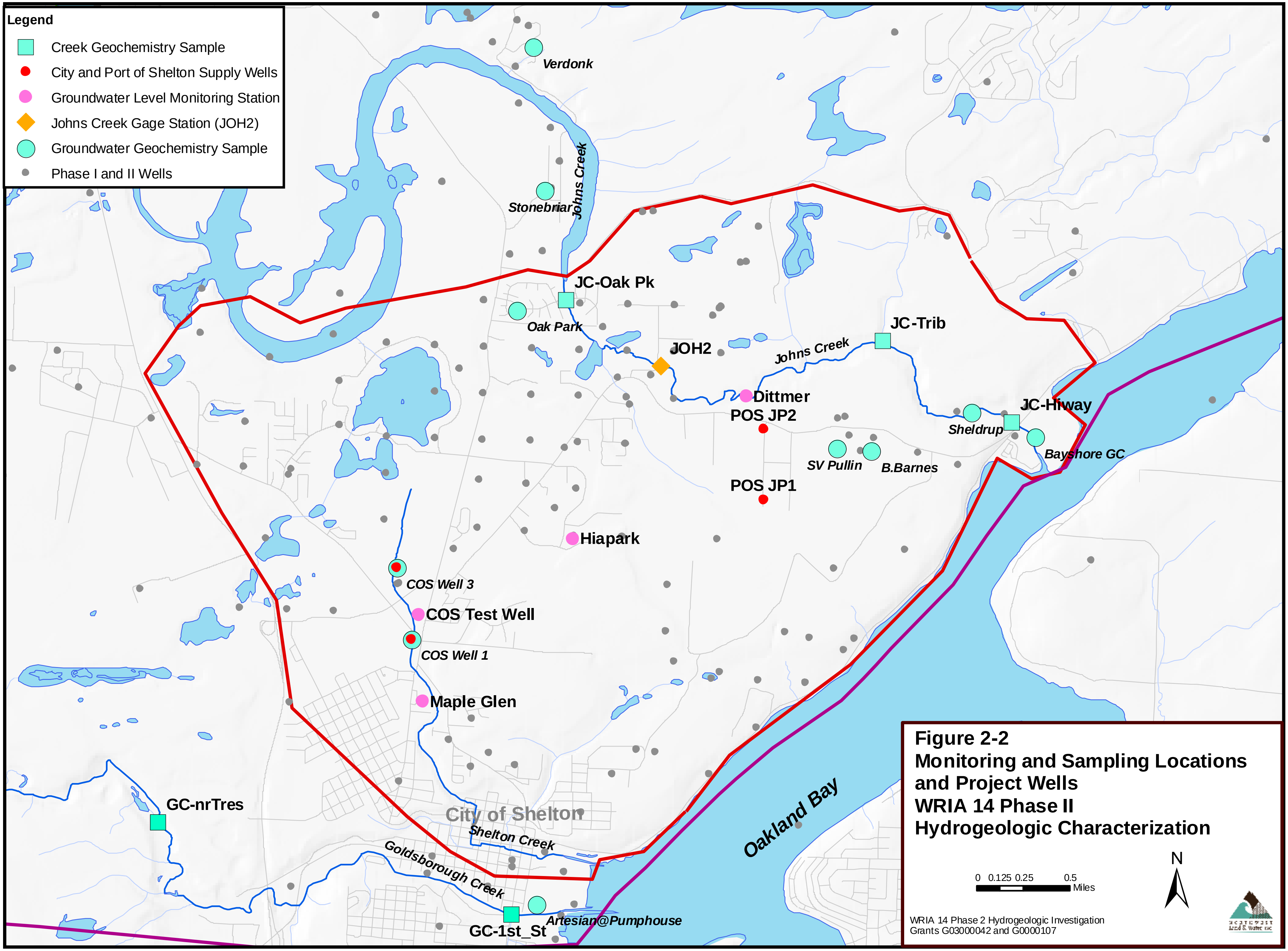


Figure 2-1
Regional Map Showing WRIA 14 Phase I and II Hydrogeologic Characterization Areas



Legend
Creek Geochemistry Sample
City and Port of Shelton Supply Wells
Groundwater Level Monitoring Station
Johns Creek Gage Station (JOH2)
Groundwater Geochemistry Sample
Phase I and II Wells
Verdonk
Stonebriar
Johns Creek
JC-Oak Pk
Oak Park
JOH2
Johns Creek
JC-Trib
Dittmer
POS JP2
JC-Hiway
Sheldrup
Bayshore GC
SV Pullin
B.Barnes
POS JP1
Hiapark
COS Well 3
COS Test Well
COS Well 1
Maple Glen
GC-nrTres
City of Shelton
Shelton Creek
Goldsborough Creek
Oakland Bay
Artesian@Pumphouse
GC-1st_St
Figure 2-2
Monitoring and Sampling Locations
and Project Wells
WRIA 14 Phase II
Hydrogeologic Characterization
0 0.125 0.25 0.5
Miles
N
WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107

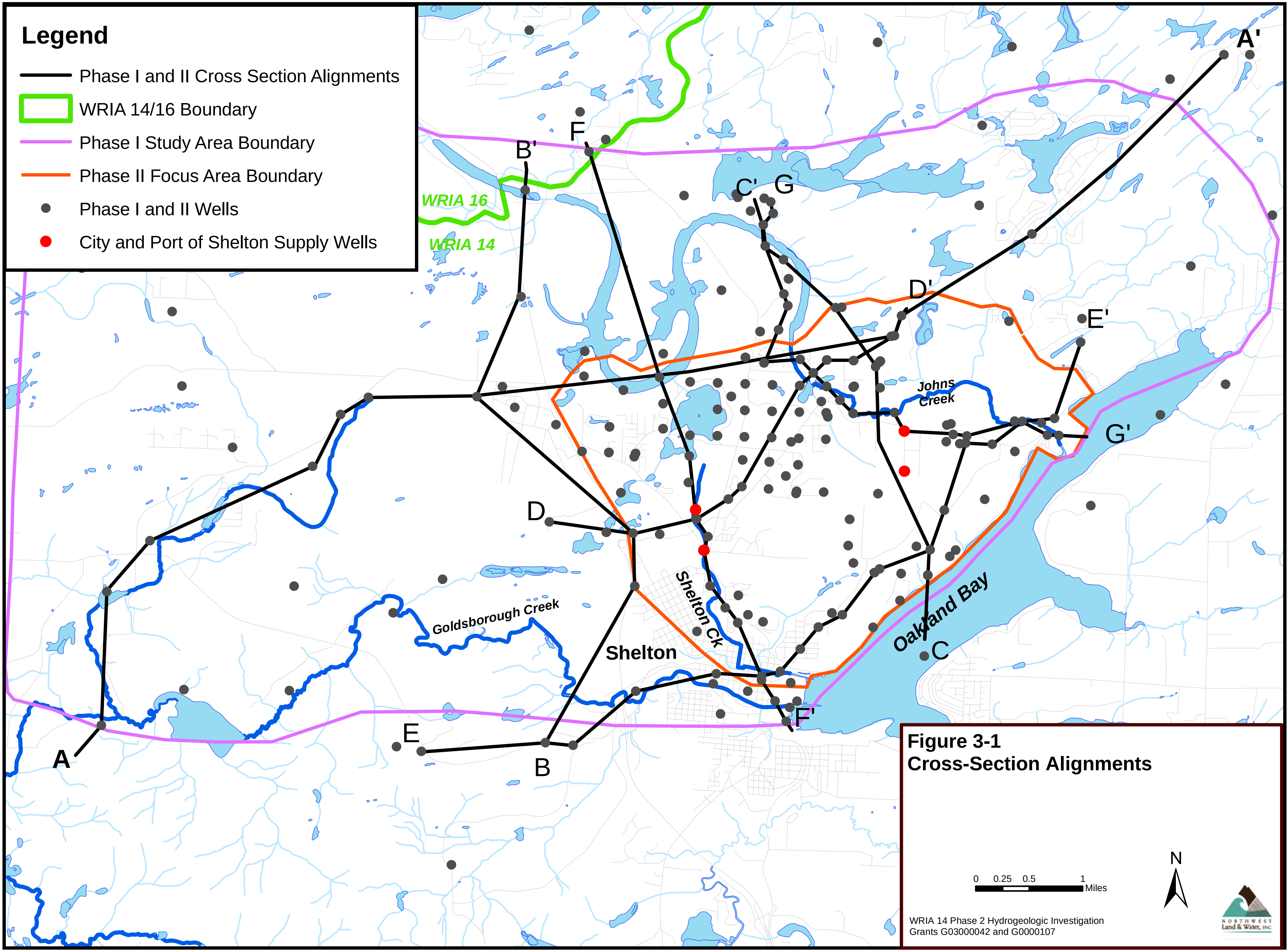


Figure 3-1
Cross-Section Alignments

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107

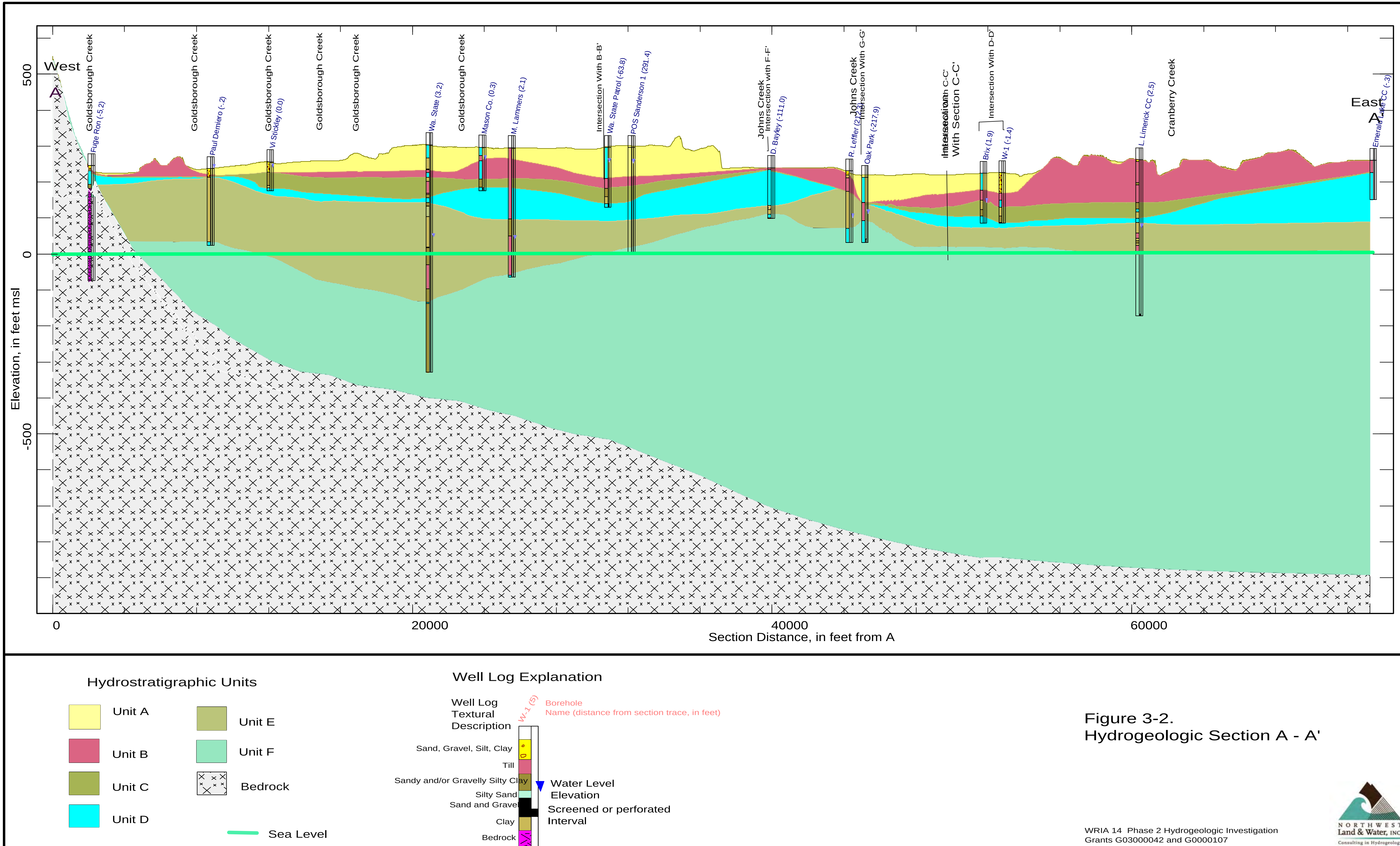


Figure 3-2.
Hydrogeologic Section A - A'

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107

NORTHWEST Land & Water, INC.
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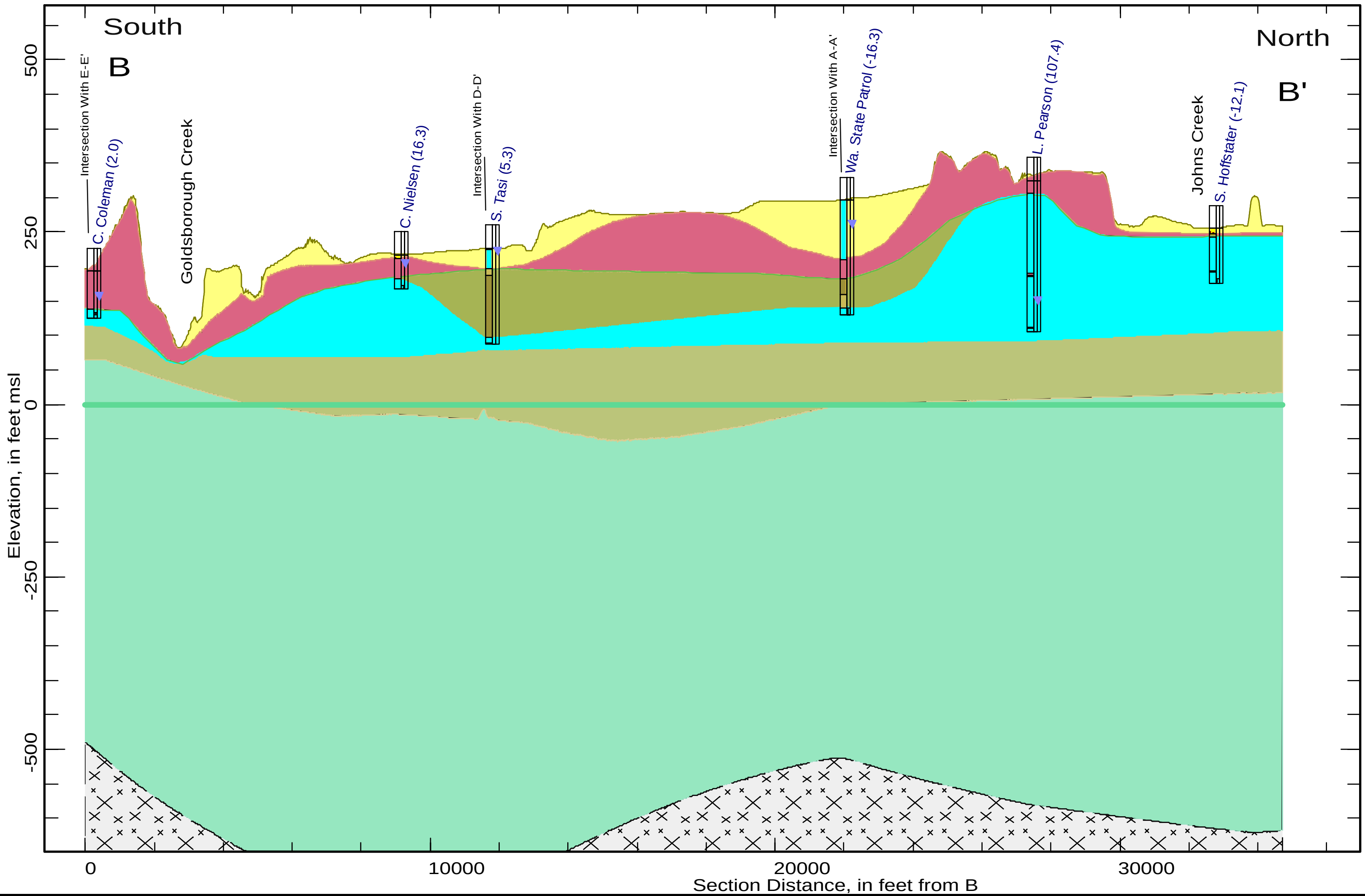

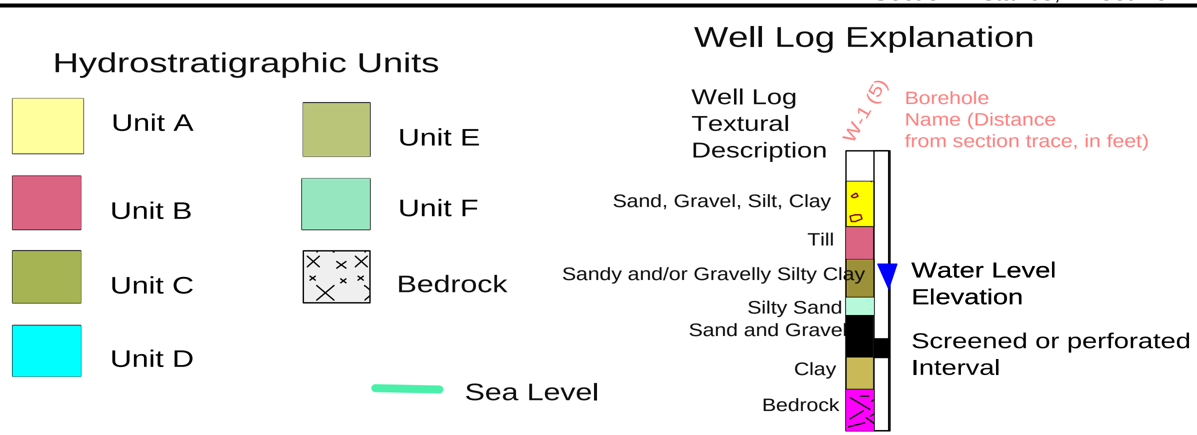

Figure 3-3.
Hydrogeologic Section B-B'

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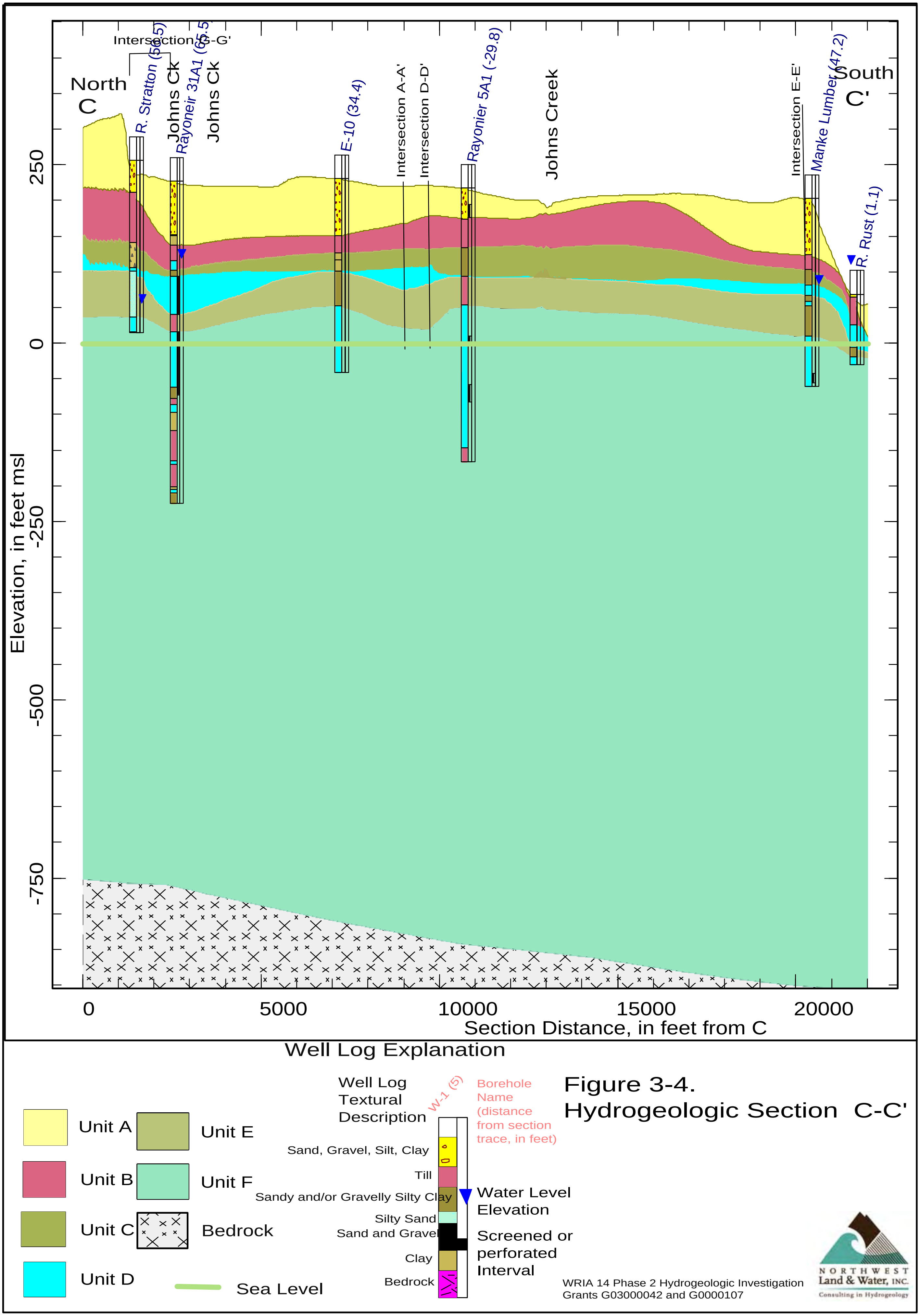

