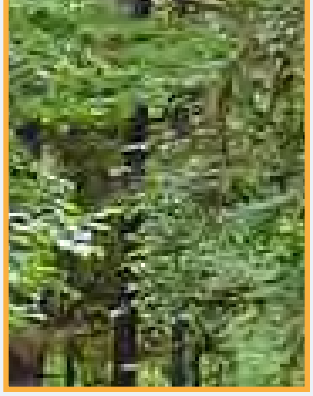
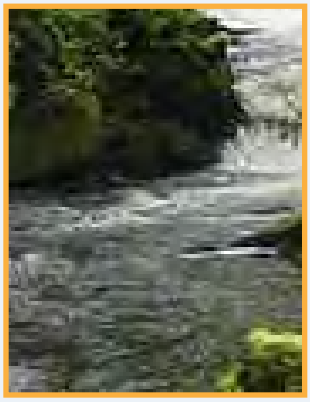
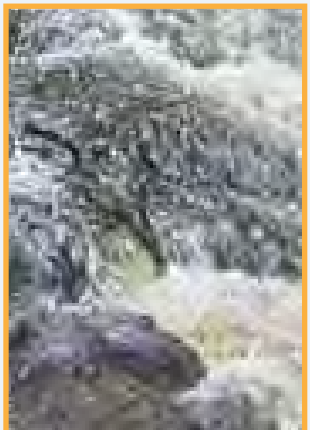


Graham Groundwater Study Report



April, 2007

Pierce County
Public Works and Utilities
Water Programs Division



PgG
Pacific Groundwater Group

BROWN AND CALDWELL
Environmental Engineers & Consultants

TABLE OF CONTENTS

Executive Summary 1

1.0 Introduction 4

1.2 Phase Activities 4

1.3 Phase II Activities 5

1.4 Study Limitations 5

2.0 Study Area Description 7

2.1 Location 7

2.2 Land Use 7

2.3 Regional Geology 7

2.4 Regional Hydrogeology 8

2.5 Drainage/Flooding Problems 8

2.6 Proposed Regional Infiltration Pond 9

3.0 Study Methods 10

3.1 Phase I Methods 10

3.2 Phase II Methods 11

4.0 Findings 17

4.1 Phase I Findings 17

4.2 Phase II Findings 17

5.0 Proposed Regional Infiltration Pond 24

5.1 Description 24

5.2 Drainage Area Characteristics 24

5.3 Potential Impacts on Flooding Problems 25

6.0 Recommendations 28

6.1 Revisit Basin Planning Boundaries 28

6.2 Investigate Site-Specific Groundwater Conditions at Proposed Pond Site 28

6.3 Update Drainage Area and Design Flows 29

7.0 References 30

LIST OF APPENDICES

APPENDIX A – Boring Logs

EXECUTIVE SUMMARY

GROUNDWATER STUDY BACKGROUND

The Graham Groundwater Study was conducted by Pierce County Public Works and Utilities Department, Water Programs Division (Water Programs), with the assistance of Brown and Caldwell (BC) and Pacific Groundwater Group (PGG). The study evaluates groundwater movement between the Muck Creek and Clover Creek drainage basins, especially as it may relate to flood related issues, and the potential down-gradient impacts of a proposed regional stormwater infiltration pond near the intersection of 224th and Meridian. The project was conducted in two phases.

Phase I involved compilation and evaluation of existing data and identification of key data gaps. Preliminary conclusions regarding groundwater movement were made from available information. Results indicated that additional groundwater data were needed to confirm groundwater flow patterns. Eight existing wells were selected and locations were identified for the installation of seven additional wells for water level monitoring.

Phase II involved collection of water level data from the fifteen wells over a period of 1 year. The data were utilized to evaluate detailed hydrogeology of the area and delineate the groundwater flow patterns. Phase II also included an evaluation of the potential impacts of the proposed infiltration pond on groundwater-related flooding.

GROUNDWATER BASIN BOUNDARIES

The groundwater level data collected during this 1-year study show that the groundwater basin boundaries in the Graham area are different from the boundaries used for basin planning. Groundwater basin boundaries were evaluated by mapping the groundwater elevations measured during the study. The original basin planning boundaries were established in 1988 using the topographic maps that were available at that time; groundwater flow patterns were not considered.

Groundwater from the Graham area, which is in the Muck Creek basin planning area, flows to the southwest and northwest. The northern flow crosses into the Clover Creek basin planning area. As shown in Figure ES-1, the groundwater divide between the Clover Creek and Muck Creek basins appears to be roughly 1-½ miles south-southeast of the basin planning area boundary.