Figure 3-4. Hydrogeologic Section C-C'

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Consulting in Hydrogeology

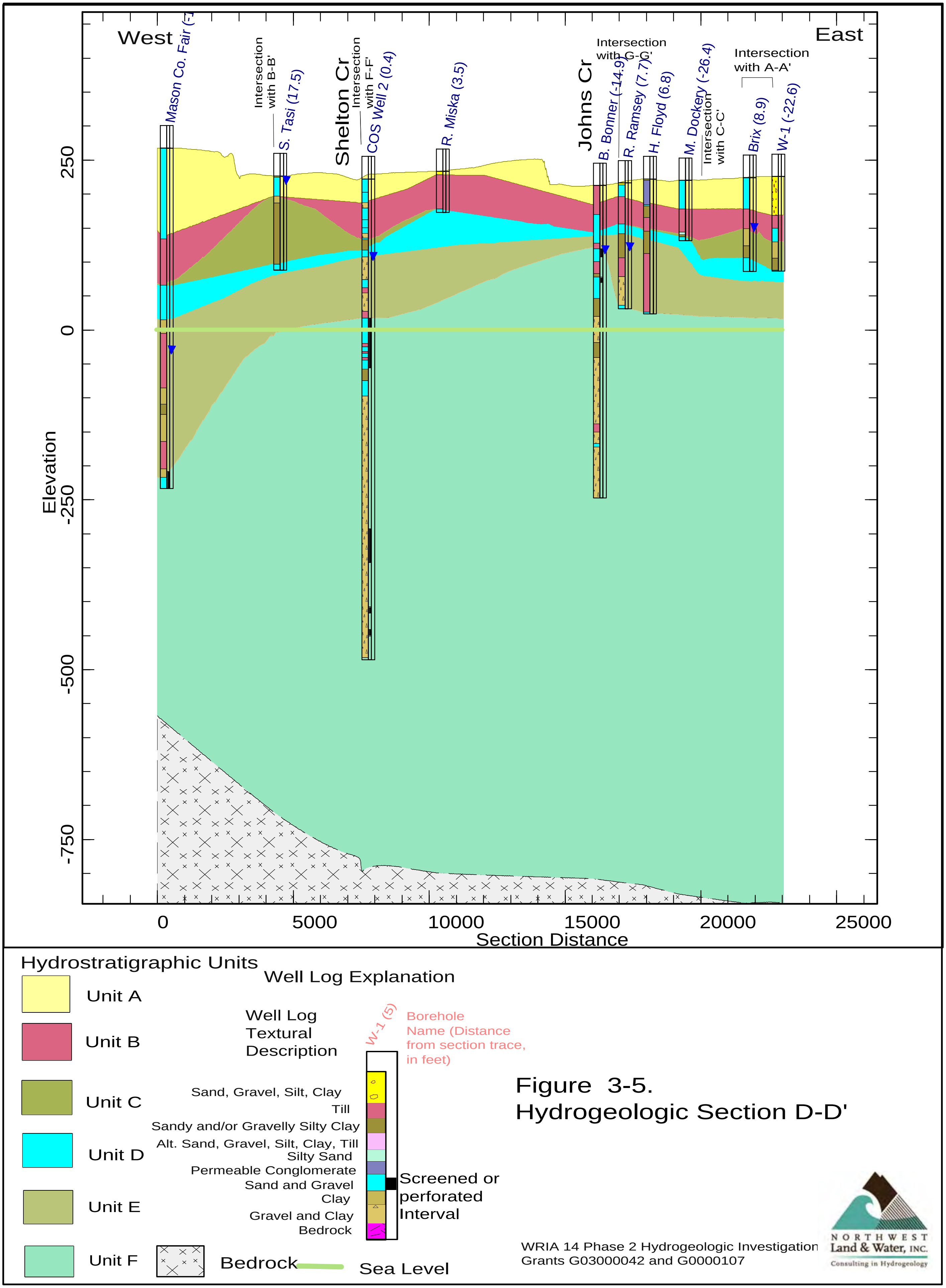

Figure 3-5.
Hydrogeologic Section D-D'

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107

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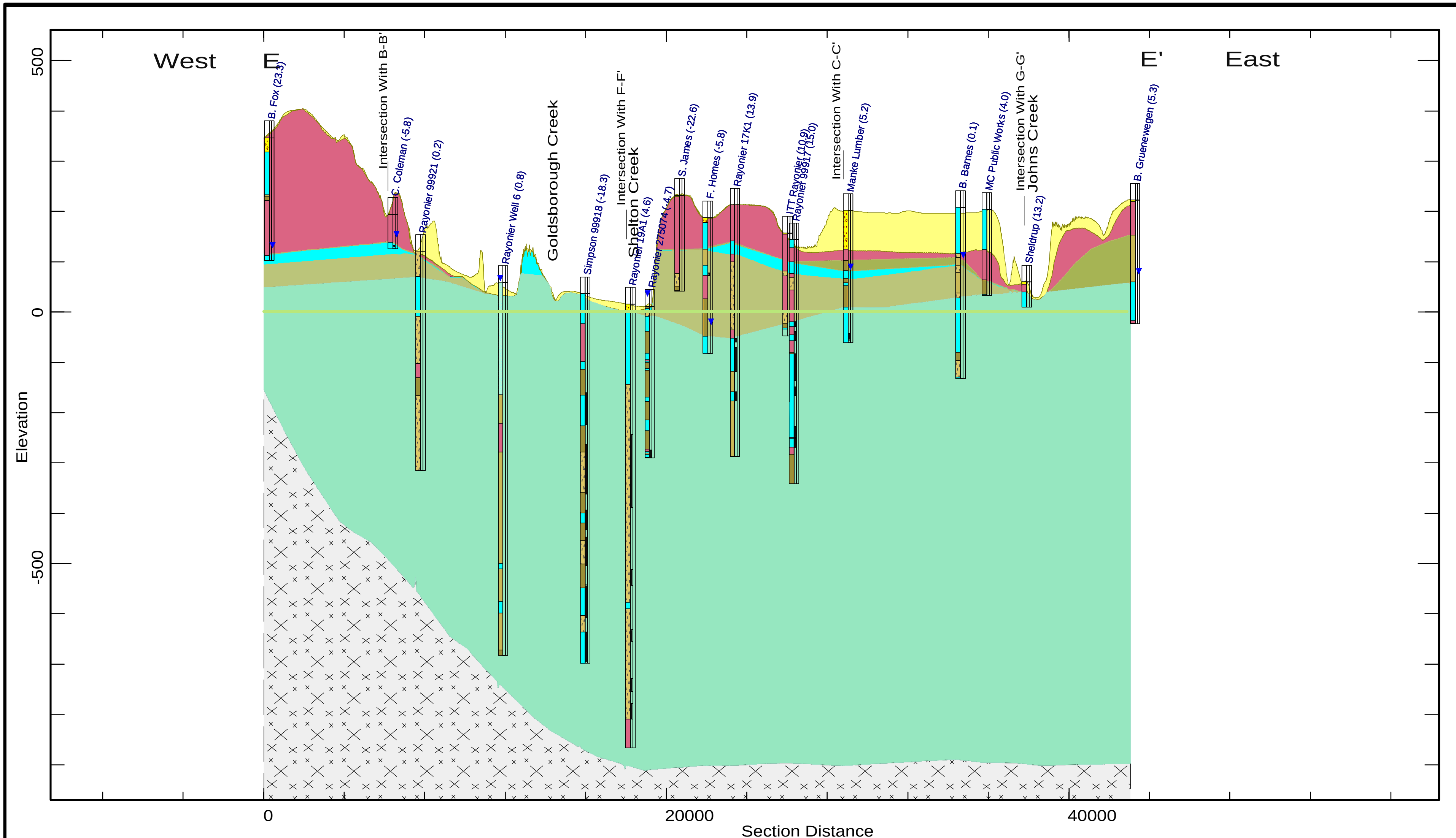

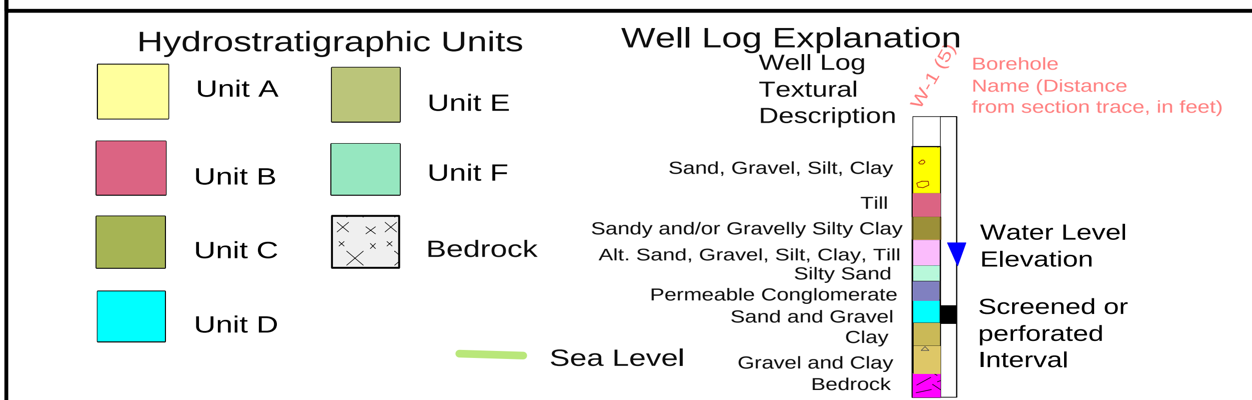

Figure 3-6.
Hydrogeologic Section E-E'

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107

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Consulting in Hydrogeology

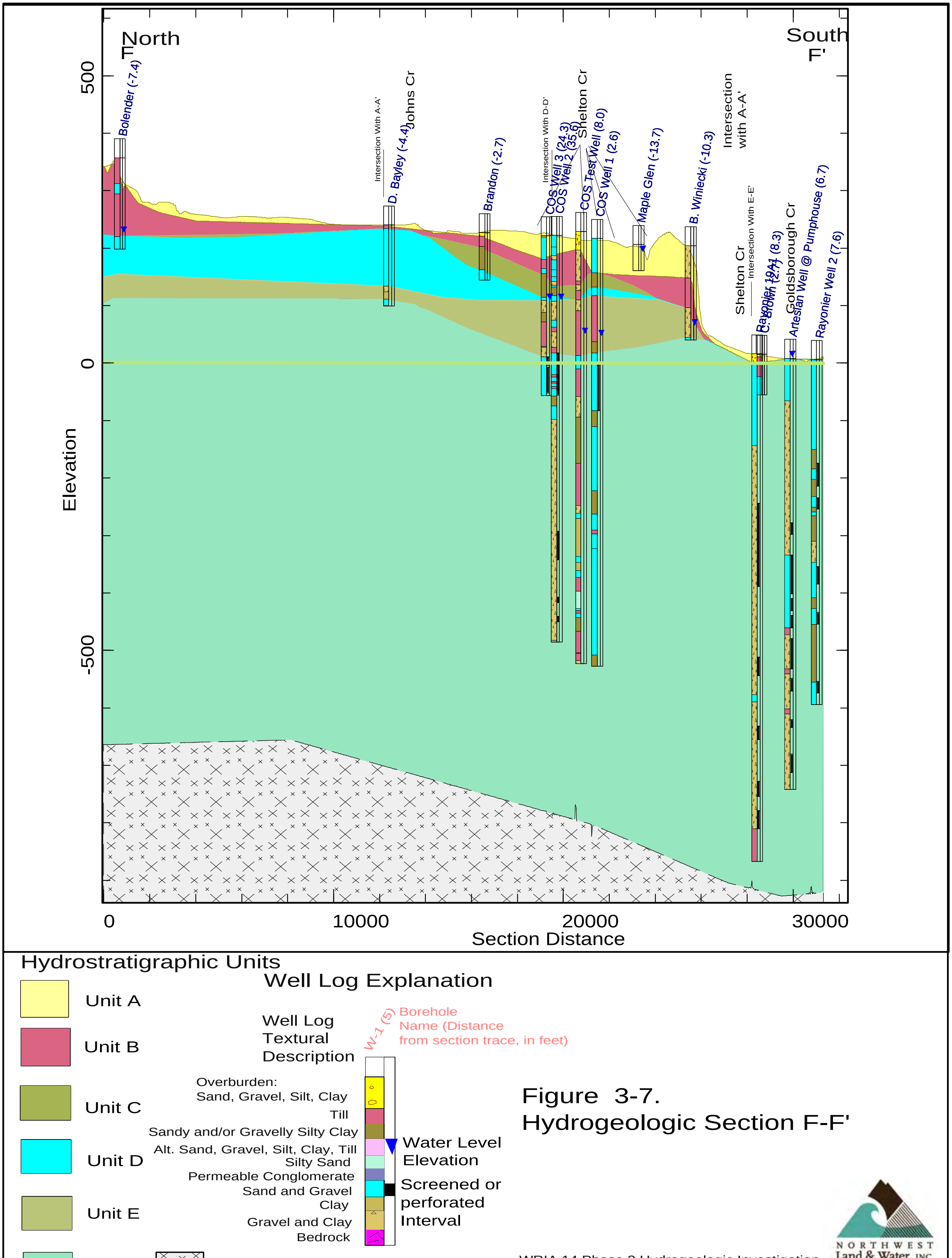


Figure 3-7. Hydrogeologic Section F-F'

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107

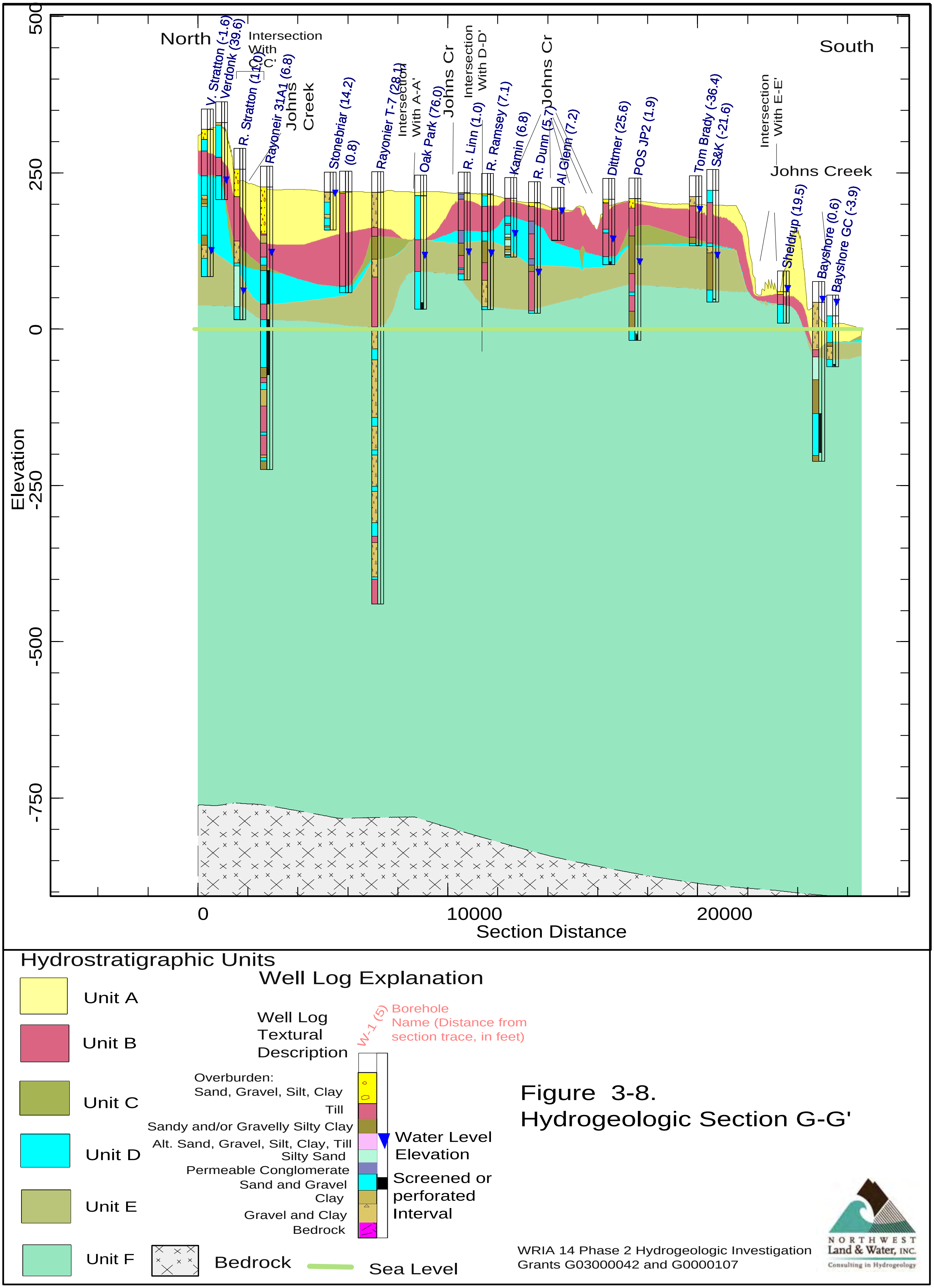
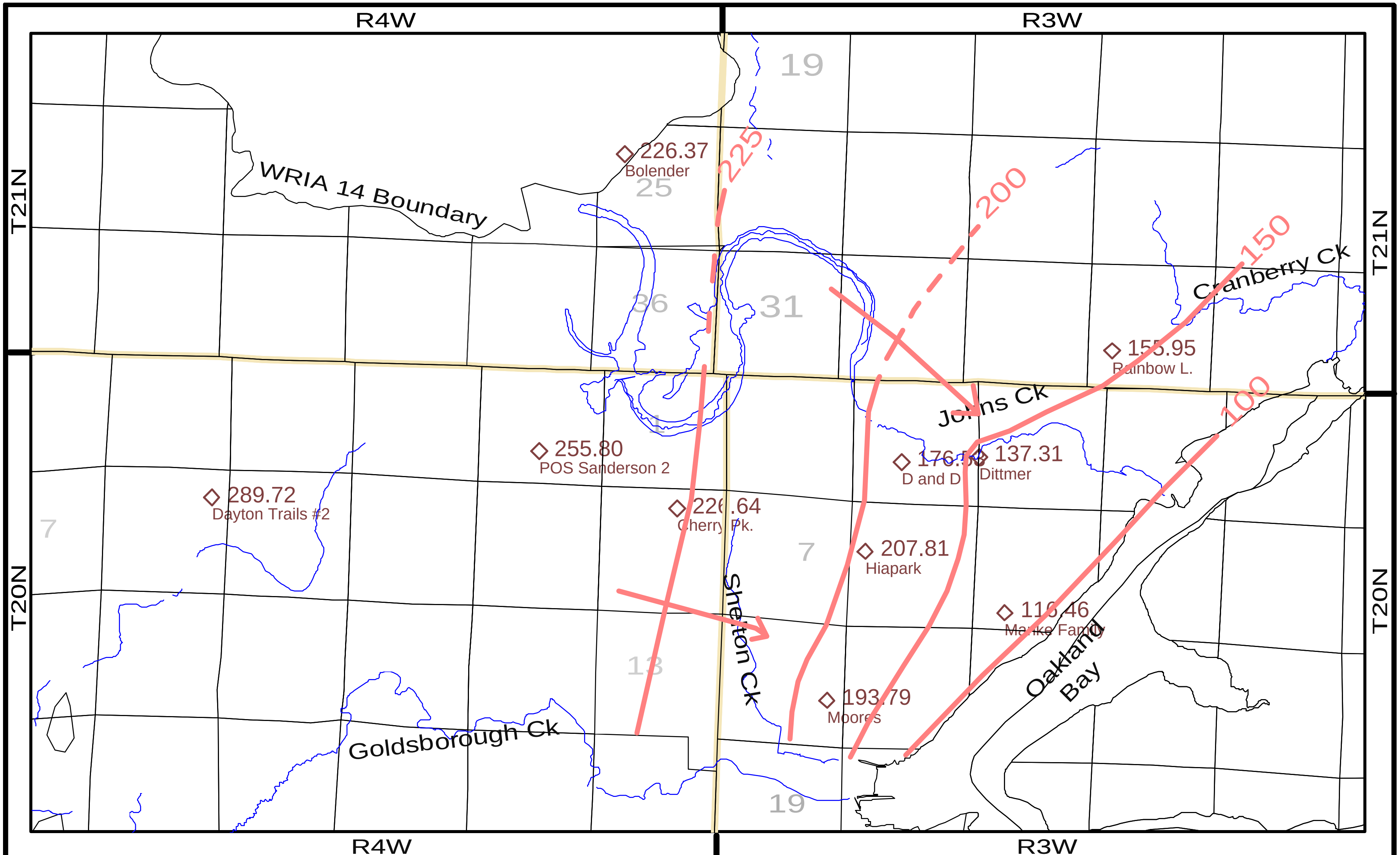


Figure 3-8.
Hydrogeologic Section G-G'

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107



Water Level Contour

101.0 Fall 2004 Unit D Well Water Level Elevation, feet MSL

◇ Unit D Well, Fall 2004 Water Level Survey

N

0 4000 8000 feet

Figure 4-1
Groundwater Level Contours
Fall 2004 Unit D Aquifer

WRIA 14 Phase 2 Hydrogeologic Characterization
Grants G03000042 and G0000107

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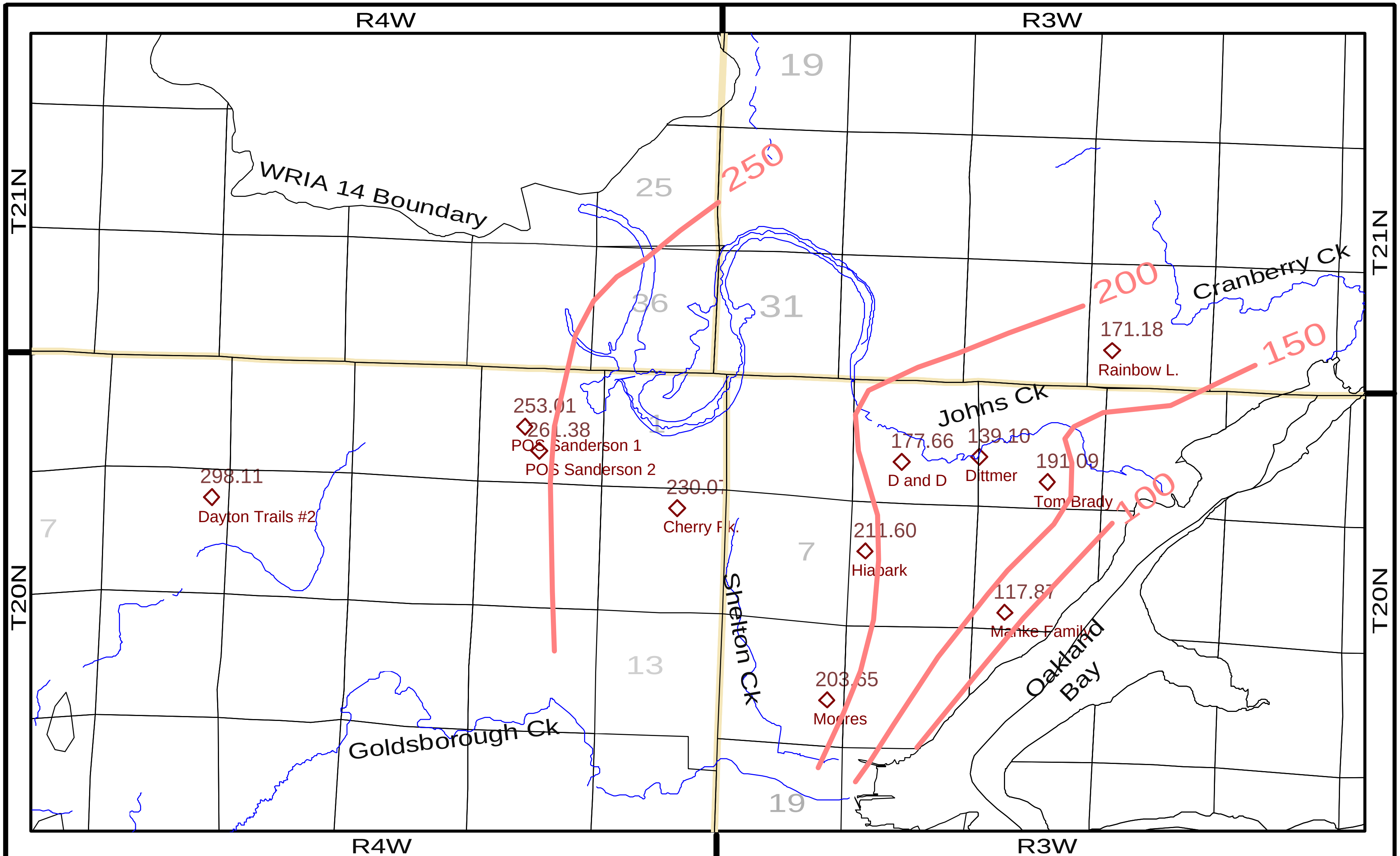


Water Level Contour

101.0 Spring 2005 Unit D Water Level Elevation, feet msl
◇ Unit D Well, Spring 2005 Water Level Survey

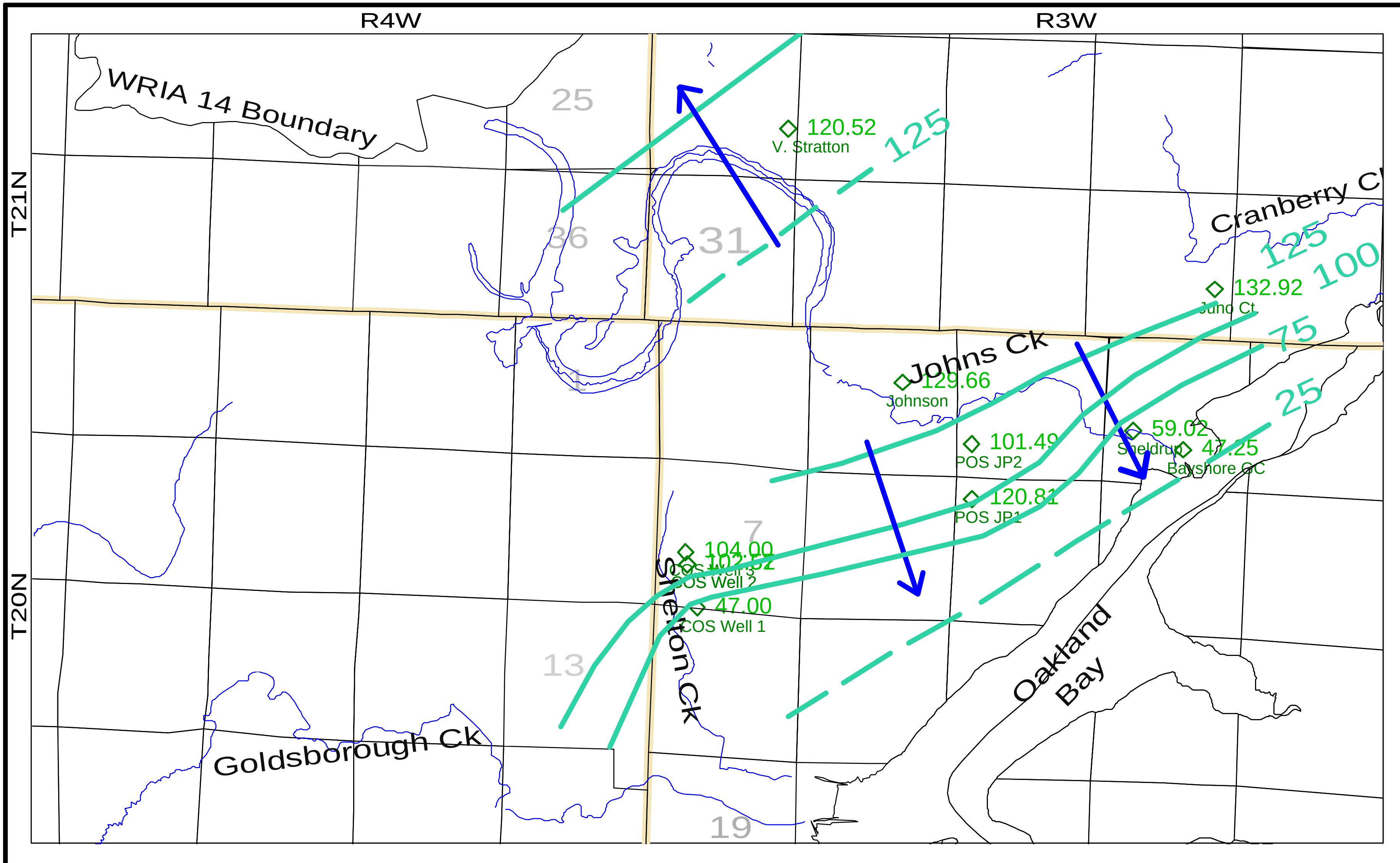
N

0 4000 8000 feet

Figure 4-2.
Groundwater Level Contours
Spring 2005 Unit D Aquifer

WRIA 14 Phase 2 Hydrogeologic Characterization
Grants G03000042 and G0000107

NORTHWEST Land & Water, INC.



◇ Unit F Wells, Fall 2004 Water Level Survey

100 Fall 2004 Unit F Water Level Elevation, feet msl

Groundwater Flow Direction

Water Level Contour

Township/Range

5 Section

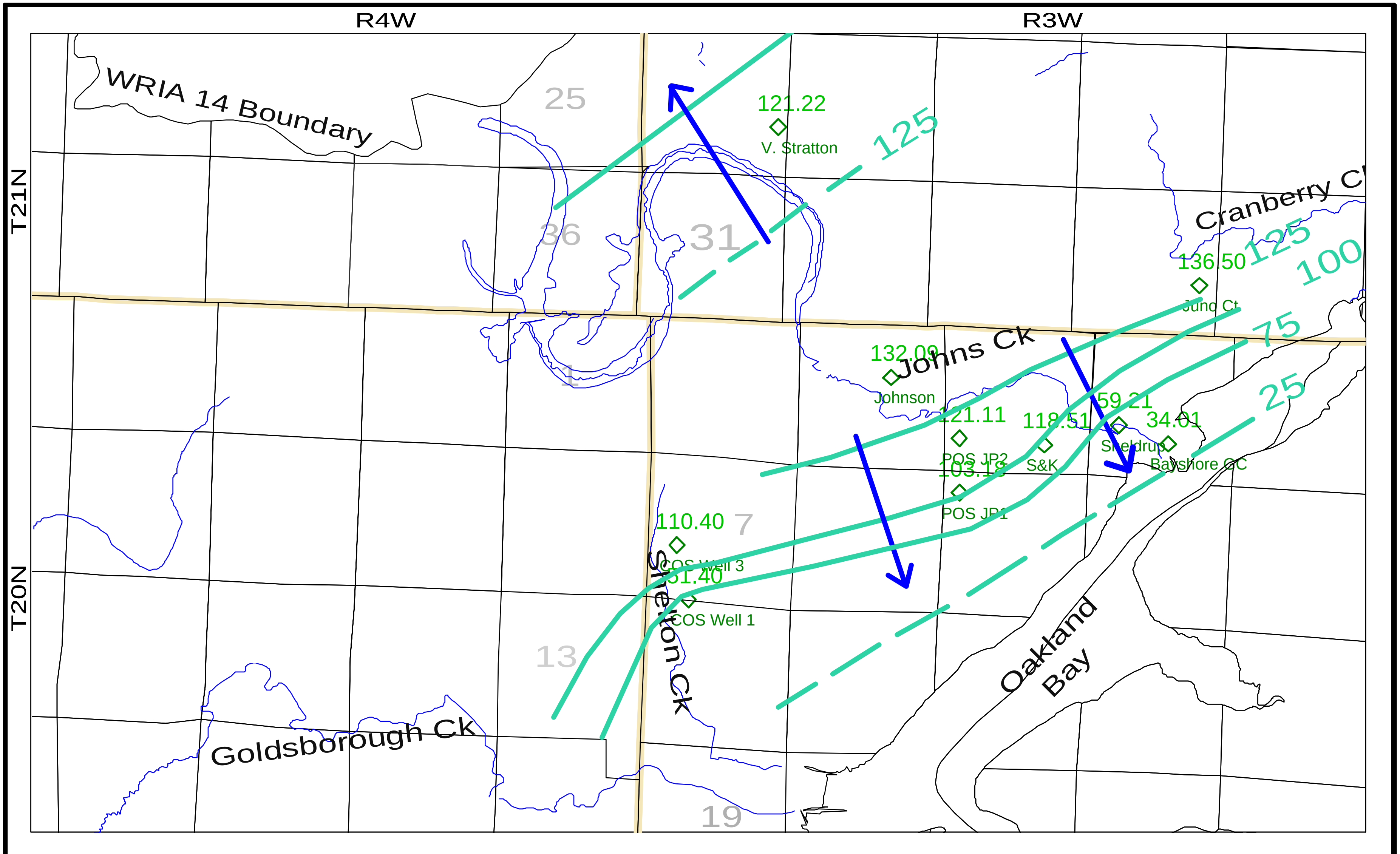
N

0 4000 8000 feet

Figure 4-3.
Groundwater Level Contours
Fall 2004 Unit F Aquifer

WRIA 14 Phase 2 Hydrogeologic Characterization
Grants G03000042 and G0000107

NORTHWEST Land & Water, INC.



◇ Unit F Wells, Spring 2005 Water Level Survey

100 Spring 2005 Unit F Well Water Level Elevation, feet msl

Groundwater Flow Direction

Water Level Contour

Township/Range

5 Section

N

0 4000 8000 feet

Figure 4-4
Groundwater Level Contours
Spring 2005 Unit F Aquifer

WRIA 14 Phase 2 Hydrogeologic Characterization
Grants G03000042 and G0000107

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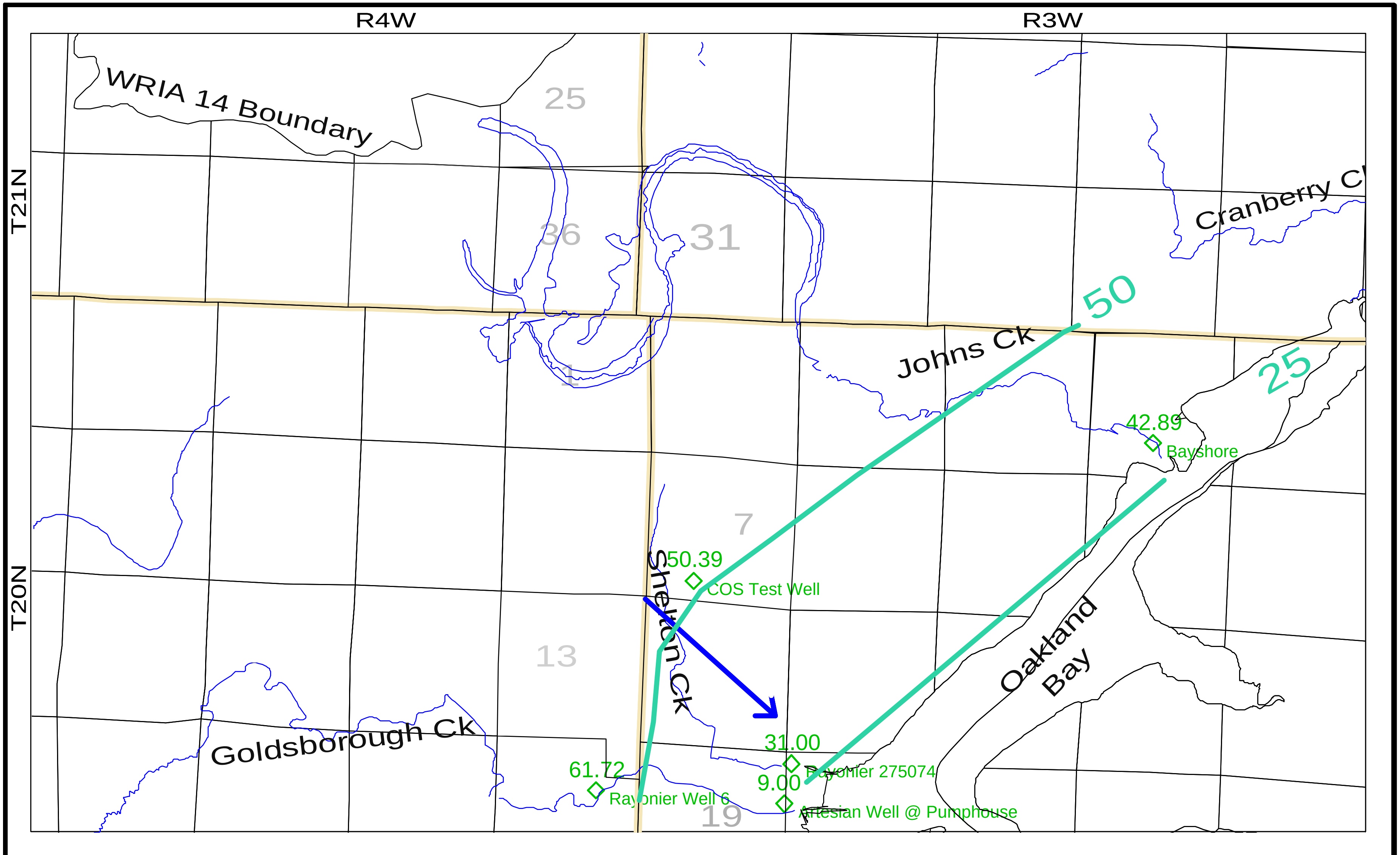

◇ Unit F Very Deep Wells, Fall 2004 Water Level Survey
100 Fall 2004 Very Deep Unit F Water Level Elevation, feet msl

Groundwater Flow Direction
Water Level Contour
Township/Range
5 Section

N

0 4000 8000 feet

Figure 4-5.
Groundwater Level Contours
Fall 2004 Unit F Very Deep Aquifer

WRIA 14 Phase 2 Hydrogeologic Characterization
Grants G03000042 and G0000107

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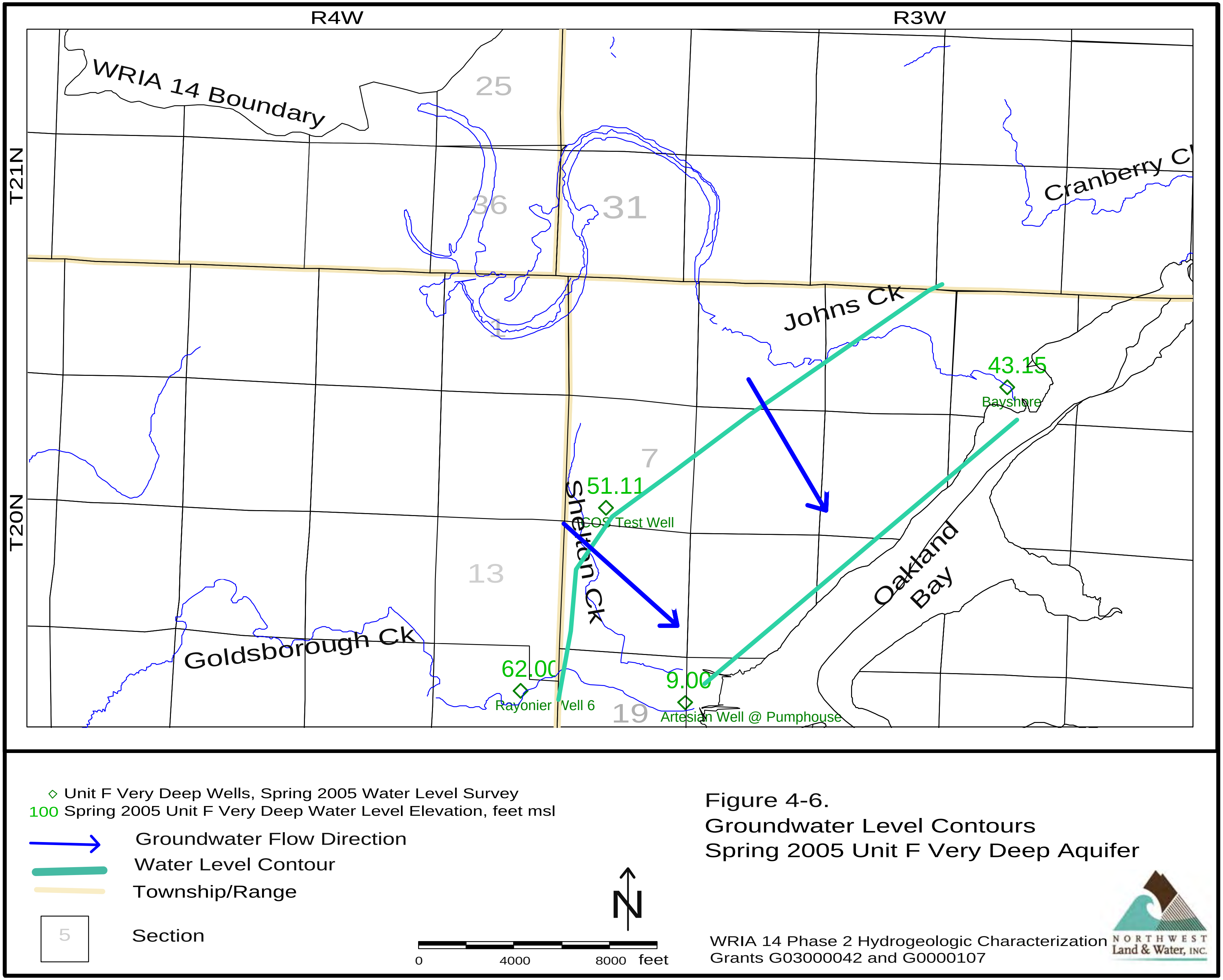