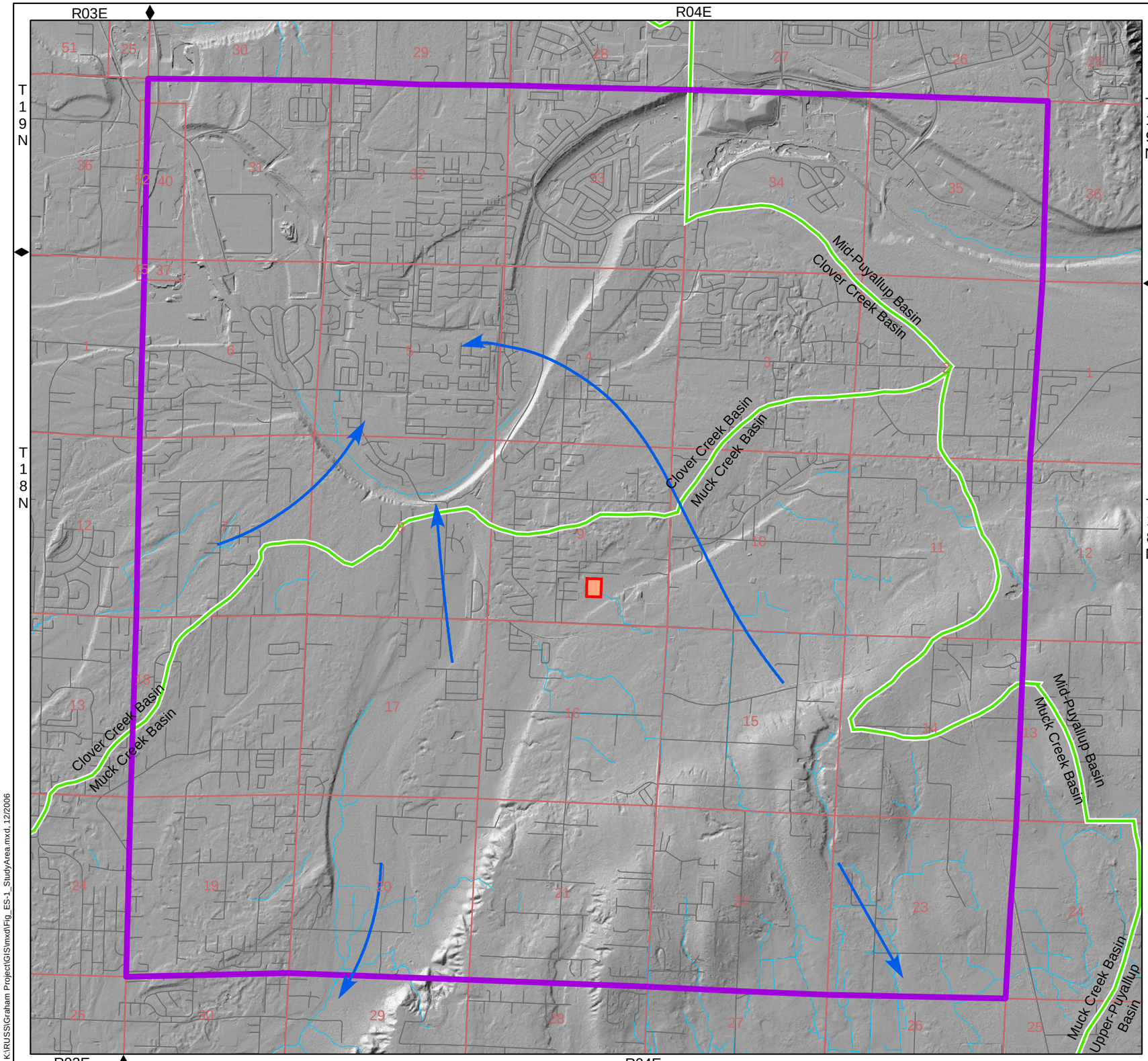


FIGURE ES-1

STUDY AREA AND VICINITY

Graham Groundwater Study

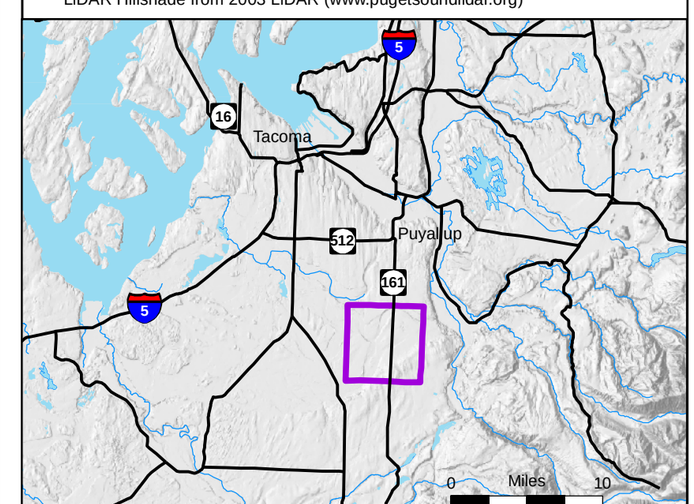
Basin Boundaries

Generalized Groundwater Flow Directions

Proposed Infiltration Pond Location

Study Area

Background Image:
LiDAR Hillshade from 2003 LiDAR (www.pugetsoundlidar.org)



0 0.5 Miles

0 3,000 Feet

1:36,000

K:\RUSS\Graham Project\GIS\mxd\Fig_ES-1_StudyArea.mxd, 12/2006

GROUNDWATER-RELATED FLOODING

Ground-water related flooding has occurred near Frederickson in the Clover Creek Basin, just north of Graham. Previous studies have shown that the flooding occurs when groundwater accumulates in a geologic feature called the Kirby Channel. During prolonged wet periods, groundwater flows into the Kirby Channel faster than it can flow away underground, causing the water table to rise above the ground surface.

Water Programs is planning to construct a regional infiltration pond near 224th and Meridian to reduce localized flood hazards that were identified within the Muck Creek Basin Plan. Local citizens have expressed concern that an infiltration facility near 224th and Meridian could exacerbate the flooding problem in the Kirby Channel.

The proposed pond would be located about 4,000 feet southeast of the Kirby Channel (see Figure ES-1). The pond site is in a low-lying area where runoff has historically collected and infiltrated. County staff has observed some temporary ponding at this location during and shortly after large rainfall events, but has not observed flooding of adjacent areas.

A combination of groundwater and surface water runoff models was used to evaluate the potential effect of the proposed pond on groundwater-related flooding. The geologic borings logs and the water level measurements collected for this study were used to develop a "MODFLOW" computer model of the groundwater aquifer around the proposed infiltration pond. MODFLOW is a computer groundwater flow model that simulates flow in an irregularly shaped system based on aquifer properties, and calculates flow-rate and cumulative volume. Conservative assumptions were used in the MODFLOW groundwater model to help ensure that it does not underestimate the potential for the pond to cause groundwater levels to rise. Another modeling program, the Western Washington Hydrologic Model, was used to estimate the amount of runoff that would flow to the proposed pond during storm events.

From the standpoint of groundwater flow an infiltration pond, such as that proposed, will create an area of concentrated recharge that will cause groundwater levels beneath the pond to rise (groundwater "mounding"). The model results provide insights into the geometry of the groundwater mound. The results suggest that the mound would dissipate before reaching the Kirby Channel, so the pond should not affect groundwater levels or flooding beneath the Kirby Channel.

The model results also suggest that the mound could reach the ground surface in the immediate vicinity of the pond. As noted above, Water Programs staff has not observed flooding of streets, basements, or crawlspaces in the residential areas adjacent to the pond site. The lack of observed flooding indicates the MODFLOW model may be over-predicting the rise in localized groundwater elevations caused by the new pond. Nevertheless, the model results suggest that the site may not be able to infiltrate much more water than currently flows there.

RECOMMENDATIONS

Basin Boundaries

The boundaries of the Muck Creek and Clover Creek basin planning areas do not reflect the groundwater contribution to surface water management issues. Water Programs should consider revision of the boundaries to include the entire area that contributes groundwater flow to the Clover Creek Basin. It may be advisable to develop a county-wide policy for such situations.

Proposed Stormwater Infiltration Pond

The MODFLOW model may over-predict groundwater elevations beneath the proposed pond site. This over-prediction is most likely because the hydrogeologic conditions at the site are different from those at the nearby wells that were used to develop the model. Before proceeding with design of the infiltration pond, Water Programs should collect additional site-specific information to characterize the local hydrogeology and refine the MODFLOW model. The additional investigations should include: (1) at least three soil borings and installation of monitoring wells at the proposed pond site; (2) monitoring groundwater levels beneath the site (especially during February through April); (3) slug testing in each well to estimate hydraulic conductivities; and (4) using the site-specific data to re-calibrate the MODFLOW model.

The Western Washington Hydrologic Model should be re-run using the latest topographic and land use data for the area that drains to the proposed pond site. This will provide updated estimates of the surface water inflow volumes for the MODFLOW model, which should then be re-run to simulate the magnitude of groundwater mounding beneath the pond site. If the refined MODFLOW model indicates that significant mounding could occur, Pierce County may wish to restrict future land use activities that would increase flows to the pond site.