Figure 4-6.
Groundwater Level Contours
Spring 2005 Unit F Very Deep Aquifer

WRIA 14 Phase 2 Hydrogeologic Characterization
Grants G03000042 and G0000107

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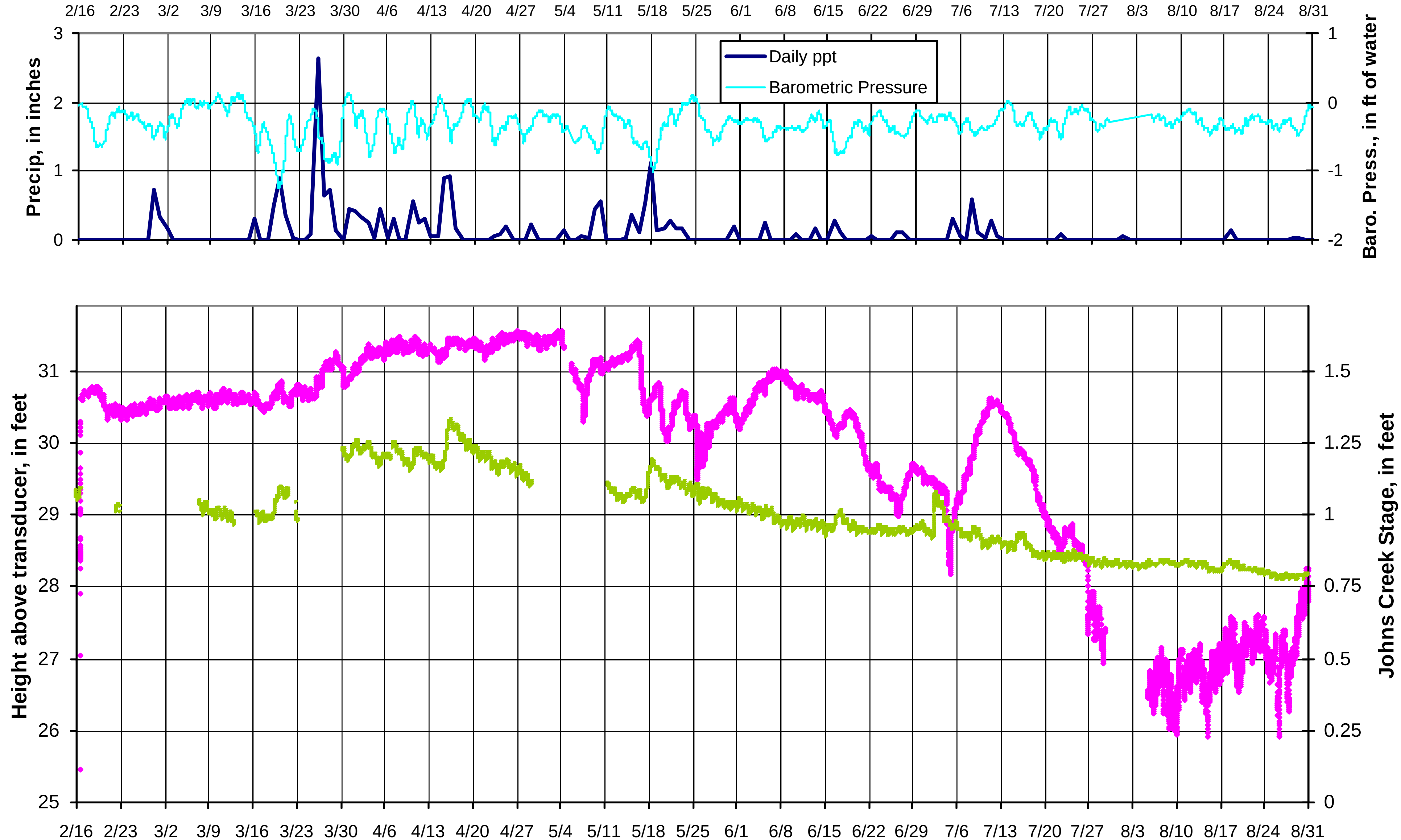

• Dittmer, corrected for barometric pressure, transducer at 108.3 ft, msl

• Johns Creek Stage, feet

Figure 4-7.
Hydrograph for Dittmer Well and Johns Creek Stage, with Barometric Pressure and Precipitation

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107

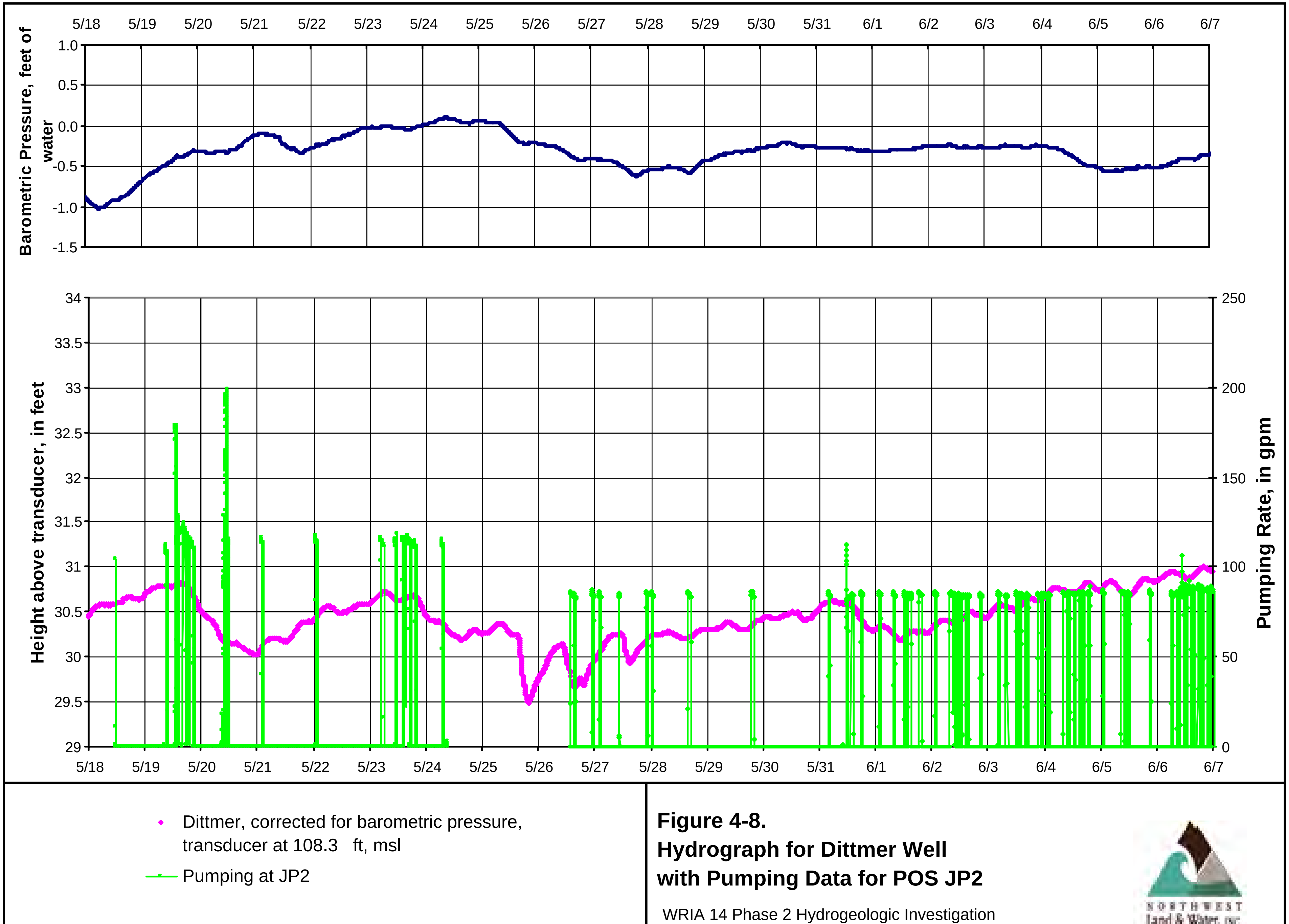

Figure 4-8.
Hydrograph for Dittmer Well with Pumping Data for POS JP2

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107

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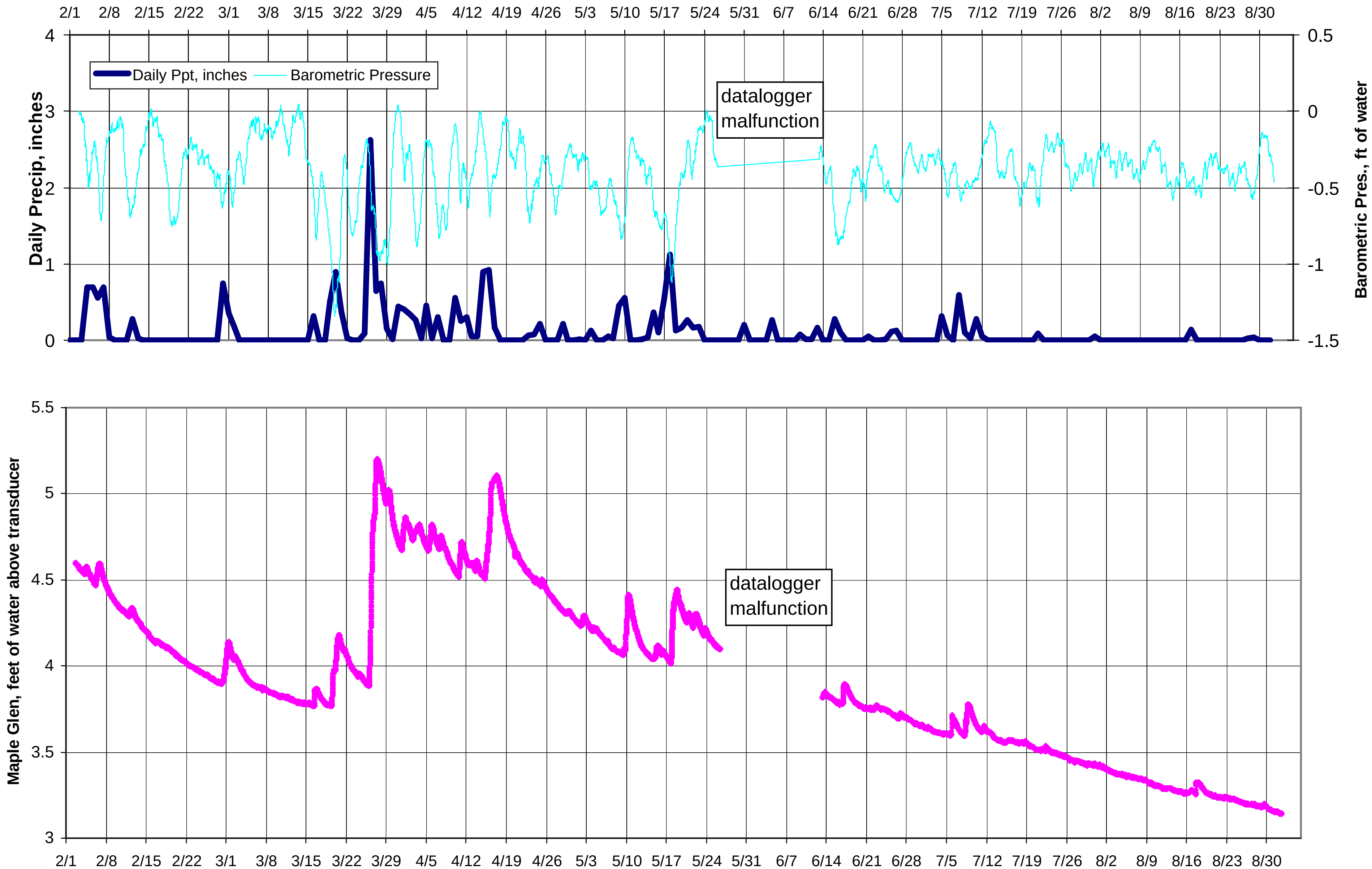

• Maple Glen, corrected for barometric pressure, transducer at 188.6 feet, msl

Figure 4-9.
Hydrograph for Maple Glen Well with Barometric Pressure and Precipitation

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107

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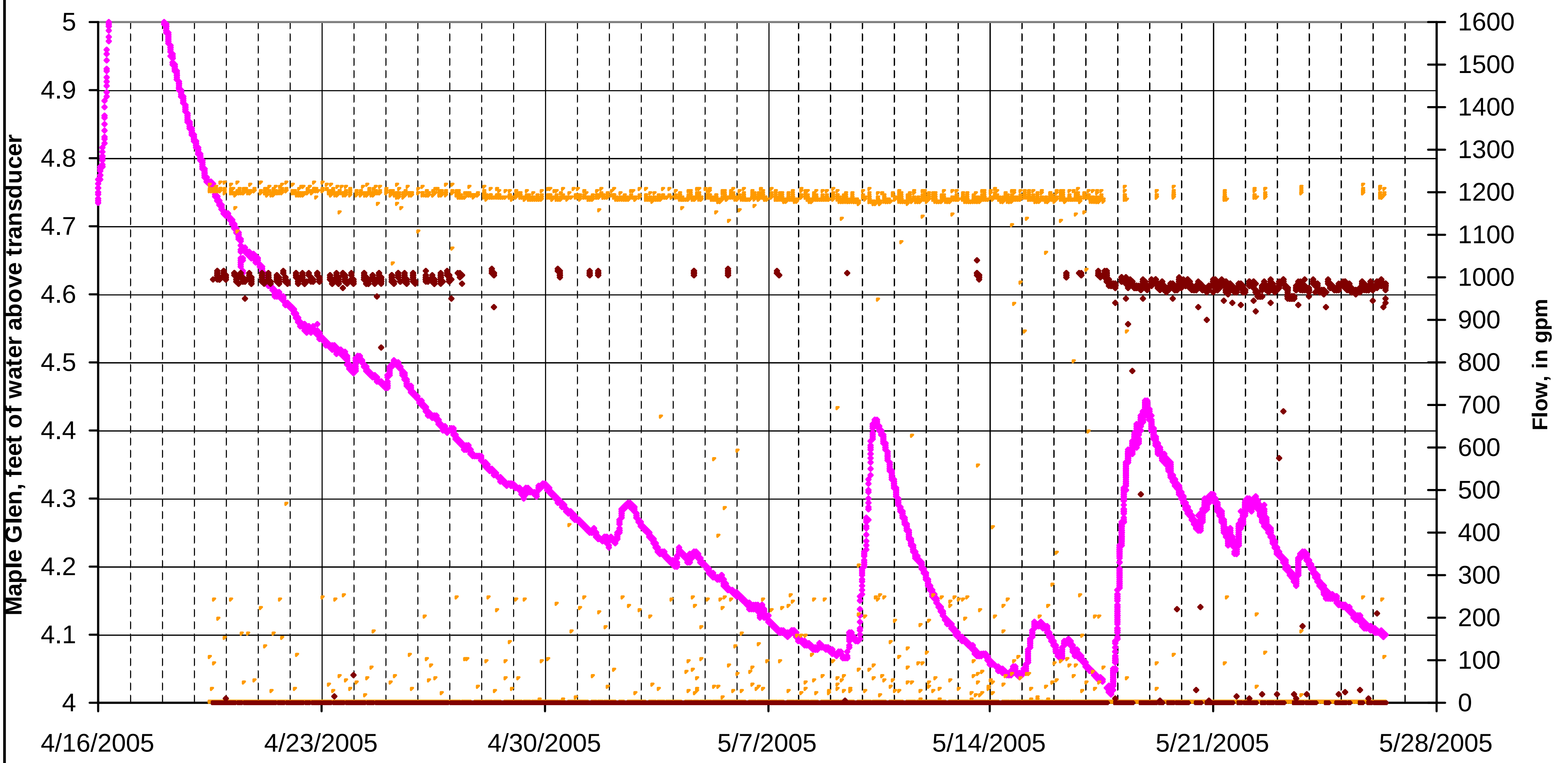
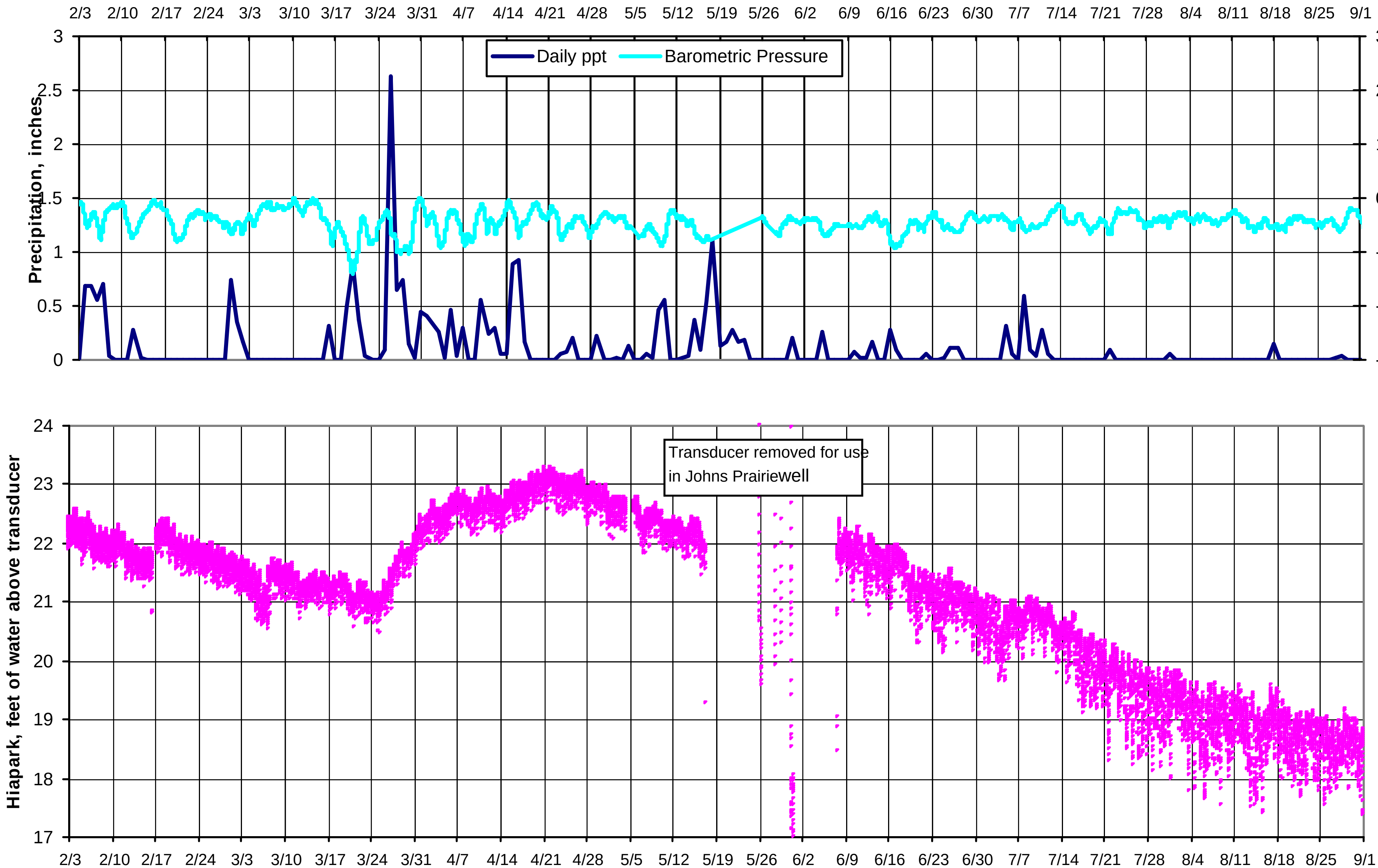


- Maple Glen, corrected for barometric pressure, transducer at 188.69 feet, msl
- Pumping Rate for City of Shelton Well 3, well bottom -57 ft msl
- Pumping Rate for City of Shelton Well 1, elevation of bottom of screen -83 feet msl

Figure 4-10.
Hydrograph for Maple Glen Well with Pumping Data for COS 1 and 3

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107

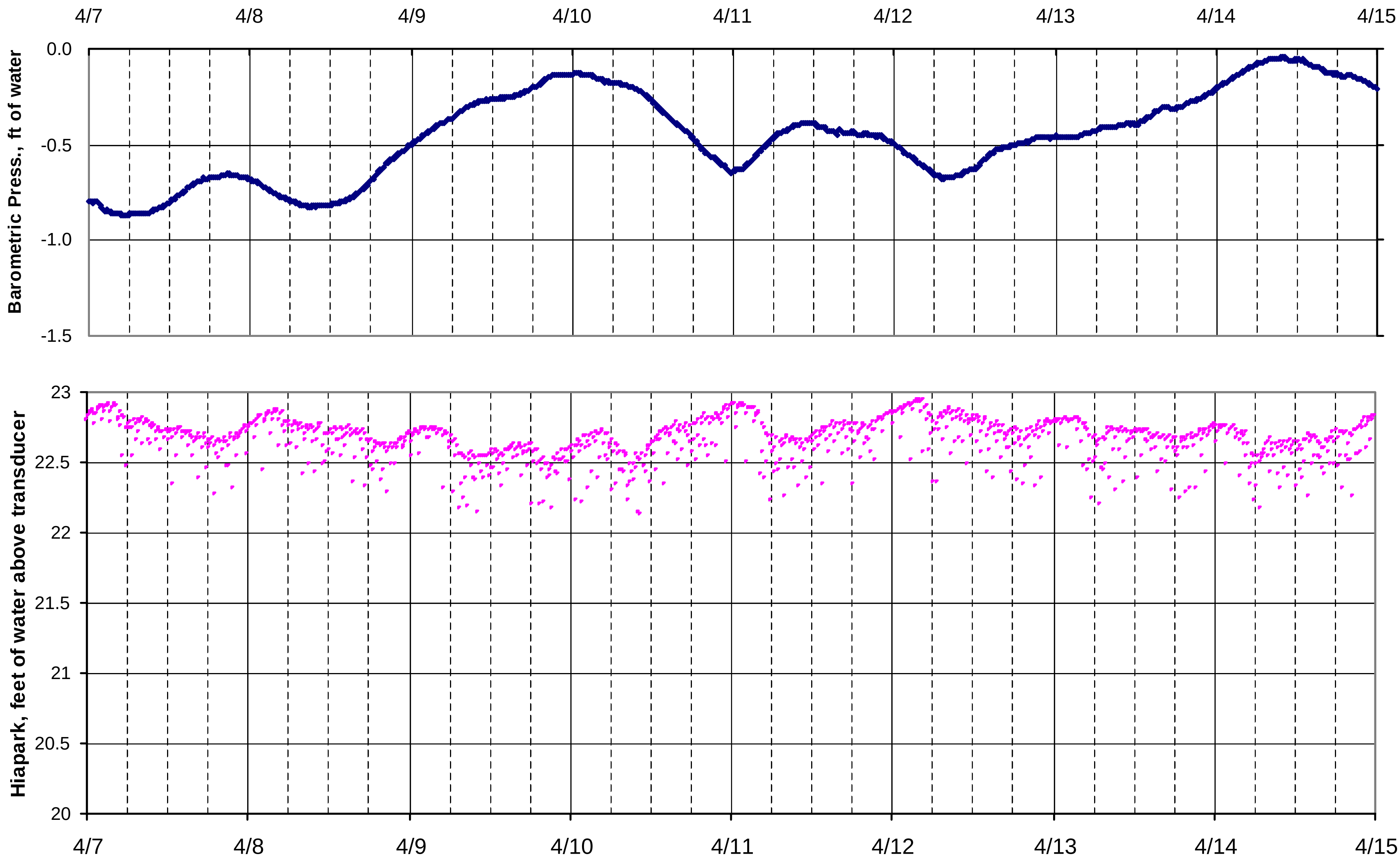
NORTHWEST Land & Water, INC



Hiapark, corrected for barometric pressure, transducer at 191.3 feet, msl

Figure 4-11.
Hydrograph for Hiapark Well with Barometric Pressure and Precipitation

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107



Hiapark, corrected for barometric pressure, transducer at 191.3 feet, msl

Figure 4-12.
Hydrograph for Hiapark Well with Barometric Pressure (1 weeK)

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107

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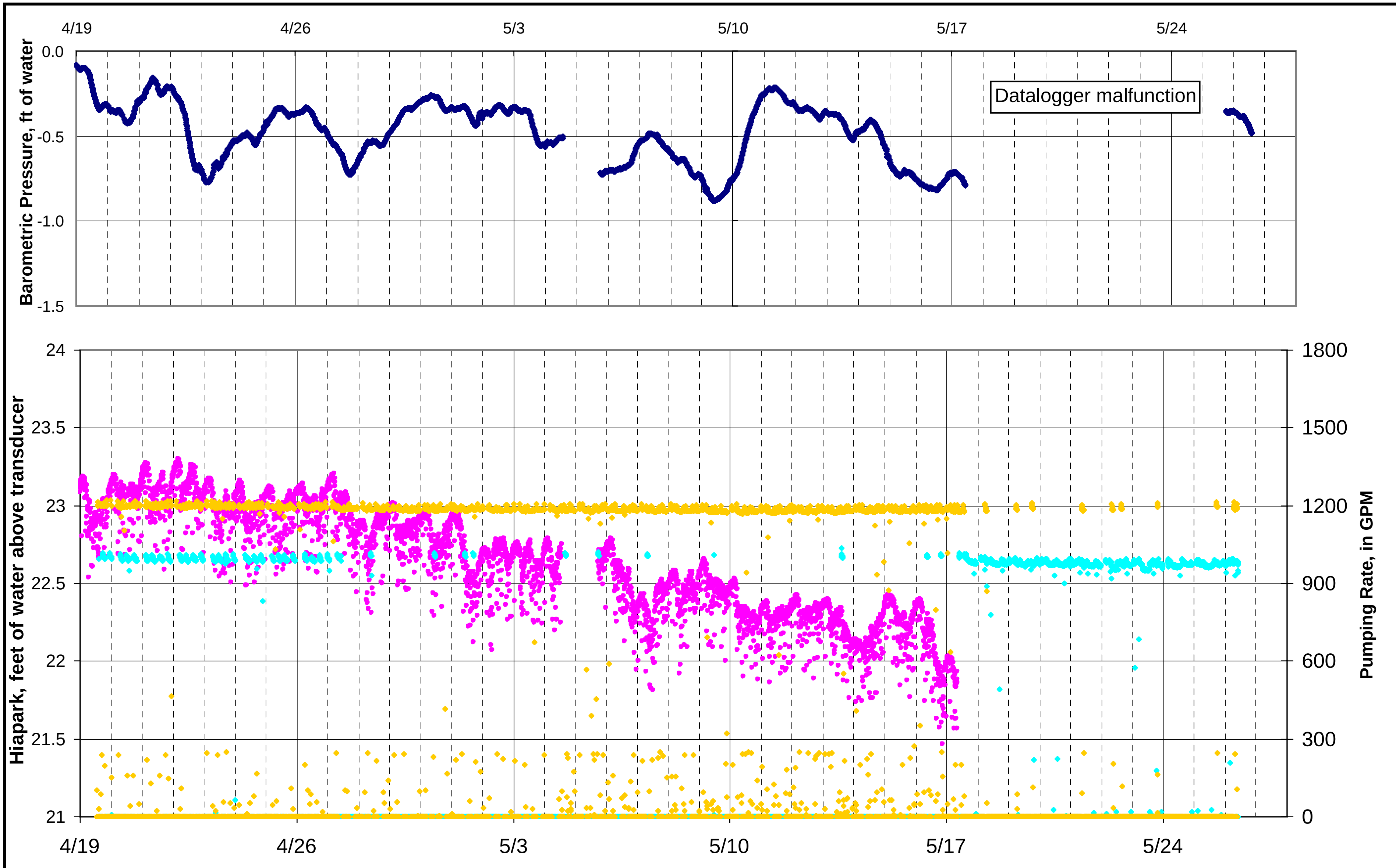

• Hiapark, corrected for barometric pressure, transducer at 191.39 ft, msl

• City of Shelton Well 1, elevation of bottom of screen -83 feet msl

• Pumping Rate for City of Shelton Well 3, well bottom -57 ft msl

Figure 4-13.
Hydrograph for Hiapark Well with Barometric Pressure and Pumping Data for COS 1 and 3

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107

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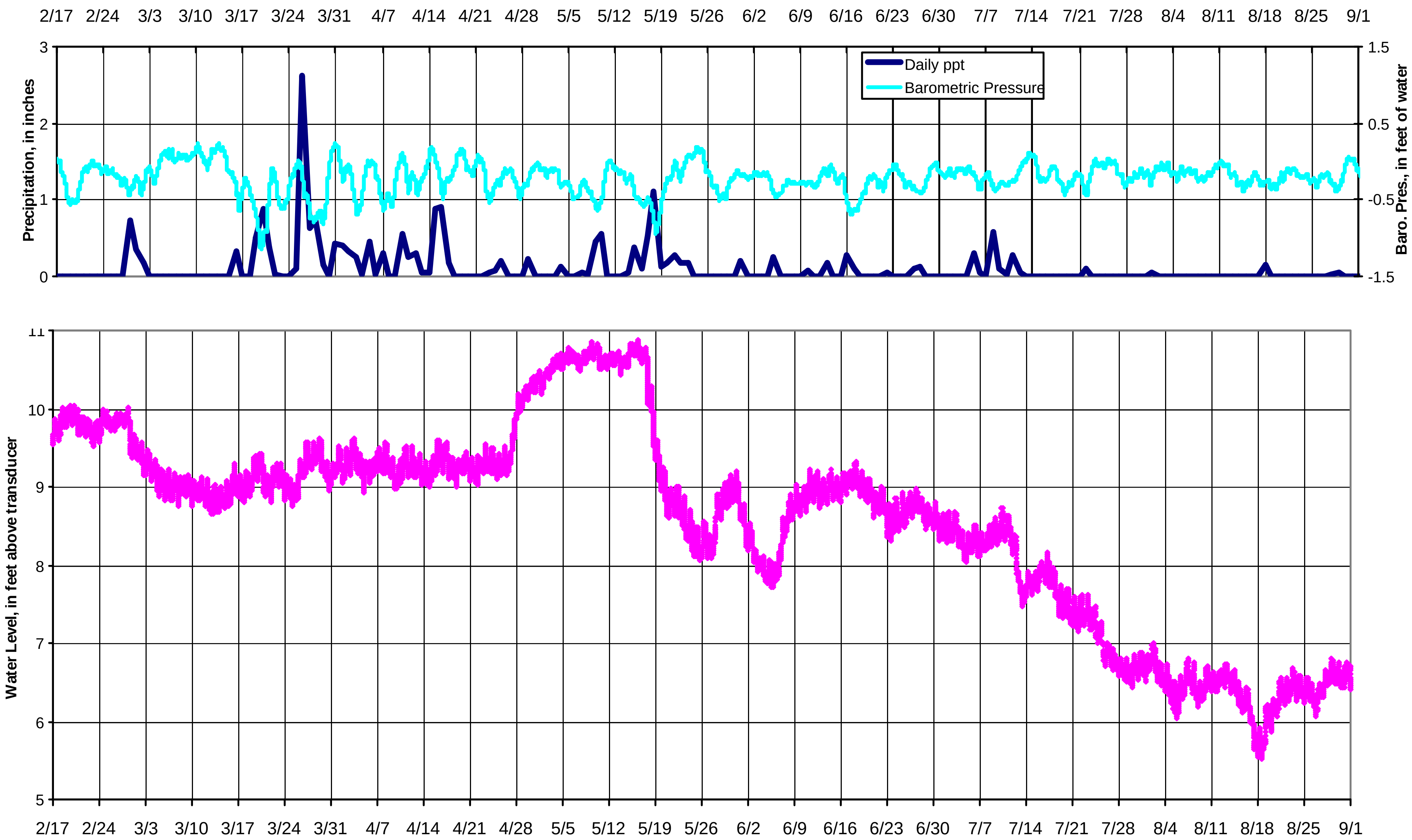

◆ Shelton Test Well, corrected for barometric pressure, transducer at 40.9 feet, msl

Figure 4-14.
Hydrograph For Shelton Test Well With Precipitation and Barometric Pressure

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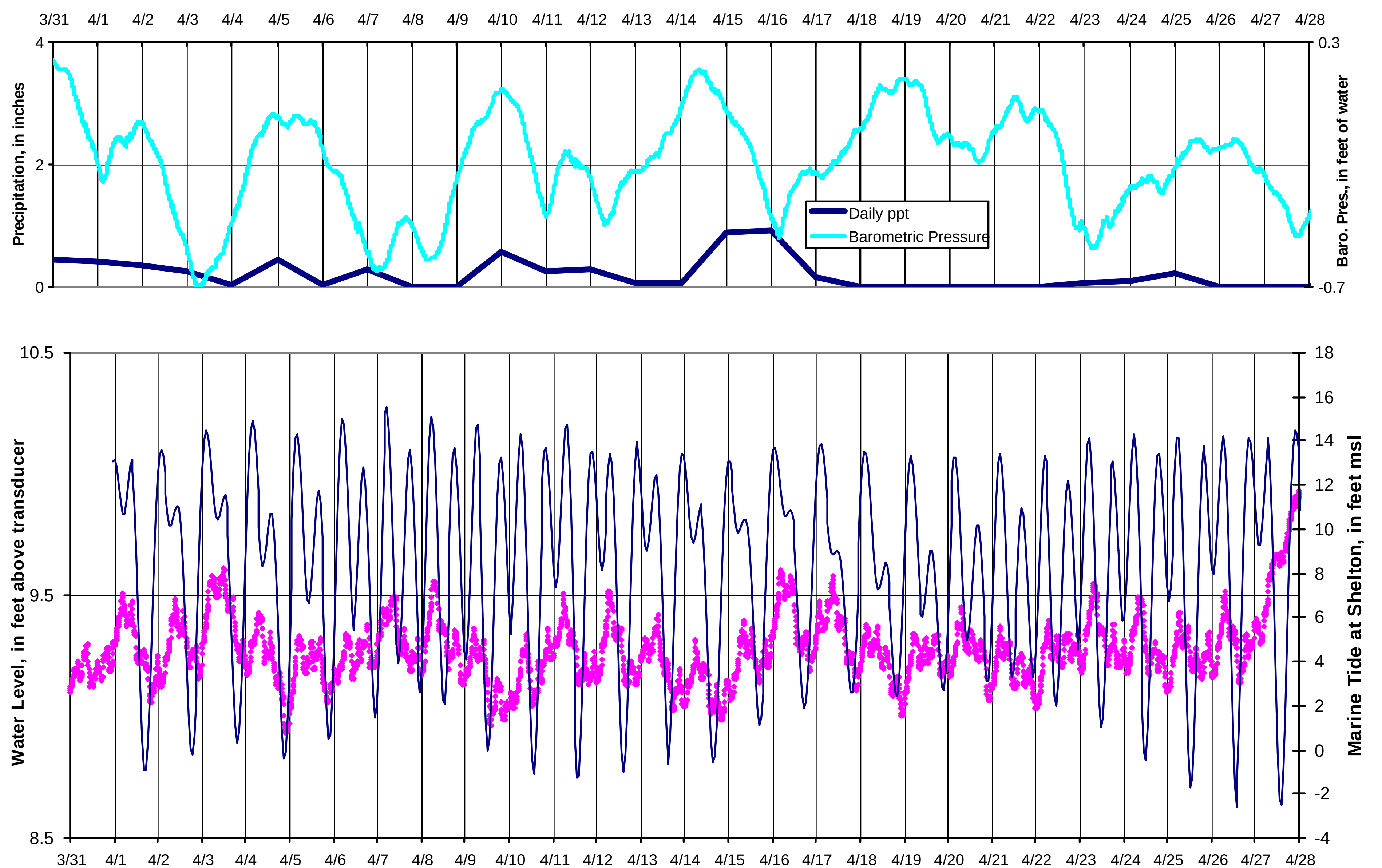
WRIA 14 Hydrogeologic Investigation
Grants G03000042 and G0000107



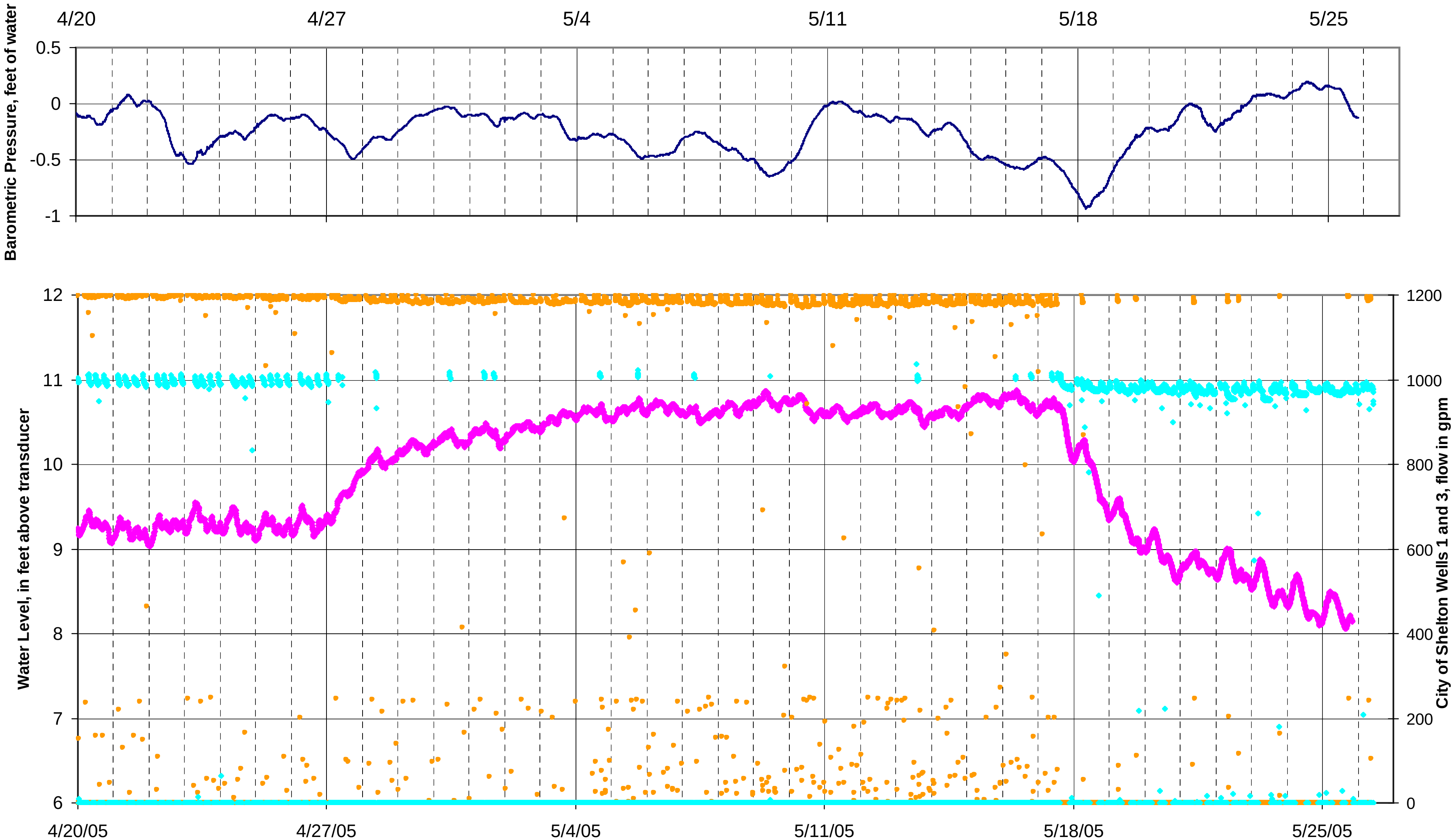
Shelton Test Well, corrected for barometric pressure, transducer at 40.9 feet, msl

Tide at Shelton

Figure 4-15.
Hydrograph for Shelton Test Well with Precipitation and Barometric Pressure (1 Month)

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107

NORTHWEST Land & Water, INC.



- Shelton Test Well, corrected for barometric pressure, transducer at 40.90 feet, msl
- Pumping Rate for City of Shelton Well 3, well bottom -57 ft msl
- Pumping Rate for City of Shelton Well 1, elevation of bottom of screen -83 feet msl

Figure 4-16.
Hydrograph for Shelton Test Well with Pumping Data for COS 1 and 3

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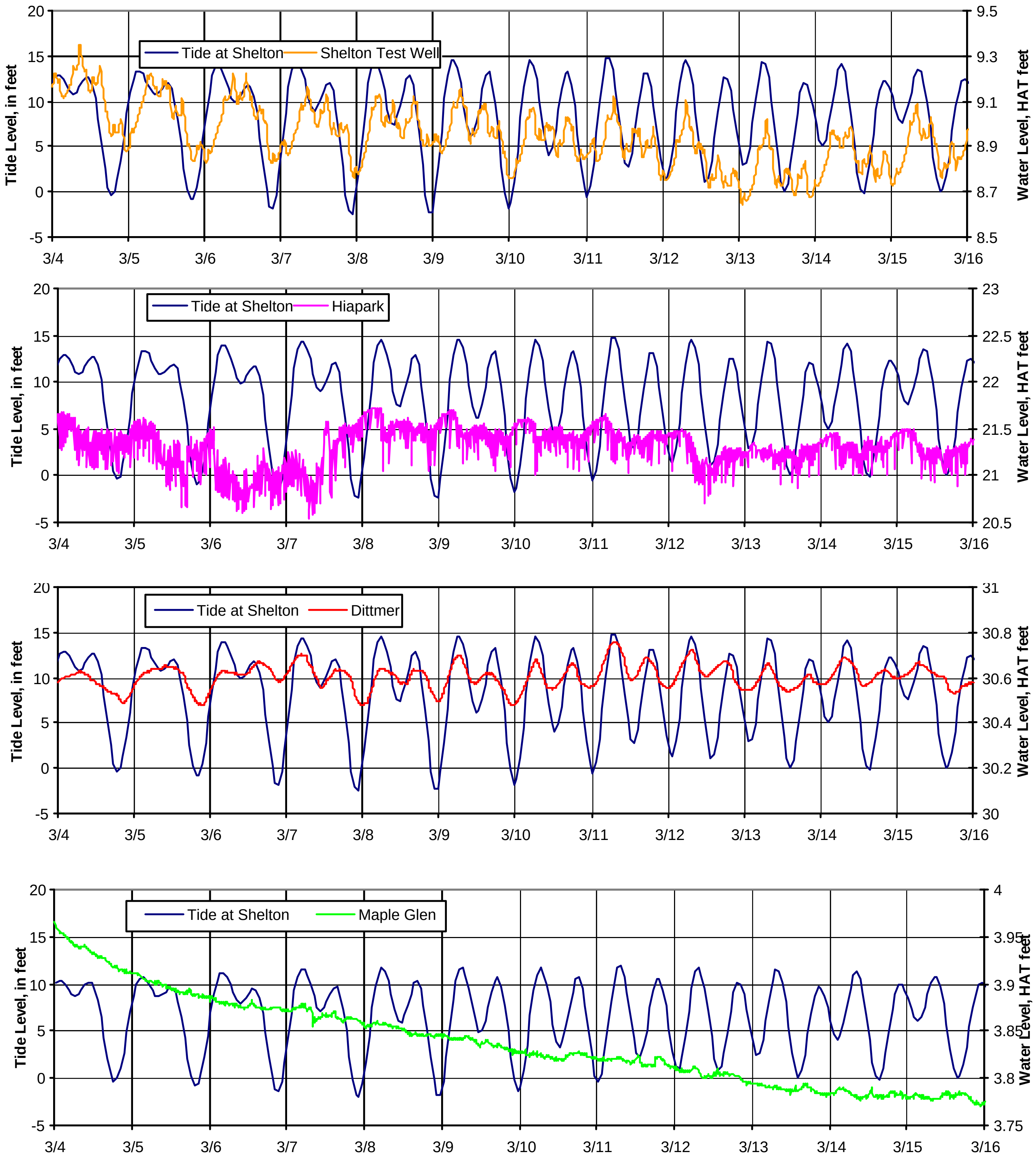
WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107