1. INTRODUCTION

1.1 PROJECT OBJECTIVES

Pierce County Public Works and Utilities, Water Programs Division, recently completed basin plans to guide surface water management in the Muck Creek and Clover Creek drainage basins. The Muck Creek Basin Plan noted that groundwater in the Graham area may flow into the Clover Creek basin and contribute to groundwater-related flooding in that basin. However, the existing data were not sufficient to accurately delineate groundwater flow paths or evaluate the potential for groundwater from the Muck Creek basin to contribute to flooding problems.

The Clover and Muck Creek basins include areas of permeable soils where infiltration is commonly used to dispose of stormwater runoff. The Muck Creek Basin Plan proposed a large regional infiltration pond west of 224th and Meridian to reduce potential future flooding in the Graham area (CIP 12NF-XXX). In response to stakeholder concerns, the basin plan called for a study (ST12-01) to evaluate the potential impacts of the proposed pond on groundwater-related flooding in the Clover Creek basin, and to evaluate groundwater movement between the Muck and Clover Creek basins.

In accordance with the basin plan recommendations, Water Programs initiated the Graham Groundwater Study in 2004. The study was conducted to address three key objectives: (1) determine the groundwater flow directions and the extent of groundwater migration in the Graham area, (2) assess the potential impact of the proposed regional infiltration pond on downgradient groundwater-related flooding, and (3) provide information for future consideration of the planning boundary between the Clover and Muck Basins.

The County retained Brown and Caldwell (BC) and Pacific Groundwater Group (PGG) to conduct the study. The study was conducted in two phases as described below.

1.2 PHASE I ACTIVITIES

Phase I involved collecting and evaluating existing data to develop a preliminary understanding of groundwater flow in the study area. The data review encompassed approximately 400 well logs obtained from the Washington State Department of Ecology (Ecology); URS (2001) groundwater flooding evaluation for Frederickson, Pierce County; and Ecology's (2001) assessment of surface water and groundwater interchange within the Muck Creek watershed. The data obtained from these sources were used to prepare a preliminary groundwater elevation contour map, construct a hydrogeologic cross-section, and identify data gaps. The preliminary groundwater elevation contour map provided an understanding of generalized groundwater flow directions. A northwest-southeast trending cross-section was constructed using well logs available from the Ecology download.

The existing data were evaluated to identify key gaps with respect to study objectives. Data coverage of the area south of 224th Street was fairly uniform; however, distinct data gaps existed in the center of the study area just north of 224th Street along Meridian Road. Data were also sparse in the northwest part of the study area.

A groundwater monitoring plan was then prepared to address the key data gaps. The monitoring program involved installation of seven new monitoring wells in the Graham area; monthly synoptic water level measurements in the seven new and eight existing wells; installation of pressure transducers and data loggers in three of the wells to allow continuous groundwater elevation monitoring; and data analysis.

1.3 PHASE II ACTIVITIES

Phase II included installing seven new monitoring wells and collecting field data to fill in the key data gaps identified during Phase I. The field data were collected in accordance with the groundwater monitoring plan developed during Phase I. Water level measurements were collected from eight existing and seven new wells in the study area, monthly for one year, to confirm and refine the groundwater flow patterns in the Graham study area. In addition, three wells were equipped with pressure transducers and data loggers to allow estimation of the time required for groundwater recharge in the southern part of the study area to affect groundwater levels downgradient within the Clover Creek basin.

1.4 STUDY LIMITATIONS

The study was conducted under the following limitations:

- The project budget allowed for limited drilling, well installation, and water level monitoring. Therefore, the data from the monitoring wells had to be interpolated over large areas.

- New wells were restricted to County-owned property along roads. Buried and overhead utilities precluded drilling at some sites. Thus, some of the new wells are not ideally located from a hydrogeologic standpoint.

- Transducer data were hit and miss since the end of February 2006. While it appears that all raw data from the data loggers have been forwarded, hand-level measurements do not appear to be available for each downloading date. Therefore, possible drift in the transducer readings is not accounted for during the later stages of automatic data collection. This limitation is considered not significant because previously measured drift was small.

- There was a limited time period for data collection.

- Water Programs' surface water model for the proposed infiltration pond was completed several years ago. Drainage area conditions could have changed due to new development and highway drainage system improvements in the study area.

2. STUDY AREA DESCRIPTION

2.1 LOCATION

The study area boundaries are defined as 176th St. E on the north, Canyon Road on the west, 252nd St. E on the south, and 128th Ave. E on the east (see Figure 2-1). The study area encompasses 25 square miles and includes Sections 31 to 35, T19N, R4E and Sections 2 to 23, T18N, R4E. Land surface elevation in the study area varies from a little over 900 ft at the top of the Graham hills in the southeast to a little below 400 ft in the northwest near the town of Frederickson. The Kirby Channel, a glacial meltwater channel, crosses the northern portion of the study area, meandering from east to west.

2.2 LAND USE

According to the Graham Community Plan (December 2005), the Graham area is very rural in character with rolling pasturelands, timberlands, and low-density rural residential housing. The study area is on the edge of the Pierce County Urban Growth Area, within an urbanizing area of the community. The northern portion of the study area contains moderate density residential development and some commercial development, including a community-scale shopping center. The northern portion of the study area is zoned as employment centers and moderate density residential, with a Rural Activity Center at 224th and Meridian. The southern portion of the study area contains rural zone classifications.

2.3 REGIONAL GEOLOGY

The study area is located within the physiographic setting called the Puget Sound Lowlands. This area is filled in with thick deposits of glacially derived soils, which can reach thicknesses of 2,000 ft. In the study area, the thickness of glacially derived soils ranges from about 600 to 1200 feet (Buchanan-Banks and Collins, 1994). Multiple periods of continental glaciation occurred in the region during the Pleistocene Epoch (2.5 million to 11,000 years ago) as Cordilleran glaciers advanced into the Puget Sound Lowland. The glacial periods were interspersed with non-glacial periods when conditions were similar to those seen today. The terminus of the most recent Puget Sound ice lobe (during Vashon time) was approximately 12 miles south of Olympia. After the last glacial retreat (approximately 11,000 years ago), the current non-glacial period afforded fluvial incision of the valleys in the Puget Sound Lowlands and subsequent deposition of fluvial and alluvial deposits, processes that are still occurring to the present.

In general, glacial deposits tend to have coarser texture, higher permeability, and greater water transmitting capacity than non-glacial deposits. Glacial deposits include recessional and advance outwash sand and gravel deposits that support many of the area's major aquifers. Glacial deposits

also include glacial till and pro-glacial lake deposits of clay and silt, neither of which provides water to wells in significant quantities.

Non-glacial sediments are typically fine-grained and form regional aquitards. These aquitards limit movement of groundwater and serve to protect underlying water-bearing zones from surface activities. They also form confining layers above confined aquifers.

2.4 REGIONAL HYDROGEOLOGY

The hydrogeology of the study area is characterized by layered aquifers that occur within deposits of the most recent glacial incursion into the Puget Sound Lowland. The study area is shown in Figure 2-1, which also presents the surficial geology on the area.