HAT = Height above transducer

Figure 4-17.
Marine Tides and Long-Term Monitoring Data

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G0300042 and G0000107

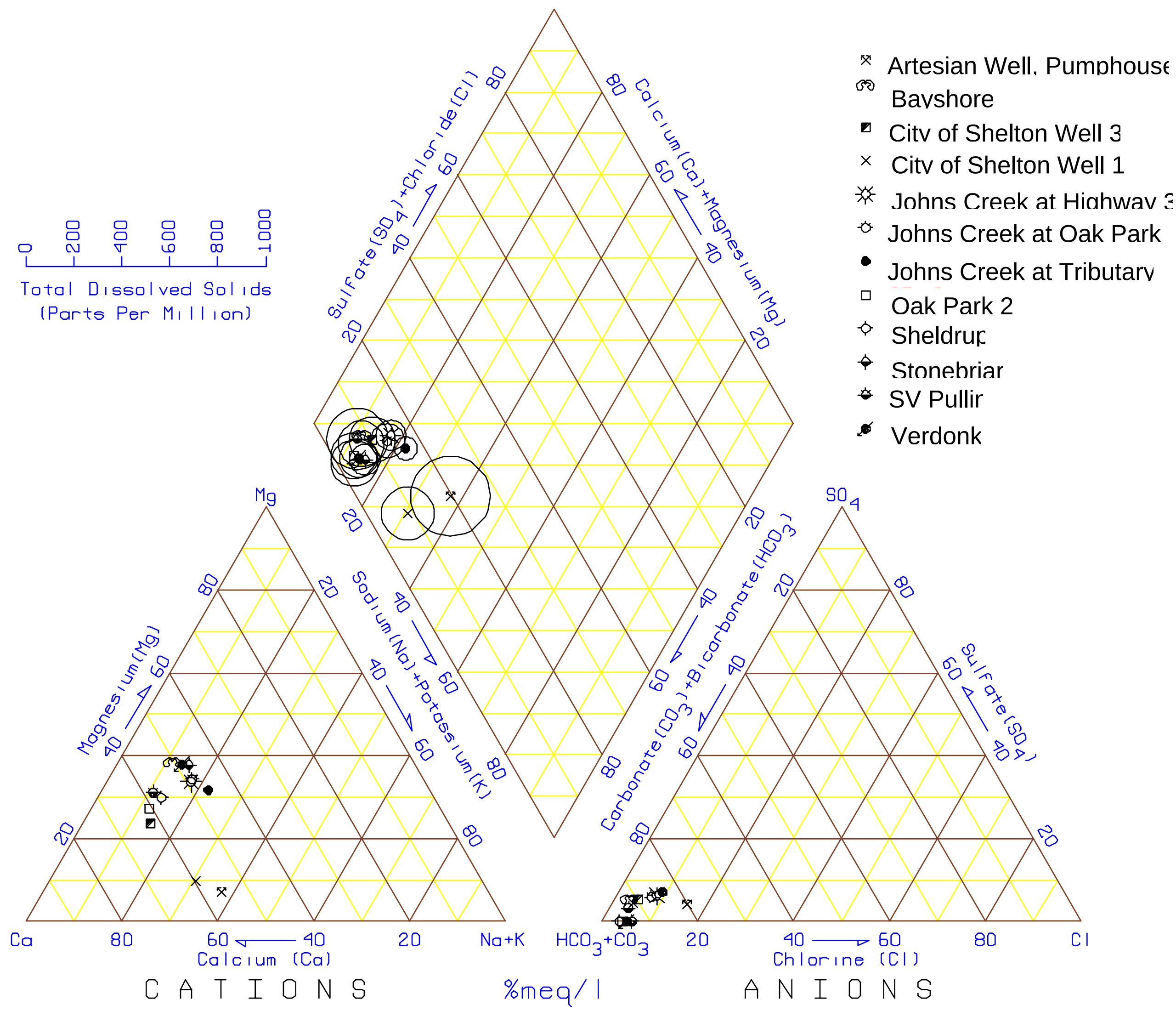


Figure 5-1.
Trilinear Diagram

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G0300042 and G0000197

NORTHWEST Land & Water, INC.

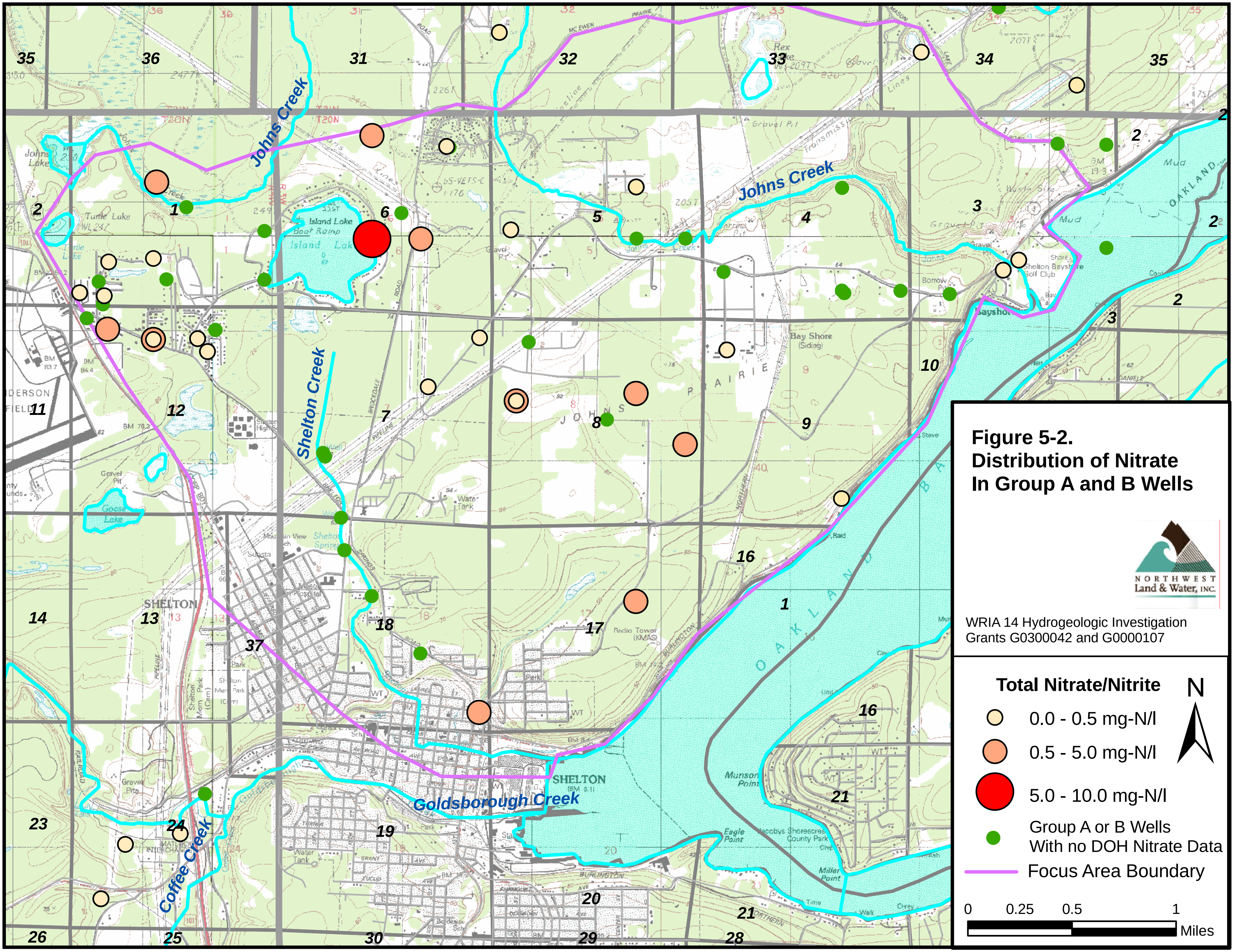
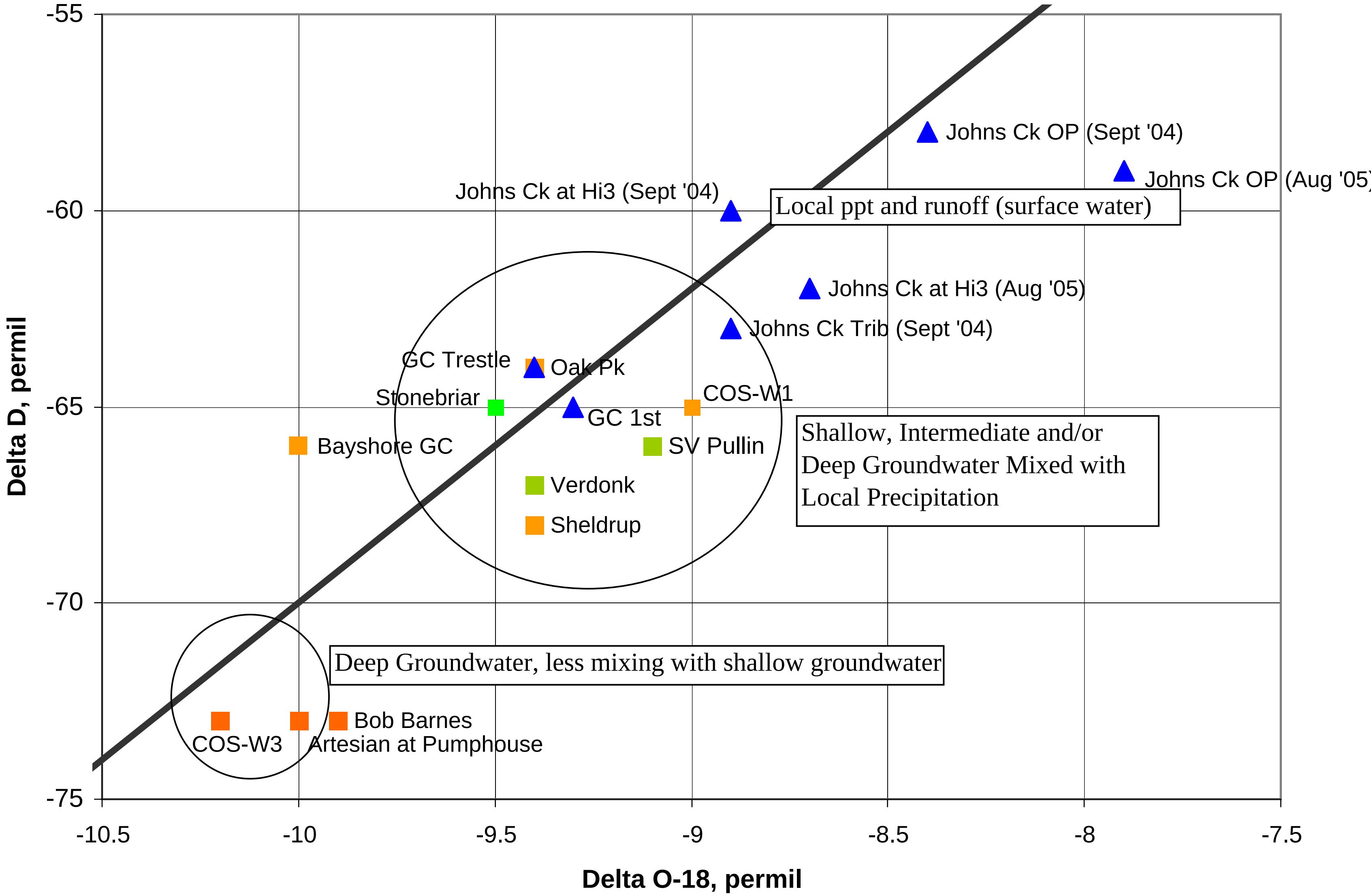


**Figure 5-2.
Distribution of Nitrate
In Group A and B Wells**



Surface Water

Groundwater From Unit F

Groundwater From Unit A

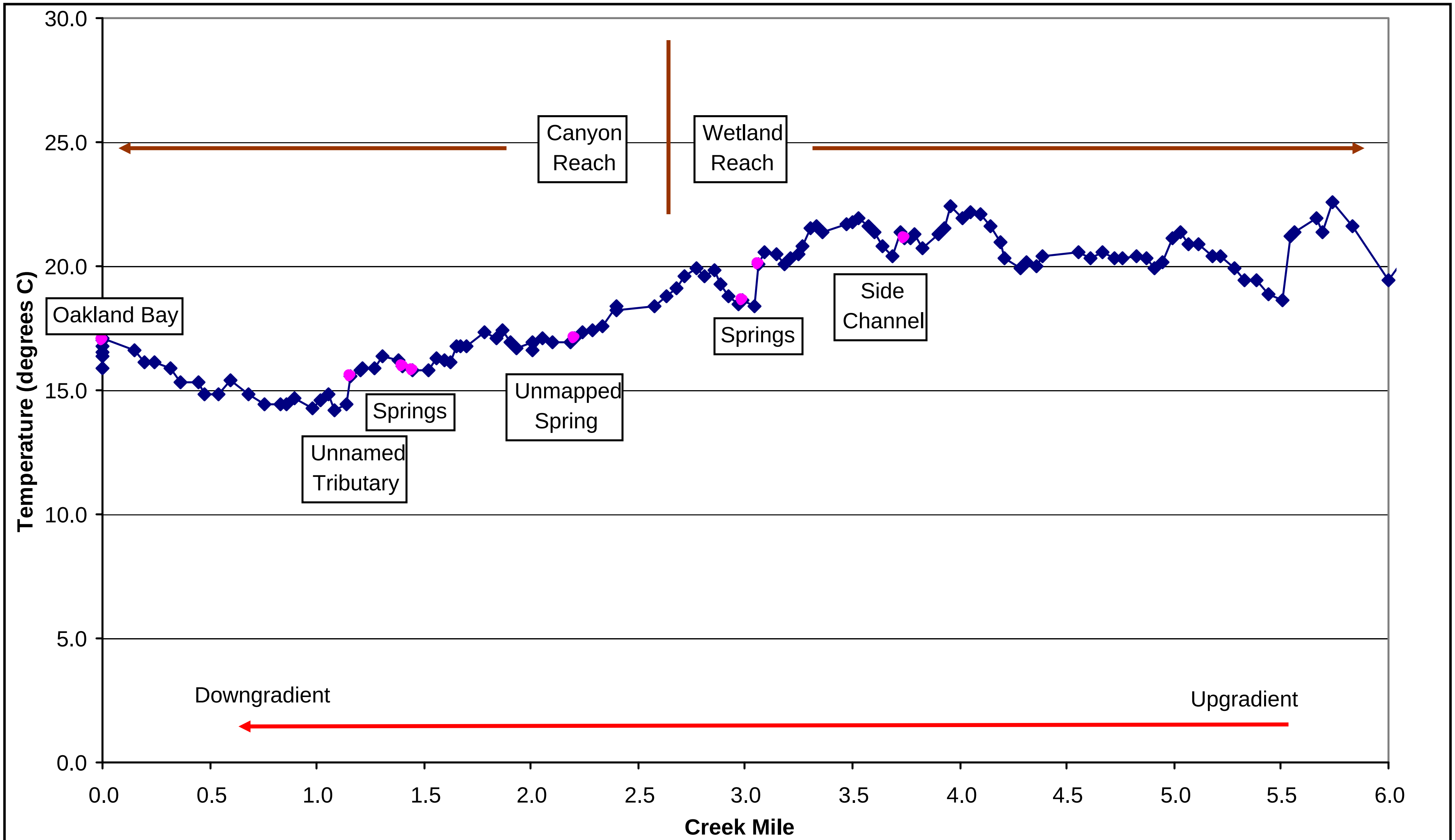
Groundwater From Unit D

Meteoric Water LIne , delta D = (8*delta O-18) +10

Figure 5-3.
Stable Isotopes with Meteoric Water Line

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G03000042 and G0000107

NORTHWEST Land & Water, INC.



Stream Temperature, FLIR Data 8/19/03

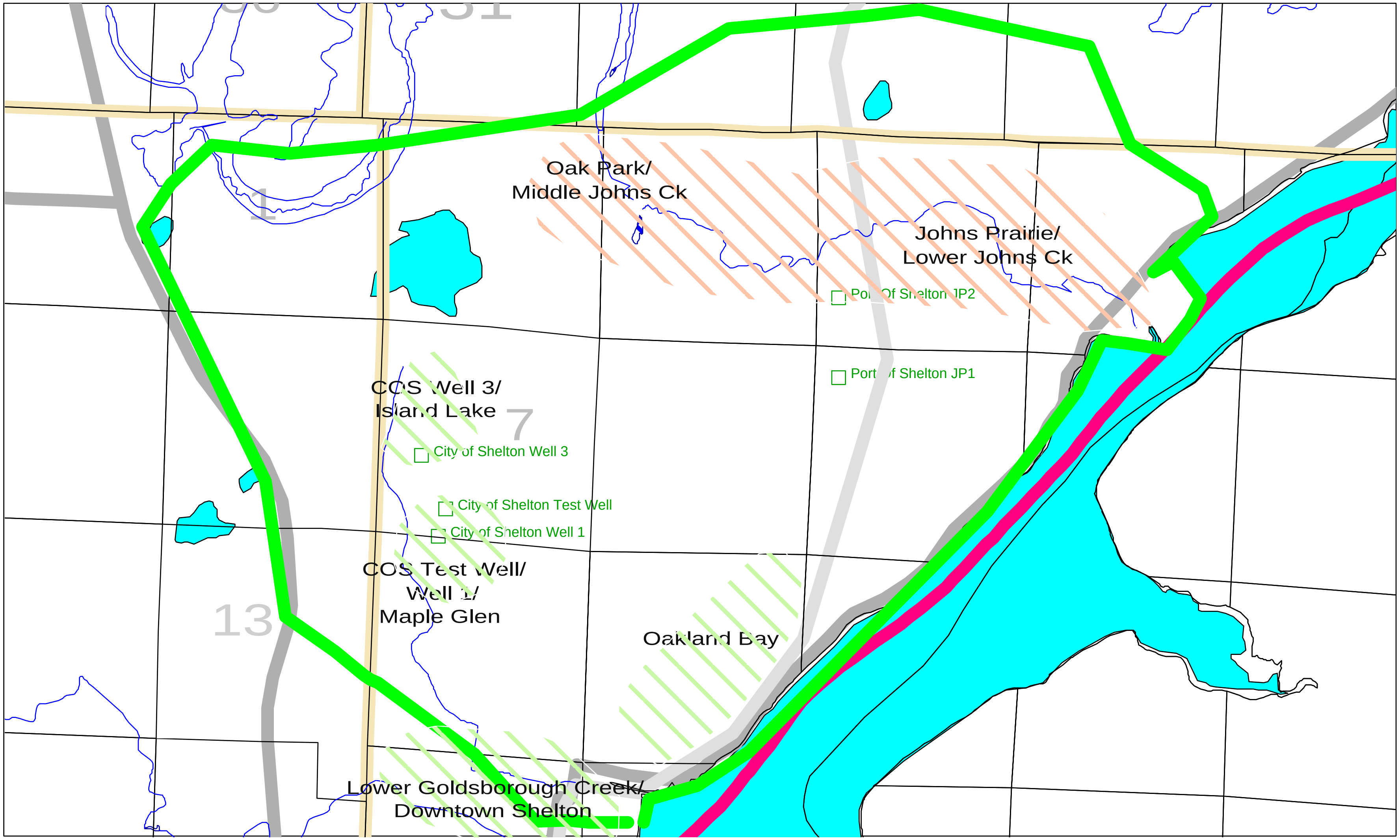
Location of Input to Johns Creek

Modified from data provided to NLW by Squaxin Island Tribe.
Data collected for and reported to Squaxin Island Tribe by Watershed Sciences, LLC,

Figure 6-1.
Johns Creek Temperature Profile

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G0300042 and G0000107

NORTHWEST Land & Water, INC.



Streams
Phase 2 Focus Area
Phase 1 Study Area
Township/Range
Railroad
Highway
COS and POS Pumping Wells

Areas of relative risk are for discussion purposes and are not meant to depict precise locations for further study

Approximate Area of High Relative Risk of Potential Impact To Hydraulic Continuity

Approximate Area of Moderal Relative Risk of Potential ImpactTo Hydraulic Continuity

Approximate Area of Low Relative Risk of Potential Impact To Hydraulic Continuity

Note: White or blank areas do not imply areas of no risk

N

0 2000 4000 6000feet

Figure 6-2.
Potential Hydraulic Continuity Impacts
In Selected General Areas

WRIA 14 Phase 2 Hydrogeologic Characterization
Grants G03000042 and G0000107

NORTHWEST Land & Water, INC.

Appendix A: Summary of Wells in Project Database

ID	Well Owner	Field Name	Well Depth (feet)	Wellhead Elevation (feet)	Township - Range - Section
0	Cherry Park	Cherry Pk.		242.8	
1	Dayton Trails			382.2	
7	Simpson Timber Formerly Rayonier Well 1	Simpson	750	8.2	
8	D and D		0	213.3	
9	Bayshore	Bayshore	254	42.8	
11	Johnson	Johnson	0	199.6	
12	Moores Water System	Moores	0	236.7	
13	Stonebriar 1		60	219.8	
14	POS JP1	POS JP1	155	211.0	
15	Rainbow Lake	Rainbow L.	0	191.6	
16	POS Sanderson 1	POS Sanderson 1		296.1	
17	Cherry Park	Cherry Pk.		251.2	
18	City of Shelton Well 2R		708	223.6	
19	Maple Glen	Maple Glen	46	206.7	
20	J.R. Kirk			207.1	
21	SV Pullin			217.6	
22	State Patrol - WDFW			204.5	
23	Simpson 9th St Well			41.4	
24	J.R. Kirk 2?			211.0	
32876	Al Glenn	Al Glenn	52	193.6	T20N R03W Sec05
32882	Al Kravitz		153	110.9	T20N R03W Sec03
33069	Arden Pierce		78	230.0	T20N R03W Sec06
33074	Arlie Umphrey		98	244.8	T20N R03W Sec05
33201	Bayshore Golf Course	Bayshore GC	81	21.3	T20N R03W Sec03
33202	Bayshore Inc.		254	35.4	T20N R03W Sec3
33225	Bernard Scoles		115	248.7	T20N R03W Sec06
33343	Bill Petty		130	202.4	T20N R03W Sec05
33459	Bob Moyer		236	194.2	T20N R03W Sec17
33579	Brandon Ric's & Karen Quinn	Brandon	83	227.0	T20N R03W Sec07
33670	Bryce Campbell		58	229.0	T20N R03W Sec07
33769	Carl Johnson		60	243.5	T20N R03W Sec08
33770	Carl Johnson		80	243.5	T20N R03W Sec08
33914	Charlie Brown	C. Brown	70	15.1	T20N R03W Sec19
34034	COS Well 3	COS Well 3	278	221.2	T20N R03W Sec07
34035	COS Test Well	COS Test Well	752	229.0	T20N R03W Sec7
34521	Dave Waite		57	240.2	T20N R03W Sec06
34756	Dietz Kadown		69	35.4	T20N R03W Sec03
34852	Don Rutherford		80	217.9	T20N R03W Sec06
34940	Doris Christiansen		192	166.7	T20N R03W Sec1
34988	Dr. J.L. Debban		152	96.1	T20N R03W Sec09
35458	Frank Pascher		116	244.8	T20N R03W Sec05
35514	Fred Peste		100	219.2	T20N R03W Sec18
35793	Gene Bergeson		72	190.6	T20N R03W Sec17
35865	George Lamagie		49	231.0	T20N R03W Sec06
35905	Gerald Billington		70	196.9	T20N R03W Sec09
36142	Harold Martin		88	215.6	T20N R03W Sec06

Appendix A: Summary of Wells in Project Database

ID	Well Owner	Field Name	Well Depth (feet)	Wellhead Elevation (feet)	Township - Range - Section
36176	Harry Floyd	H. Floyd	199	222.5	T20N R03W Sec05
36206	Hazel Britton		110	190.6	T20N R03W Sec17
36280	Him Lie Realty Inc.		136	230.0	T20N R03W Sec06
36327	HTJP partnership		92	232.0	T20N R03W Sec07
36350	I T T Rayonier inc.	ITT Rayonier	204	157.2	T20N R03W Sec17
36448	Jack Marquett		37	231.0	T20N R03W Sec06
36540	James Mc Comb		110	196.9	T20N R03W Sec09
36553	James Quesenberry		68	68.6	T20N R03W Sec16
36563	James Smerud		65	215.9	T20N R03W Sec05
36579	Jamie Tiffany		112	226.1	T20N R03W Sec06
36596	Jay Abel		149	228.7	T20N R03W Sec18
36622	Jeff Canklin		105	226.1	T20N R03W Sec06
36706	Jerry Richart For Jack Rossi		67	136.8	T20N R03W Sec16
36735	Jim Barstow		80	238.2	T20N R03W Sec08
36743	Jim Braham		55	190.3	T20N R03W Sec18
36821	Jim Rutledge		140	212.6	T20N R03W Sec05
36875	Joe & Joane Hilderbrand		51	237.2	T20N R03W Sec07
36906	Joe Wilbur		70	232.0	T20N R03W Sec07
37004	John Gregory		83	226.1	T20N R03W Sec06
37018	John Hickam		20	248.7	T20N R03W Sec06
37167	Joseph Acquire		98	202.4	T20N R03W Sec05
37336	Kenn Mcintosh		50	230.0	T20N R03W Sec06
37434	L.G. Doug Shelton		48	220.2	T20N R03W Sec05
37548	Larry Brimmer		48	246.4	T20N R03W Sec06
37616	Larry Warren		127	216.5	T20N R03W Sec06
37617	Larry Warren		135	216.5	T20N R03W Sec06
37658	Lee Eyler		68	237.2	T20N R03W Sec07
37833	Lois Pearson		73	231.3	T20N R03W Sec06
37850	Loren Hansen		59	248.7	T20N R03W Sec06
37851	Loren Rhoades		128	248.7	T20N R03W Sec06
37904	Luther Pitman		210	0.0	T20N R03W Sec2
37973	Manke		185	206.0	T20N R03W Sec09
37975	Manke Lumber Co.	Manke Lumber	263	202.4	T20N R03W Sec9
38094	Marty Jensen		253	0.0	T20N R03W Sec16
38139	Mason County Garbage		157	202.4	T20N R03W Sec05
38146	Maureen Dockery	M. Dockery	89	220.2	T20N R03W Sec05
38352	Mickey Goodwin		69	202.4	T20N R03W Sec05
38353	Mickey Goodwin		82	231.0	T20N R03W Sec06
38387	Mike Fitzgerald		179	211.6	T20N R03W Sec05
38391	Mike Fox		51	238.9	T20N R03W Sec06
38428	Mike Ogden		138	202.4	T20N R03W Sec05
38510	Monty Niarshall		220	62.3	T20N R03W Sec17
38544	Mr. M. Holt		61	68.6	T20N R03W Sec16
38732	Odus Hutchins		133	202.4	T20N R03W Sec05
39007	Peter Quaade		48	231.3	T20N R03W Sec06
39114	POS JP2	POS JP2	227	208.8	TN RW Sec
39187	R. Miska	R. Miska	60	233.3	T20N R03W Sec07

Appendix A: Summary of Wells in Project Database

ID	Well Owner	Field Name	Well Depth (feet)	Wellhead Elevation (feet)	Township - Range - Section
39347	Raymond Orr		52	231.0	T20N R03W Sec06
39357	Rayonier Inc., Simpson Timber		735	166.0	T20N R03W Sec19
39359	Rayonier, Inc.	Rayonier 39359	252	4.3	T20N R03W Sec20
39438	Richard Dunn	R. Dunn	177	202.4	T20N R03W Sec05
39452	Richard Hopkins		43	231.3	T20N R03W Sec06
39482	Richard Rust	R. Rust	99	68.6	T20N R03W Sec16
39539	Rick Leffler	R. Leffler	200	231.3	T20N R03W Sec6
39632	Robert East		106	96.1	T20N R03W Sec09
39679	Robert Linn	R. Linn	139	217.9	T20N R03W Sec05
39707	Robert Ramsey	R. Ramsey	185	216.2	T20N R03W Sec05
39947	Ron Shipley	Oak Park	181	213.2	T20N R03W Sec06
40074	S. & P. Properties		63	230.7	T20N R03W Sec07
40163	Sebert Auseth		68	190.6	T20N R03W Sec17
40177	Sharon & Ray James	S. James	190	231.6	T20N R03W Sec17
40183	Sheldrup Construction	Sheldrup	50	59.7	T20N R03W Sec03
40228	Sidney Cooper		119	202.4	T20N R03W Sec05
40411	Steve Erickson		72	240.2	T20N R03W Sec06
40469	Steve Wood		40	230.0	T20N R03W Sec06
40488	Stock Sobotka #1		88	237.2	T20N R03W Sec07
40489	Stock Sobotka #2		88	237.2	T20N R03W Sec07
40738	Thomas Gray		170	101.1	T20N R03W Sec09
40818	Tom Bolling		60	244.8	T20N R03W Sec05
40820	Tom Brady	Tom Brady	78	211.8	T20N R03W Sec04
41076	Venn Helgert		40	238.9	T20N R03W Sec06
41236	Washington State Highway Dept.	Wa. State Hi. Dept	171	204.5	T20N R03W Sec04
41250	Wayne Clary		48	204.4	T20N R03W Sec18
41424	William White		140	218.5	T20N R03W Sec05
41527	Larry Clausen		76	136.8	T20N R03W Sec16
41528	Tracy Johnson		52	215.6	T20N R03W Sec06
42056	Island West / Kamin	Kamin	94	209.0	T20N R03W Sec05
42057	Island West / Kamin		99	209.0	T20N R03W Sec05
42065	Island West / Kamin		57	209.0	T20N R03W Sec05
42066	Island West / Kamin		57	209.0	T20N R03W Sec05
42173	Dave Strom		79	237.2	T20N R03W Sec07
42227	Real Estate Transaction		58	217.9	T20N R03W Sec06
42228	Real Estate Transaction		57	217.9	T20N R03W Sec06
42239	Erma Rutherford		56	217.9	T20N R03W Sec06
42246	Miska - Era Conklin & Co		60	237.2	T20N R03W Sec07
42294	Robert Barhite		95	218.5	T20N R03W Sec05
42296	Robert Barhite		40	218.5	T20N R03W Sec05
42314	Dittmer	Dittmer	105	207.9	T20N R03W Sec05
42331	Larry Warren		30	212.6	T20N R03W Sec05
42369	J.A. Tobler		72	240.2	T20N R03W Sec06
42506	Gary Cronce		61	230.7	T20N R03W Sec07
42511	Gary Cronce		61	230.7	T20N R03W Sec07
42514	June Sims		88	202.4	T20N R03W Sec05
42517	Dana Carroll		111	269.4	T20N R03W Sec08

Appendix A: Summary of Wells in Project Database

ID	Well Owner	Field Name	Well Depth (feet)	Wellhead Elevation (feet)	Township - Range - Section
42518	Hiapark	Hiapark	79	244.1	T20N R03W Sec08
42520	Don / Const. Inc. Johnson		80	211.6	T20N R03W Sec05
42521	Don / Const. Inc. Johnson		81	211.6	T20N R03W Sec05
42522	Don / Const. Inc. Johnson		80	211.6	T20N R03W Sec05
42527	Tim & Roberta Welch		60	231.0	T20N R03W Sec06
42708	Kelly Neill		146	206.0	T20N R03W Sec05
42796	Andy Tuson		59	227.7	T20N R03W Sec06
42811	Dave Walterick		56	238.2	T20N R03W Sec08
42812	S&K Builders	S&K	179	222.3	T20N R03W Sec04
42844	Kelly Buechel		40	219.2	T20N R03W Sec18
42847	Kelly Buechel		40	219.2	T20N R03W Sec18
42911	Rick Simpson		70	220.2	T20N R03W Sec05
43007	Tracy Young		73	240.2	T20N R03W Sec06
43068	David Strom		70	239.8	T20N R03W Sec07
43069	David Strom		60	239.8	T20N R03W Sec07
43076	Bob Hatton		36	211.0	T20N R03W Sec05
43120	Dawn Butchere		140	222.5	T20N R03W Sec05
43128	Brad (Gary Cronce) Owen		78	75.1	T20N R03W Sec16
43137	Jess Morris		90	215.6	T20N R03W Sec06
43140	Fredson Homes		270	188.0	T20N R03W Sec17
43141	Fredson Homes	F. Homes	120	188.0	T20N R03W Sec17
43382	Detray's Quality Homes		117	230.0	T20N R03W Sec06
43390	Don Johnson		88	35.4	T20N R03W Sec03
43391	Don Johnson	D. Johnson	88	206.8	T20N R03W Sec05
43486	Carol Bergeson		67	68.6	T20N R03W Sec16
43830	Al Brotche		69	269.4	T20N R04W Sec01
44059	Arne Johnsen		76	230.7	T20N R04W Sec12
44403	Bill Fox	B. Fox	244	346.8	T20N R04W Sec22
45040	Charles Ackerman		265	223.4	T20N R04W Sec20
45483	Curt Nielsen	C. Nielsen	49	217.2	T20N R04W Sec13
45484	Curt Stracke		94	456.1	T21N R04W Sec30
45574	Dan & Tina Parker		57	235.6	T20N R04W Sec01
45621	Dan Wells		40	253.0	T20N R04W Sec15
45765	Dave Strom		66	235.6	T20N R04W Sec01
46094	Do. Mc Dougall		82	285.4	T20N R04W Sec02
46101	Dolly Owens		122	240.2	T20N R04W Sec01
46191	Don Links		30	235.6	T20N R04W Sec01
46305	Donald Smith		66	237.9	T20N R04W Sec01
46449	Dwight Mackay		80	269.4	T20N R04W Sec01
46450	Dwight Mckay		80	269.4	T20N R04W Sec01
46691	Emerald Lake Comm Club	Emerald Lake CC	109	260.2	T21N R03W Sec24
46915	Frank & Janice Pascher		69	279.9	T20N R04W Sec12
47943	Himlie Realty		91	270.7	T20N R04W Sec12
48115	J Tancrell		29	217.2	T20N R04W Sec13
48594	Jerry Ward		73	400.0	T21N R04W Sec31
49245	Joseph Meyer		190	218.2	T20N R04W Sec21
49354	Keith Fuller		39	221.8	T21N R03W Sec32

Appendix A: Summary of Wells in Project Database

ID	Well Owner	Field Name	Well Depth (feet)	Wellhead Elevation (feet)	Township - Range - Section
49355	Keith Fuller		57	221.8	T21N R03W Sec32
49356	Keith Fuller		59	221.8	T21N R03W Sec32
49357	Keith Fuller	Stonebriar	60	218.4	T21N R03W Sec32
49434	Ken Potts		120	311.0	T21N R03W Sec30
49600	Lake Limerick Country Cb.	L. Limerick CC	434	262.5	T21N R03W Sec27
49749	Lee Laferrier		35	229.0	T21N R03W Sec31
50450	Mike Lammers	M. Lammers	360	295.3	T20N R04W Sec3
50781	Neal William Iii	N. William	176	377.6	T20N R04W Sec8
51246	Pete Fassio		161	219.5	T21N R03W Sec32
51627	Rae Lake Subdivison		130	237.9	T20N R04W Sec01
51740	Ray Notar		135	236.9	T21N R03W Sec30
51769	Raymond Schwietering		98	230.7	T20N R04W Sec12
51818	Rex Anderton		55	221.8	T21N R03W Sec32
52047	Robert & Irene Dethlefs	R. Dethlefs	159	357.4	TN RW Sec
52613	Sam Tasi	S. Tasi	139	226.7	T20N R04W Sec12
52986	Steve Tyner		107	236.9	T21N R03W Sec30
53348	Tom Boiling		134	380.9	T20N R04W Sec5
53627	Vi Stickley	Vi Stickley	81	256.2	T20N R04W Sec17
53786	Walter Kratcha		94	305.1	T20N R04W Sec16
53840	Washington State Patrol	Wa. State Patrol	166	296.6	T20N R04W Sec2
53901	Wesley Morgan		83	229.0	T21N R03W Sec31
53909	West Realty		104	269.4	T20N R04W Sec01
54061	Williams Scffernick		119	265.4	T21N R03W Sec21
54783	Brix Living Trust / John Jean	Brix	138	224.1	T21N R03W Sec33
54865	Don Knudsen		410	-32806.7	T21N R03W Sec36
54893	Paul Demiero	Paul Demiero	214	237.5	T20N R04W Sec18
55054	Dennis Haymore		188	494.1	T21N R04W Sec19
55217	David Bayley	D. Bayley	141	240.2	T20N R04W Sec21
55220	Scott Hoffstater	S. Hoffstater	80	255.6	T21N R04W Sec26
55222	David Bailey		109	235.6	T20N R04W Sec01
55223	David Bayley		103	235.6	T20N R04W Sec01
55228	Evans & Waite / Verdone	Verdonk	123	330.1	T21N R03W Sec32
55236	Nancy Wright		60	252.0	T20N R04W Sec12
55318	James Strong		221	363.2	T21N R04W Sec32
55321	David Bailey		108	235.6	T20N R04W Sec01
55322	David Bailey		111	235.6	T20N R04W Sec01
55337	Gary Wilson		60	241.2	T20N R04W Sec01
55363	Arthur Bushey		78	242.8	T21N R03W Sec28
55367	Les Pearson	L. Pearson	220	324.8	T21N R04W Sec35
55652	Barry Gesche		220	304.8	T21N R03W Sec30
55712	Barbara Matheson		160	296.3	T21N R03W Sec30
55713	Art And Vicki Thompson	A. Thompson	0	336.3	TN RW Sec
55894	Singh Wtr Sys / G. Dempsey		380	235.2	T21N R04W Sec22
55966	Mason County Pud #1		221	230.3	T21N R03W Sec32
55997	John Glenn		39	219.5	T21N R03W Sec32
56253	Dick Shrum		99	288.7	T20N R04W Sec01
56393	Juno Court	Juno Ct.	0	235.3	TN RW Sec

Appendix A: Summary of Wells in Project Database

ID	Well Owner	Field Name	Well Depth (feet)	Wellhead Elevation (feet)	Township - Range - Section
60745	David Strom		66	237.2	T20N R03W Sec07
99901	E-9		125	219.8	
99902	E-10	E-10	272	230.7	
99903	P-4		26	223.4	
99904	JPA-2		708	206.0	
99905	W-1	W-1	139	225.7	
99907	Rayonier 5A1	Rayonier 5A1	383	216.9	
99908	Mason Co Fair Assoc. 26N1		209	96.8	
99909	Mason Co Fair Assoc. 11R2	Mason Co. Fair	501	267.7	
99910	Rayonier 15L1		404	279.2	
99911	Rayonier 31A1	Rayoneir 31A1	452	227.4	
99912	Rayonier 19A1	Rayonier 19A1	883	16.1	
99913	Rayonier 17K1	Rayonier 17K1	500	212.9	
99914	Simpson Timber Co. 20E1		926	3.9	
99915	Rayonier,Inc		500	208.0	T20N R03W Sec05
99917	Rayonier Test Well	Rayonier 99917	485	144.0	T20N R03W Sec17
99918	Simpson Timber	Simpson 99918	735	37.1	T20N R03W Sec19
99919	Rayonier Well 2	Rayonier Well 2	600	5.9	T20N R03W Sec20
99921	Rayonier,Inc. Test Well 3	Rayonier 99921	436	121.1	T20N R04W Sec24
99922	Rayonier T-7	Rayonier T-7	658	218.5	
248885	Fuge Ron	Fuge Ron	320	245.7	T20N R04W Sec19
248892	Eric Tiegler		70	215.6	T20N R03W Sec06
249243	Josh Johnson		61	231.0	T20N R03W Sec06
249994	Brad Wilson		154	38.4	T21N R03W Sec25
252028	City Of Shelton		30	18.0	T20N R03W Sec19
252276	Wal Mart		25	231.3	T20N R04W Sec12
252298	Allen Ray		121	279.9	T20N R04W Sec12
252695	Fredrickson Richard		68	246.4	T20N R03W Sec06
256686	Harold Wilson		59	235.6	T20N R04W Sec01
256815	Mikesell, Fred		71	255.9	T21N R03W Sec30
274090	B. Scoles		75	238.9	T20N R03W Sec06
274091	B. Scoles		75	238.9	T20N R03W Sec06
274093	Bernhard Winiecki	B. Winiecki	164	204.4	T20N R03W Sec18
274160	Brad Bonner		100	212.6	T20N R03W Sec05
274161	Brad Bonner		383	212.6	T20N R03W Sec05
274162	Brad Bonner	B. Bonner	460	212.6	T20N R03W Sec05
274163	Brad Bonner		500	212.6	T20N R03W Sec05
274274	COS Well 1	COS Well 1	745	217.3	T20N R03W Sec07
274275	City of Shelton		745	221.1	T20N R03W Sec07
274276	COS WELL 2	COS Well 2	708	222.4	T20N R03W Sec07
274400	Edward Hellman		116	212.0	T20N R03W Sec08
274401	Edward Hellman		116	212.0	T20N R03W Sec08
274568	George Lombardie		90	269.4	T20N R03W Sec08
274635	Jack Bartz			4.3	T20N R03W Sec20
274962	Mike Fox / B & M Investment		88	248.7	T20N R03W Sec06
275074	Rayonier Inc.	Rayonier 275074	301	11.2	T20N R03W Sec20
275456	Nicolas Cardona		67	219.2	T20N R03W Sec08