2.4.1 Key Strata & Aquifers

Three hydrostratigraphic units characterize the shallow groundwater system in the study area. From oldest to youngest, these are:

- Qva: Advance outwash of the Vashon glaciation, characterized by sand and gravel with some silt and clay.
- Qgt: Glacial till of the Vashon glaciation, characterized by unsorted compact silty sand and gravel commonly described as "hardpan" on well logs.
- Qgd: Glacial drift of the Vashon glaciation, characterized mostly by recessional outwash composed of relatively loose sand and gravel with some silt and clay.

In addition to these glacially deposited soils, two other units are presented in the surficial geologic map (Figure 2-1). These are Qa and Qp, which are quaternary alluvium and quaternary peat, respectively. In general, these two deposits are likely not significant with respect to the Graham area groundwater flooding study and are not discussed further in this report.

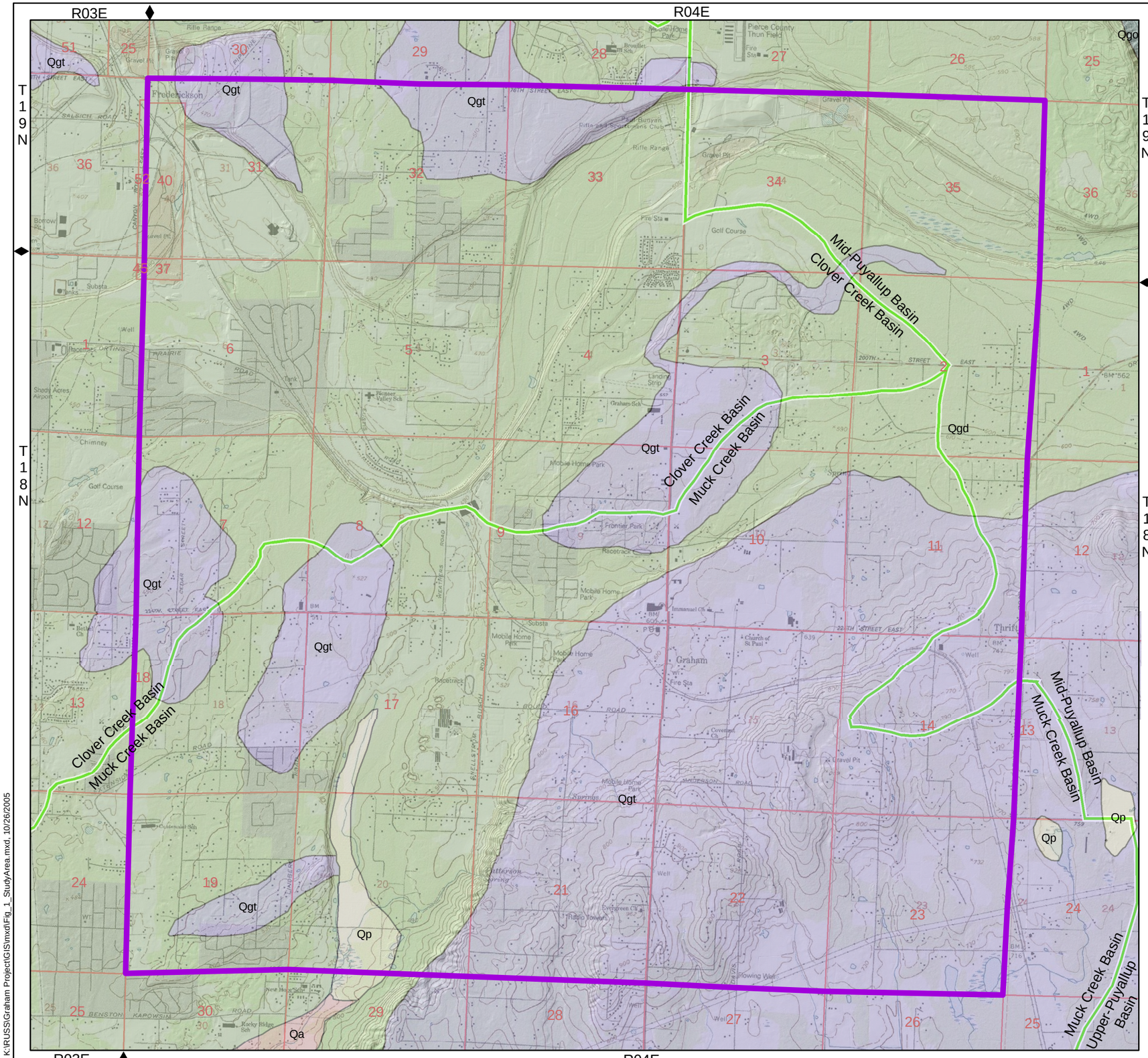
2.5 DRAINAGE/FLOODING PROBLEMS

The Graham Groundwater Study area encompasses the northeast portion of the Muck Creek basin and the southeast portion of the Clover Creek basin. Nearly all of the stormwater runoff in the Muck Creek portion infiltrates locally or collects in shallow depressions and seeps into the ground. The Muck Creek Basin Plan identified relatively few existing drainage/flooding problems within the Muck Creek portion of the study area (Pierce County Public Works and Utilities, 2003).

FIGURE 2-1

STUDY AREA GEOLOGY

Graham Groundwater Study



Study Area

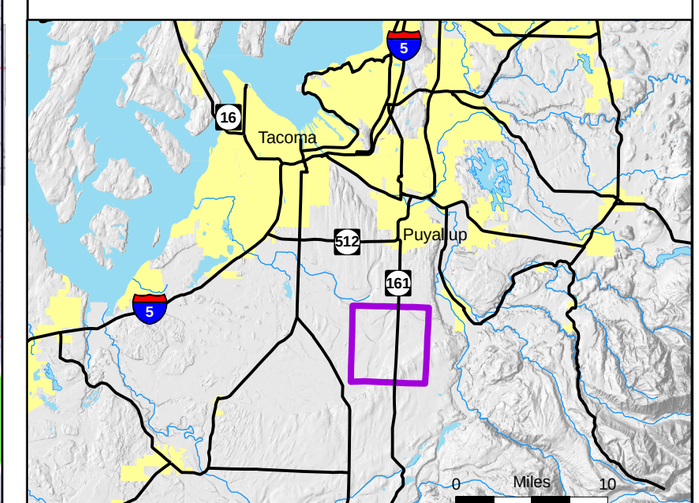
Basin Boundaries

Geologic Units*

- Qp - Peat deposits
- Qa - Alluvium
- Qgd - Continental glacial drift
- Qgt - Continental glacial till

*1:100,000-Scale Digital Geology of Washington State
Washington State Department of Natural Resources
Division of Geology and Earth Resources

Background Images:
USGS 7.5' Topo of Frederickson, WA 1994
LiDAR Hillshade from 2003 LiDAR (www.pugetsoundlidar.org)



0 0.5 Miles

0 3,000 Feet

1:36,000

K:\RUSS\Graham Project\GIS\mxd\Fig_1_StudyArea.mxd, 10/26/2005

The Muck Creek plan noted that runoff from much of the Graham area collects in a natural depression about one-half mile northwest of 224th and Meridian. During most storm events, the runoff collected in this location infiltrates quickly, but ponding occurs during large events. Water Programs' staff is not aware of any existing drainage or flooding problems in the residential areas north and west of the depression (H. Schmidt, 2006). The Muck Creek plan suggested that future development could impact the infiltration that occurs within the natural depression and potentially cause flooding of adjacent areas. Therefore, the plan recommended building a regional infiltration pond within this natural depression.