Appendix A: Summary of Wells in Project Database

ID	Well Owner	Field Name	Well Depth (feet)	Wellhead Elevation (feet)	Township - Range - Section
275457	Nicolas Cardona		62	219.2	T20N R03W Sec08
275468	Robert Paulk		125	222.5	T20N R03W Sec05
275836	Carol Flercher		69	270.7	T20N R04W Sec12
275837	Carol Flercher		69	270.7	T20N R04W Sec12
276024	Don Knudson		78	270.7	T20N R04W Sec12
276026	Donald & Constance Sendridge		40	223.1	T21N R03W Sec31
276308	J. J. Gilmore		169	74.2	T21N R03W Sec35
276355	Joe Hall Construction		0	229.7	T20N R04W Sec12
276356	Joe Hall Construction		0	229.7	T20N R04W Sec12
276357	Joe Hall Construction		0	229.7	T20N R04W Sec12
276358	Joe Hall Construction		0	229.7	T20N R04W Sec12
276501	Melvin Arnold		33	223.1	T21N R03W Sec31
276502	Melvin Arnold		33	223.1	T21N R03W Sec31
276702	POS Sanderson 2	POS Sanderson 1	139	305.7	T20N R04W Sec02
276832	Rae Lake Subdivison		130	269.4	T20N R04W Sec01
276833	Rae Lake Subdivison		130	269.4	T20N R04W Sec01
276874	Richard Rust		99	237.9	T20N R04W Sec01
276875	Richard Rust		62	237.9	T20N R04W Sec01
276876	Richard Rust		66	237.9	T20N R04W Sec01
276877	Richard Rust		83	237.9	T20N R04W Sec01
276878	Richard Rust		117	237.9	T20N R04W Sec01
276903	Robert Jacobson		37	318.6	T21N R03W Sec22
277238	Washington State D.O.C.	WA State	632	303.8	T20N R04W Sec9
277407	Eileen Gormley		116	304.8	T21N R03W Sec30
277413	Bruce Gruenewegen	B. Gruenewegen	246	222.8	T21N R03W Sec34
277469	Rayonier Inc.	Rayonier 277469	742	59.1	TN RW Sec
277505	Ned Wilson		120	304.8	T21N R03W Sec30
279018	Norman Jones		50	238.9	T20N R03W Sec06
279019	Norman Jones		50	238.9	T20N R03W Sec06
300004	Rodgers Williams		83	248.7	T20N R03W Sec06
300005	Rodgers Williams		83	248.7	T20N R03W Sec06
300034	Simpon Co.		926	4.9	T20N R03W Sec20
301824	Don Young		106	246.4	T20N R03W Sec06
312862	Sherry Speaks		220	366.8	T21N R04W Sec24
313948	Lee Defrates		97	270.7	T20N R04W Sec12
320725	Michael & Caroline Kinley		180	323.2	T21N R03W Sec20
322012	Antonio Apaez		35	269.4	T20N R03W Sec08
322160	Paul Hunter		370	519.1	T21N R04W Sec20
329435	Mason Co Pub Utility Dist 3	Mason Co.	121	296.9	T20N R04W Sec4
331403	Rick Leffler		65	68.6	T20N R03W Sec16
335699	Vern Stratton	V. Stratton	235	319.2	T21N R03W Sec30
337493	Jack And Kippy Dalton		120	202.4	T20N R03W Sec05
337494	Beacon Homes		200	351.1	T21N R04W Sec25
337577	David Strom		120	273.3	T20N R03W Sec8
337907	Cheryl Coleman	C. Coleman	68	193.9	T20N R04W Sec23
338112	Rick Stratton	R. Stratton	241	255.9	T21N R03W Sec30
341148	Dawn Butcher		181	218.5	T20N R03W Sec05

Appendix A: Summary of Wells in Project Database

ID	Well Owner	Field Name	Well Depth (feet)	Wellhead Elevation (feet)	Township - Range - Section
341201	Chuck Raymond		79	215.6	T20N R03W Sec06
342182	S & K Builders		180	196.9	
342184	Bob Barnes	B. Barnes	341	208.3	T20N R03W Sec4
347622	Emerald Lake #1		113.5	266.4	T21N R03W Sec24
347867	Gary Cronce		61	230.7	T20N R03W Sec07
350285	Robert Herr		147	256.6	T21N R03W Sec23
356369	Manke Family Resources	Manke Family	101	175.3	T20N R03W Sec09
360338	Lee And Judith Parks		275	190.6	T20N R03W Sec10
364198	Steven And Bridgit Erckenbrack		139	202.4	T20N R03W Sec05
365664	Enchantment Heights Llc		403	391.4	T21N R04W Sec23
999906	Rayonier 5N2		460	243.8	

Appendix B

Kennedy/Goldsborough Watershed Planning Unit
Water Resource Inventory Area (WRIA) 14

September 25, 2004

Dear Mason County Landowner:

We are members of the WRIA 14 Planning Unit, a local group of citizens and government representatives who have been charged with preparing a plan for our local watershed. As part of this effort, we have hired a consultant team led by Northwest Land & Water to gather some information for us on the aquifers underlying the watershed. This study is extremely important to us because groundwater is the source of water for our community and currently little is known about how this groundwater system works. New information will help us better manage this vital resource.

We would like to ask for your cooperation by allowing NW Land & Water to monitor the level of water in your well over a 6 month period. This monitoring may include one or more measurements of the depth to water in your well OR continuous measurements using an electronic recording device. This study will not have any effect on well owners' water withdrawals.

We will share the data gathered from your well with you. The well level information can be compared to past or future water level data, which will be useful to you in tracking the performance of your well.

We believe this study will be mutually beneficial by providing you with useful data on your well levels and providing us with a better understanding of our groundwater system. We greatly appreciate your assistance. If you have any questions, please contact Jim Mathieu at 206-525-0049 or jim@nlwinc.com.

Sincerely,

Members of the WRIA 14 Watershed Planning Unit

Theresa L. Parsons
[illegible]
Bob Simmons
Warren Davis
[illegible]
[illegible]
[illegible]

Constance C. Olsen
Diane M-Jones
[illegible]
Diane Cooper

Signatories:

Theresa Parsons, City of Shelton

Nancy Ness, Citizen Member

Bob Simmons, WSU Cooperative Extension

Warren Dawes, Southwest Puget Sound Watershed Committee

John Konovsky, Squaxin Island Tribe

Tom Clingman, Thurston County

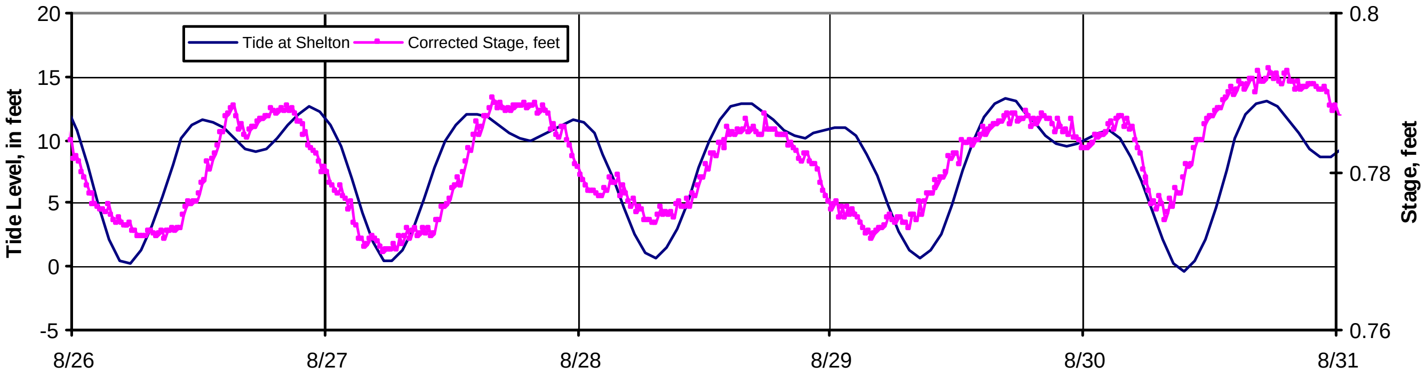
Herb Baze, Mason County Commissioner

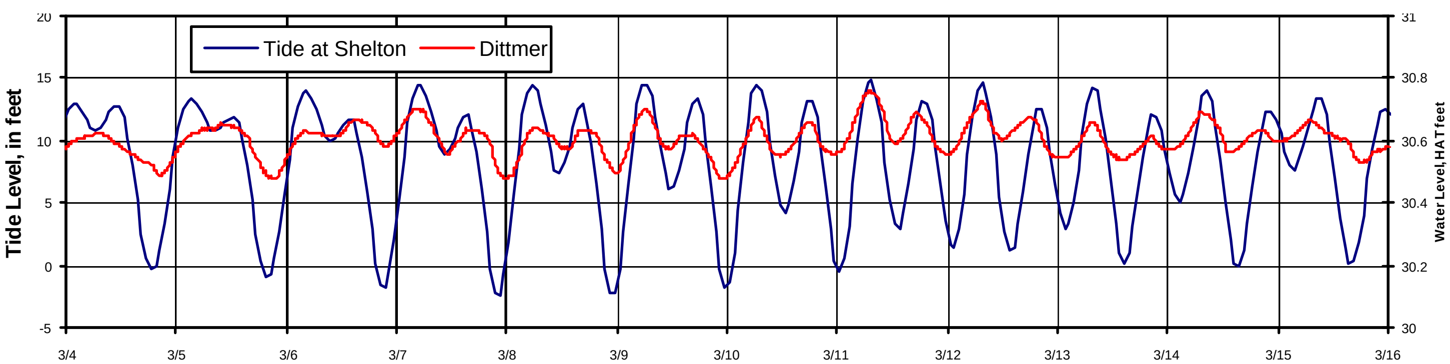
Constance Ibsen, Lower Hood Canal Watershed Implementation Committee

Diane Marcus-Jones, Mason County

Phil Wiatrak, Washington State Department of Ecology

Diane Cooper, Taylor Shellfish



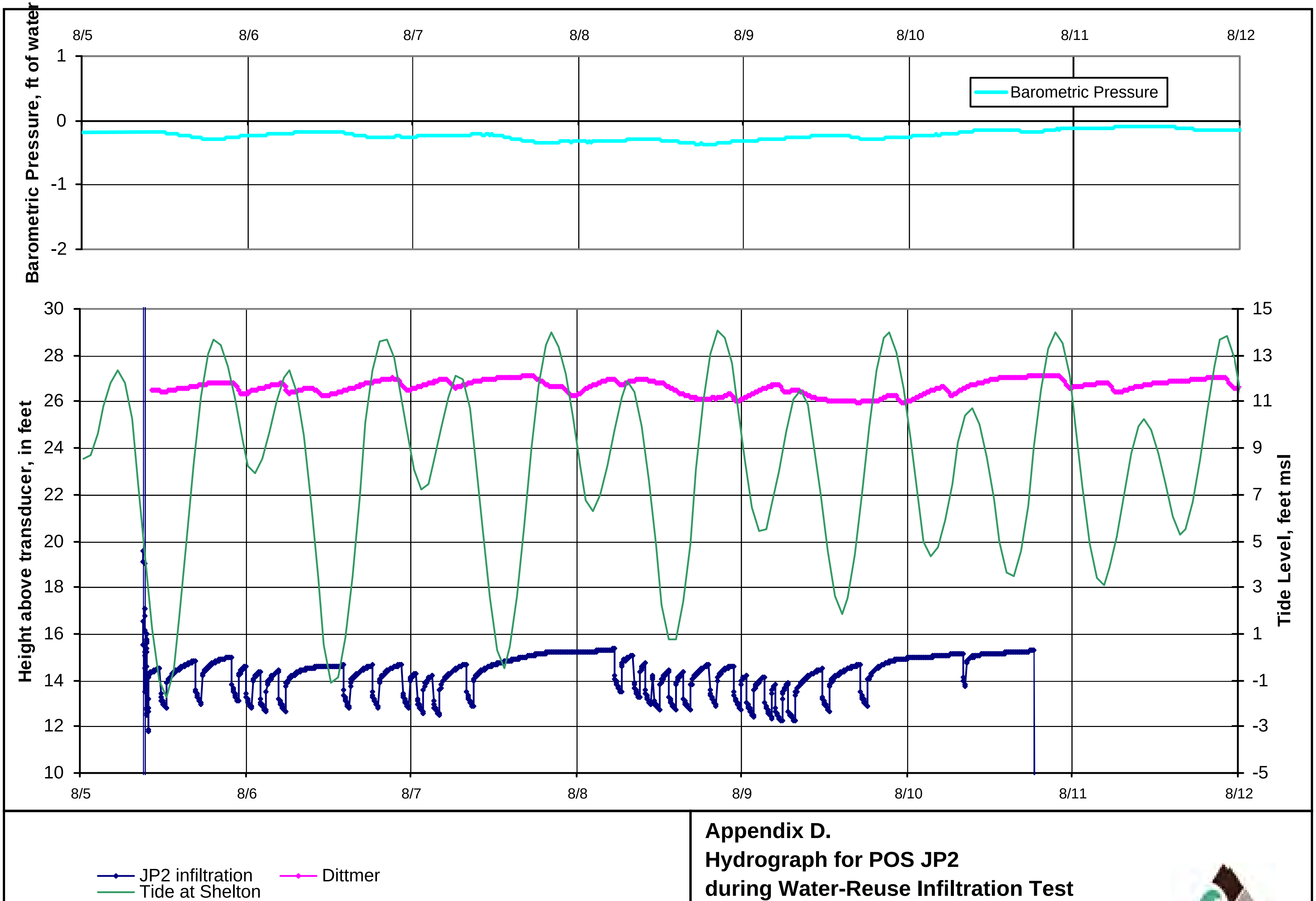


HAT = Height above transducer

Note: Johns Creek Stage and Dittmer are diiffernet time periods

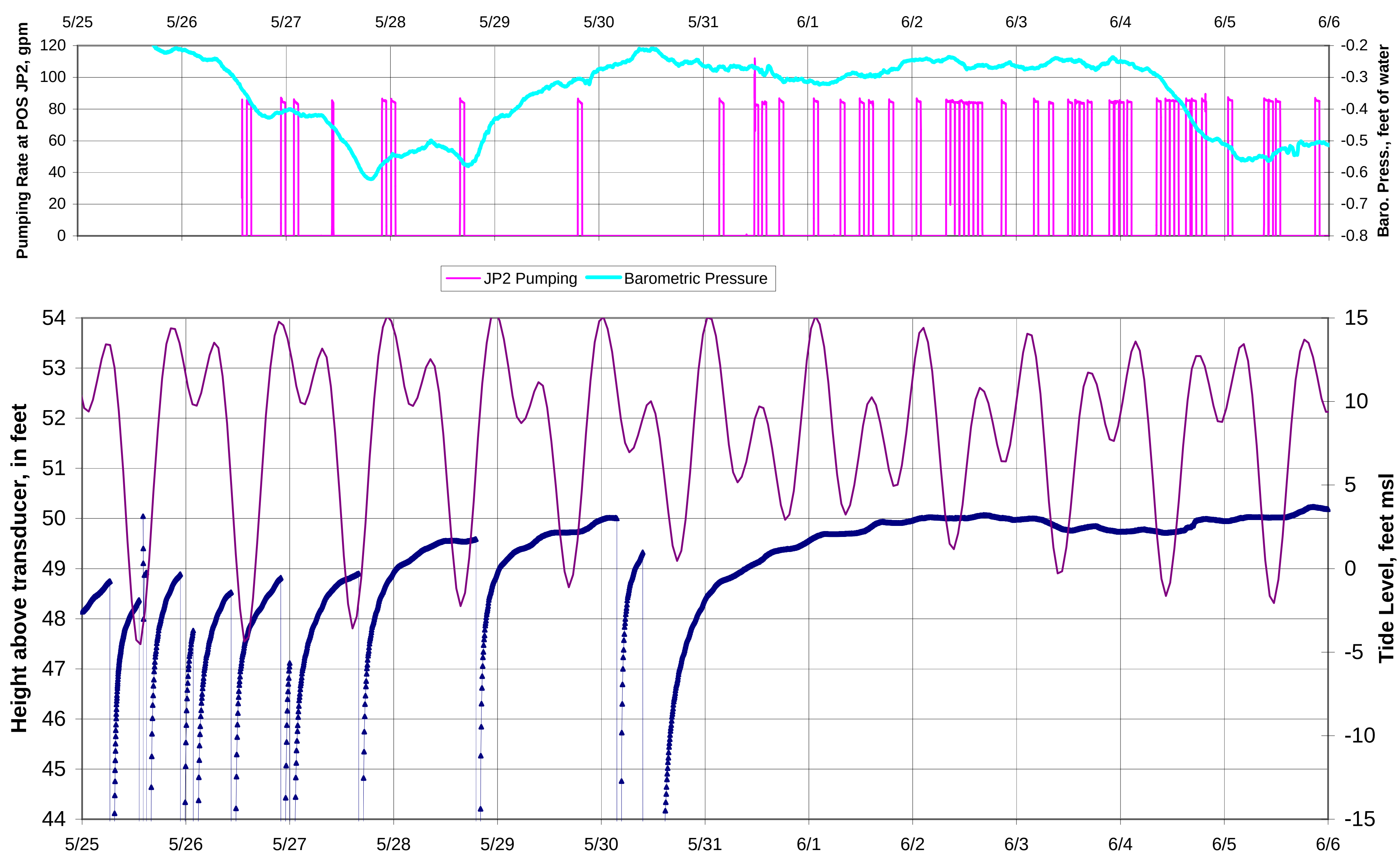
Appendix C
Marine Tides and Long-Term Monitoring Data at Johns Creek (JOH2) and Dittmer

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G0300042 and G0000107



Appendix D.
Hydrograph for POS JP2
during Water-Reuse Infiltration Test

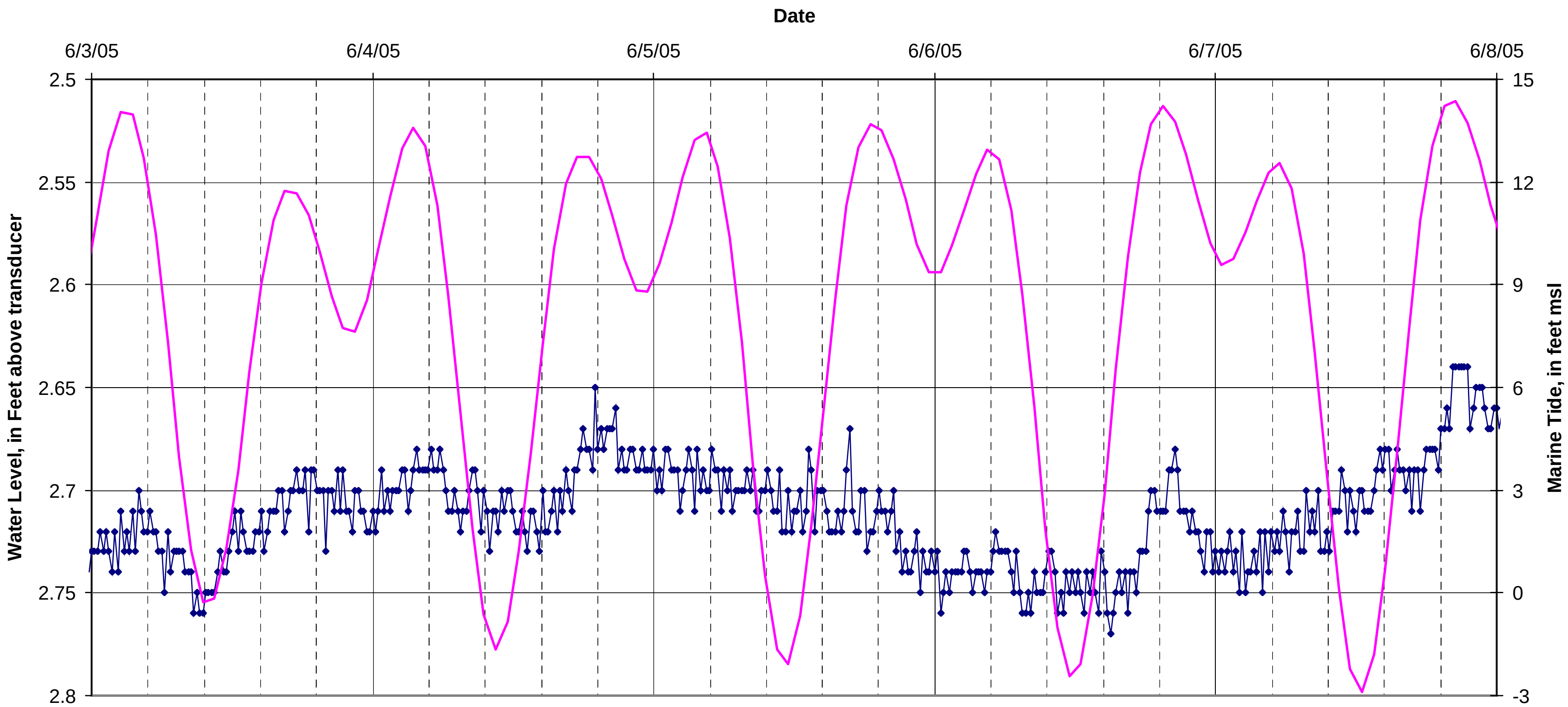
WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G0300042 and G00001



Appendix E.
Hydrograph for POS JP1 with JP2 Pumping, Marine Tides, and Barometric Pressure

WRIA 14 Phase 2 Hydrogeologic Investigation
Grants G0300042 and G0000107

NORTHWEST Land & Water, INC.



Sheldrup, barometrically corrected water level data from Squaxin Island Tribe

Tide at Shelton

Appendix F.
Sheldrup Water Level Data and Marine Tide at Shelton

WRIA 14 Phase II Hydrogeologic Characterization
Grants G03000042 and G0000107

Northwest Land & Water, Inc.