The portion of the Graham Groundwater Study area within the Clover Creek basin has had significant flooding problems, particularly in the Frederickson area. Most of the problems are associated with high groundwater. Since 1996, the Frederickson area has had several significant groundwater-related flooding events, which appear to be related to extended periods (several months or more) of exceptionally high rainfall (URS, 2001). Groundwater from the Graham area in Muck Creek basin appears to flow northwest into the Clover Creek Basin, where it may be contributing to seasonal high water tables and flooding problems in the Frederickson area (Pierce County Public Works and Utilities, 2003). The original basin planning boundaries were established in 1988 using the topographic maps that were available at that time; groundwater flow patterns were not considered.

2.6 PROPOSED REGIONAL INFILTRATION POND

A large portion of the Graham area drains to a natural depression located about one-half mile west of the shopping center at the intersection of Meridian and 224th Street. The Muck Creek Basin Plan proposed a large regional infiltration pond (CIP 12NF-XXX) at this location to reduce the potential for future flooding of area roads and adjacent development. The basin plan noted that surface ponding occurs at this location during large storm events, but in recent years the ponding has not caused flooding of adjacent developed areas. The basin plan also suggested that groundwater from the Graham area could be contributing to flooding problems in the southeast portion of the Clover Creek basin. To address concerns about the potential impacts that infiltration of groundwater might have outside the project site, the basin plan prescribed this Graham Groundwater Study.

Preliminary modeling cited in the basin plan indicated the regional facility would need about 120 acre-ft of capacity to store runoff from a 100-year event. This preliminary pond size was based on an assumed drainage area of about 2,440 acres and an infiltration rate of 0.5 inch per hour (Pierce County Public Works and Utilities, 2003). Water Programs subsequently refined the preliminary modeling used for the Muck Creek Basin Plan. Water Programs determined that the actual drainage area for the proposed pond location is only about 850 acres, and that infiltration rates could range from 2 to 30 inches per hour (H. Schmidt, 2006). Section 5 contains more information on the proposed infiltration pond.

3. STUDY METHODS

3.1 PHASE I METHODS

Well logs from Ecology's well log database along with other existing hydrogeologic data were used to complete the preliminary groundwater flow map. A well-depth search criterion was used to identify wells containing hydrogeologic data representative of the regional shallow aquifer and water table. Wells with a maximum depth of 75 ft were selected for areas identified as lowlands; wells with a maximum depth of 300 ft were selected for areas identified as hillslopes; and wells with depths between 100 and 300 ft were selected for areas identified as hilltops. Approximately 400 well logs in the Ecology database passed the search criterion within the study area.

Sections	Township	Description	Well-Depth Criterion (ft)
31-35	19N	Lowland	0-75
2-10 and 17-19	18N	Lowland	0-75
11,15,16,20	18N	Hillslope	0-300
14,21-23	18N	Hilltop	100-300

The locations of the wells are approximated based on public land survey information recorded on the well log by the well driller at the time of drilling. In most cases the descriptions are to the ¼, ¼ section. The actual location of the well is approximated by placing the well within the centroid of the smallest ¼ section description on the well log. In most cases this means the actual well location can be off as much as 660 ft.

Ecology's well log spreadsheet file of downloaded well logs does not contain depth-to-water data, so this information was digitized by perusing each well log. These depth-to-water measurements, taken at the time of drilling, were recorded on the well log by the well driller. Using the depth-to-water information, the elevation of the groundwater could be calculated by knowing the elevation of the wellhead. The wellhead elevation was estimated for each well location using a 10-meter digital elevation model (DEM) of the Fredrickson quadrangle.[1] The elevation of the water level was calculated by subtracting the water level depth from the wellhead elevation. For locations where more than one well is located, the average water level elevation was used. Finally, additional water level data from the Hidden Valley Landfill monitoring wells, which are located just north of the study area near 176th Street and Meridian Avenue, were used to augment the Ecology data.

[1] The datum for the quadrangle is NGVD 29.

Once the groundwater elevations were established for the mapped wells, the data were hand contoured. The hand contoured map was then digitized into a Geographic Information System (GIS).

Other data reviewed during development of the preliminary groundwater elevation contour map included approximately 30 geologic logs from the Washington State Department of Transportation (WSDOT) project along Meridian Road. Most of these boreholes were fairly shallow (less than 10 ft deep) and were reported as either dry or with no information on the depth-to-water. Nine of the WSDOT logs contained depth-to-water information and most of them reported water levels up to 50 ft higher than nearby well logs from the Ecology database. This may indicate a perched water table (above the regional shallow aquifer water table) and or higher water levels in 1996-1999 (years when the boreholes were drilled). Most of the WSDOT logs describe 1 to 10 ft of sand and gravel over sandy silt or silt, suggesting the water levels in these shallow logs represents locally perched groundwater; therefore, the WSDOT water levels were not used in the construction of the preliminary water table map.

Descriptions of materials encountered during drilling and recorded on the well logs were used to create a preliminary northwest-southeast hydrogeologic cross-section across the study area. The preliminary cross-section was subsequently revised based on new borings drilled during Phase II as described below.

3.2 PHASE II METHODS

The study methods used in Phase II were based on completion of new soil borings, construction of new monitoring wells, selection of existing wells to include in the monitoring network, and water level measurements. Rather than rely upon GIS data, the wells used in the monitoring network were surveyed so that groundwater elevations could be tied to a single known datum. The datum used for Phase II work is NAVD 88 (North American Vertical Datum of 1988). This datum is approximately 3.5 feet higher than NGVD 29, which means the elevation values for NAVD 88 are smaller numbers than those in NGVD 29.

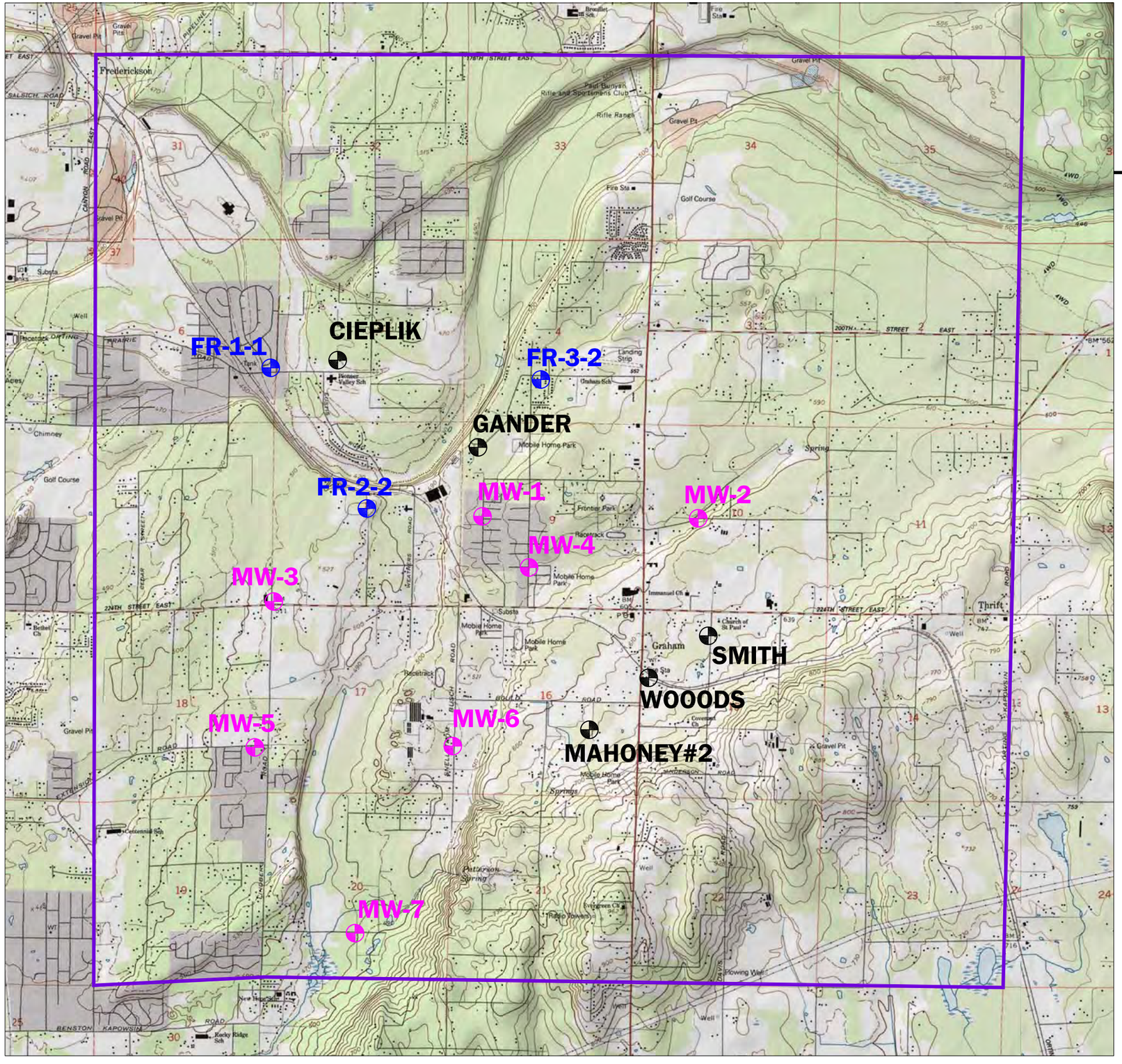
3.2.1 Soil Boring and Logging

Seven new wells were installed for this project during the summer of 2005 (Figure 3-1). Two types of drilling methods were used to complete the borings and well installation. Of the seven borings, four were completed using hollow-stem auger and three were completed using sonic drilling.

Initial drilling was accomplished using a hollow-stem auger rig to advance 8-inch-diameter augers. This drilling method was used initially because it is cost effective, it is particularly versatile for monitoring well construction, it allows accurate evaluation of depth to water during the drilling process, and it produces soil waste cuttings in a controllable manner. This last feature is important when drilling along County rights-of-way. Furthermore, this method requires less working space

FIGURE 3-1
GROUNDWATER MONITORING WELL LOCATIONS

Graham Groundwater Flooding Study



Study Area

New Monitoring Wells

Existing Monitoring Wells

Domestic Wells

0 100 200
Scale In Feet

Pierce County
Public Works & Utilities
Water Programs

PgG

than other drilling methods. However, a drawback with using the hollow-stem auger method is that it can meet refusal in soils containing cobbles and boulders.

Borings MW-2, MW-5, MW-6, and MW-7 were completed using the hollow-stem auger method. Split-spoon soil samples were collected during hollow-stem augering and visually classified using the Unified Soil Classification System (USCS). The hollow-stem auger was not able to complete the other three borings because it could not penetrate the coarse-grained materials (large gravel and cobbles) encountered at those locations.

The remaining wells (MW-1, MW-3, and MW-4) were installed using sonic drilling technology. This method was chosen because it can drill through coarse-grained material and generates limited quantities of cuttings, which is a desirable attribute when drilling on rights-of-way in developed areas.

For this project, 6-inch outer casing was advanced the full depth of the boring and upon reaching the bottom, the PVC well was installed. Soil sampling was accomplished through an inner casing advanced in conjunction with the outer casing. This inner casing acts like an inner core barrel, which collects sample cores as it is advanced. Therefore, soil sampling using the sonic drilling method provided essentially continuous core—in this case—about 4 inches in diameter.

Boring logs are included in Appendix A.

3.2.2 Monitoring Well Installation

For both drilling methods employed, monitoring wells were installed in each borehole after reaching desired depth. Monitoring wells were installed in each borehole using 2-inch-diameter Schedule 40 PVC casing and commercially slotted screen. The casing was flush-threaded using no solvent-welded joints. Sand packs were placed around the screen sections for the wells using Colorado silica sand. Bentonite chip surface seals were placed from near the top of the sand pack to the land surface. The wells were installed in accordance with WAC 173-160.

After installation, each well was developed to remove fine sand and silt from the bottom of the well, to confirm communication with the aquifer, and to clear the water as much as reasonably possible. The wells were developed using high-pressure air followed by bailing with a hand bailer. Each well was completed with an 8-inch-diameter, flush-mounted monument set in concrete surface pads.

3.2.3 Manual Water Level Measurements

In addition to the seven new wells, eight existing wells were included in the suite of monitoring wells. Three of the existing wells were installed for the Fredrickson groundwater flooding evaluation (URS, 2001). The remaining five wells were domestic water supply wells identified by County staff.

Table 1 presents physical data for each well used in the monitoring network, including location, depth, screened interval, and elevation. Figure 3-1 shows the locations of the wells.

Using the suite of monitoring wells, synoptic water-level measurements were made on a monthly basis starting on August 11, 2005 and continuing to August 17, 2006. As used in this report, "synoptic" monitoring means that water levels in all of the wells were measured in one monitoring event during one day providing a "snapshot" of water levels on that day. The first synoptic set of measurements did not include MW-4; it was not installed until the middle of August because of scheduling difficulties with the driller. The synoptic water level measurements were tracked in graphical form during the year of monitoring to produce water level trend plots. Water level measurements were completed using an electric well sounder.

These data were qualitatively evaluated by plotting hydrographs. These plots show groundwater head versus time (date) and provide a quick way to evaluate rising and lowering groundwater head elevations as a function of precipitation.

3.2.4 Groundwater Mapping

The synoptic groundwater level data were used to develop two series of maps. These are groundwater elevation contour maps and depth-to-water maps.

3.2.4.1 Groundwater Elevation Contour Mapping

These maps are based on the synoptic groundwater level data collected by County staff. Maps were completed for the following synoptic water level measurement events:

- October 13, 2005
- February 13, 2006
- May 12, 2006
- July 11, 2006

A fifth map was completed early in the monitoring period for data collected on August 11, 2005. However, at that time MW-4 had not yet been completed, so this map was not used in the hydrogeologic evaluation.

The maps were generated by hand contouring groundwater elevation data. Hand contouring these data was deemed preferable to computer-aided contouring packages because hand contouring is not affected by boundary conditions where no data exist. Also, surface hydrologic features that can affect groundwater flow can be considered during hand contouring.

3.2.4.2 Depth to Groundwater

Maps that show depth to groundwater were completed using GIS mapping techniques. After completion of the groundwater elevation contour maps, the contour surfaces were digitized, then gridded with a computer. This gridded surface was then mathematically subtracted from the topography using GIS techniques. Since the groundwater elevation surface mimics the topography but varies much more gradually, the resulting maps highlight areas of steep topography (e.g., the oxbow of the Kirby Channel shows prominently in the maps).

3.2.5 Lag Time Study

The monthly snapshot water level measurements were augmented with a transducer study, which was completed to evaluate the lag time between recharge events in the Graham area and groundwater day-lighting events in the Clover Creek basin. For the lag-time study, three wells along the currently understood groundwater flow line were instrumented with transducers. These wells are (from south to north) MW-4, MW-1, and FR-1-1 (Figure 3-1).

The transducers used were Solinst Levelloggers that combined water-level sensors (the actual pressure transducer) and data logger functions. The data logger controls monitoring frequency, stores data, and allows in-field downloads.

Since these submersible transducers were completely under water, they were not vented to the atmosphere through a vent tube. Therefore, these transducers measured the combined pressure from the water in the well casing and the atmosphere on top of the water. For this reason, another low pressure transducer/data logger was installed to monitor atmospheric (barometric) pressure only. The atmospheric pressure response was then subtracted from total response to obtain the change in water level over time.

After the wells were instrumented, the data loggers collected data for a one-week period. After this week, the data from data loggers were downloaded and emailed to the consultant team. The purpose of this one-week period of data collection was to confirm that the data loggers were functioning properly and to estimate transducer drift.

The data loggers were set to collect data at one-hour intervals. Data collection occurred from August 18, 2005 to the spring and early summer of 2006. During the monitoring year, some difficulty in obtaining regular downloads of the transducer data occurred. For example, the consultant team did not receive barometer data for the month of June 2006. The transducers were, however, able to record groundwater level data responding to the unusual precipitation events that occurred during the 2005/2006 winter.

PGG completed a detailed evaluation of the transducer data. This evaluation included estimating the lag time between recharge events in the Graham Hill area to discharge events in downgradient areas such as the Kirby Channel. Three assumptions are inherent in this analysis:

- The three instrumented wells are located along a single flow line. This assumption is supported by the synoptic groundwater measurements, which showed that MW-4 was always upgradient of MW-1 and that both MW-1 and MW-4 were always upgradient of FR-1-1. A limitation is that FR-1-1 likely receives groundwater inflow from areas to the southwest in addition to inflow from the direction of MW-1 and MW-4.

- The groundwater level data in the two downgradient wells reflect groundwater inflow to the well location as opposed to recharge that is occurring at the well location. This assumption is supported by the fact that MW-4 exhibited very detailed and intricate responses to precipitation. Data from FR-1-1 showed significantly gentler responses to the precipitation events.

- Data from MW-4 represents upland recharge and data from FR-1-1 represents lowland (Kirby Channel) discharge data. The peak in MW-4 data is at an earlier time than the same peak in FR-1-1 data, suggesting that this assumption is correct.

The first step in the lag time evaluation was to plot the data on groundwater head versus time (date) plots, similar to the hydrographs generated from the synoptic water level data. However, the transducer data plots are based on many more data points (every hour compared to once a month) and this detail allowed digital evaluation of the timing of peaks using spreadsheets. A qualitative observation of a peak on the hydrograph gives way to an exact date and time (within one hour) of that peak in the spreadsheet. By knowing the exact timing of the peak for each well and knowing the distance between wells, simple arithmetic allows calculating the lag time between wells.

3.2.6 Precipitation

Rainfall data from the McMillin Reservoir in Tacoma were obtained to compare with groundwater elevation data in three existing monitoring wells that were installed for the groundwater flooding evaluation near Frederickson (URS, 2001). The three wells are FR-1-1, FR-2-2, and FR-3-2. These were used because County staff has been monitoring them since the fall of 1998, which provided a long enough record to compare with rainfall. Precipitation data were from March 1941 to the end of June 2006. These data, along with the groundwater level data, were plotted and qualitatively reviewed for cause and effect relationships. Based on the obvious cause and effect relationship indicated in the Graham study monitoring wells, an antecedent precipitation index (API) analysis was performed. An API analysis smoothes precipitation plots and allows a relatively simple method for evaluating groundwater response to precipitation events. The API analysis is based on the following equation:

$$API_d = (API_{d-1} * C) + P_d$$

Where:

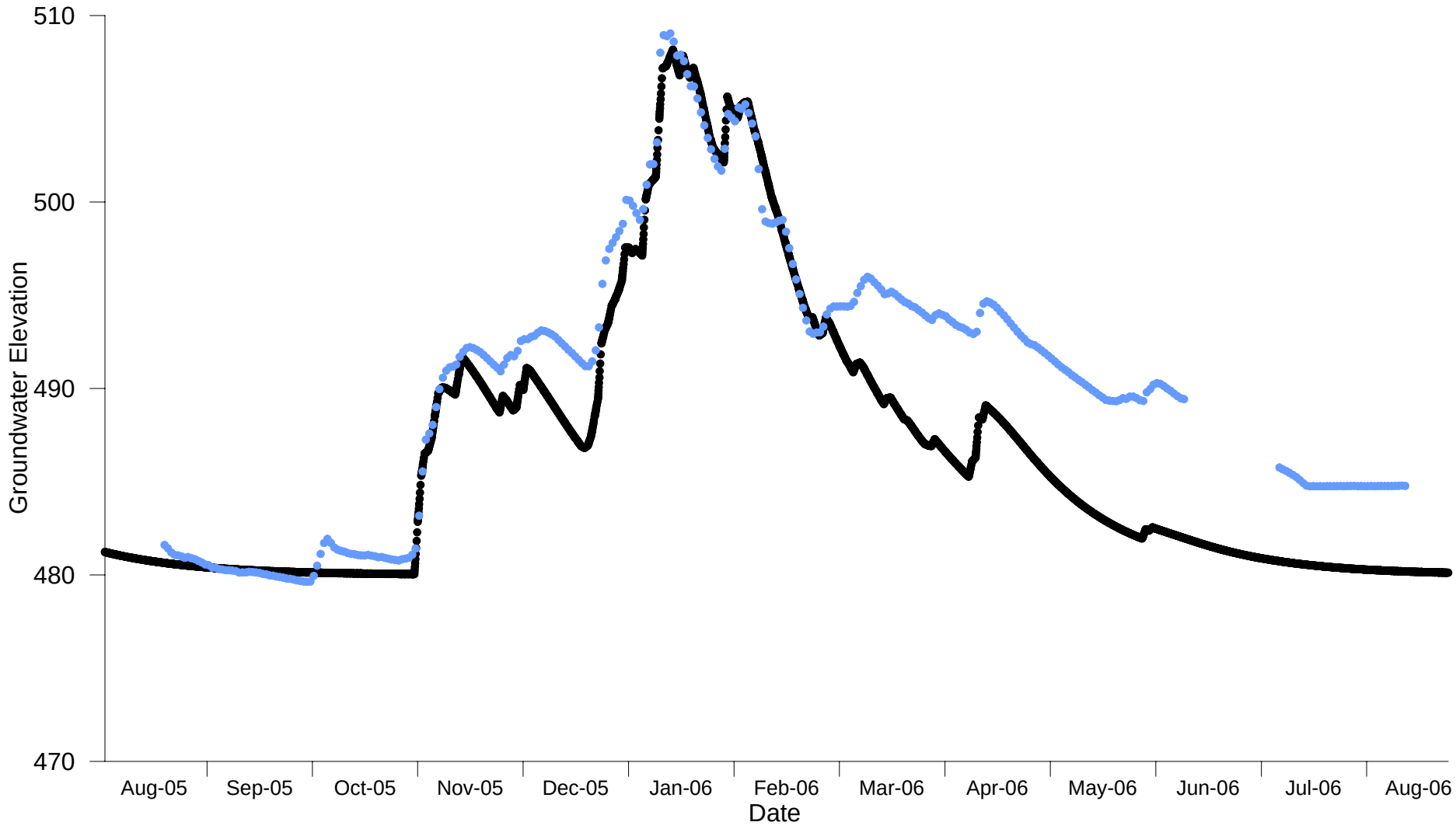
API_d = antecedent precipitation index for day d
API_{d-1} = antecedent precipitation index for day d-1
C = decay coefficient
P_d = daily precipitation

3.2.7 Groundwater Modeling

A MODFLOW model was developed to simulate the potential impacts of the proposed infiltration pond on local groundwater levels. Initially, key aquifer property values were estimated using well log information, which resulted in a range of hydraulic conductivity (K) from less than 10 to nearly 1,000 ft per day.

The model domain extends nine times the length of the infiltration pond in all directions. The infiltration pond was assumed to be 300 feet by 300 feet. The cell size of the model grid was set to 30 ft by 30 ft throughout the model domain, with a constant head boundary of 500 feet elevation applied to the perimeter of the grid. The initial saturated thickness of the aquifer was set to 50 ft. The infiltration pond was simulated in the middle of the model domain using the Recharge Boundary Condition.

The initial MODFLOW simulations provided a wide range of results, reflecting the uncertainty associated with the key aquifer properties used in the model. To help reduce this uncertainty, a calibration run of the model was performed to better estimate the key aquifer properties of hydraulic conductivity (K) and storage (S). K and S were estimated based on the response of water levels in MW-4 over the monitoring period—especially during December 2005 and January 2006. The aquifer parameters were estimated by simulating the response to rainfall at the location of MW-4. The recharge allowed into the model was generated using precipitation data from the McMillan Reservoir Station in Tacoma for the 2005/2006 winter period. The hydraulic conductivity and storage were varied until a match of groundwater head response reasonably simulated the measured response at MW-4. Figure 3-2 shows the correlation between observed and simulated groundwater elevations at MW-4.



LEGEND

Observed

Simulated

FIGURE 3-2
COMPARISON OF OBSERVED AND SIMULATED GROUNDWATER LEVELS AT MW-4

Pierce County
Public Works & Utilities
Water Programs

BROWN AND CALDWELL
Environmental Engineers & Consultants

PgG

GRAHAM GROUNDWATER STUDY

4. FINDINGS

4.1 PHASE I FINDINGS

Phase I was conducted to develop a preliminary understanding of the groundwater basin boundaries and groundwater flow patterns in the Graham study area, identify key data gaps, and develop a monitoring plan to address the key data gaps. The most significant Phase I finding was that the groundwater flow patterns do not appear to coincide with the surface water basin divide between the Clover and Muck Creek basins. Groundwater from much of the Graham area flows northwest into the Clover Creek basin. Key data gaps included depths to groundwater and aquifer properties in some portions of study area. Phase I culminated with the preparation of a monitoring plan to address the key data gaps. The monitoring plan was implemented in Phase II.

4.2 PHASE II FINDINGS

The Phase II water level measurements confirmed the groundwater flow directions estimated during Phase I. The soil borings showed that the surficial soils contained a much higher percentage of silt than had previously been suspected based on the generally understood characteristics of the Vashon Recessional Outwash. Exceptionally wet weather during December 2005 and January 2006 caused substantial increases in groundwater elevations. The following sections describe the key Phase II findings in more detail.

4.2.1 Study Area Hydrogeology

The hydrogeology of the study area is dominated by the complex depositional and erosional environments that existed during the most recent glacial incursion into the Puget Lowland, which is called the Vashon Stade of the Frasier Glaciation. Various environments occurred while the glacier was advancing southward and during the time it was melting.

The melting stage is referred to as recessional time but that term is misleading. The ice did not actually move back to the north, rather it simply melted in place, allowing for many micro depositional regimes that left behind a complex assemblage of varying soil compositions. Deposition of soils during the recession of the Vashon glacier is integral to characterizing the hydrogeology of the study area.

During this time, glacial lakes named Lake Puyallup and Lake Russell formed east and west, respectively, of the Graham Upland, which is now defined by the surface water divide between the Puyallup and Nisqually River drainages. Both pro-glacial lakes existed for a short period of time between the onset of Vashon ice lobe recession and opening of Puget Sound to the Strait of Juan de Fuca. These lakes are part of the dynamic and complex depositional regime that existed in the Puget

Lowland during ice recession. Figure 4-1 shows the configurations of the two lakes at the time when Lake Puyallup was at an elevation of 450 feet, which is the approximate elevation of the Kirby Channel nick point.

At the beginning of recessional time Lake Puyallup was higher than Lake Russell. As the ice front receded to the north, nick points in the topographic divide between the two lakes were sequentially exposed from south to north. As each nick point was exposed to Lake Puyallup, catastrophic flooding occurred while Lake Puyallup sought its new temporary surface level. This process was repeated five times until the ice melted northward of present-day Ruston and, finally, the level of Lake Puyallup equaled the level of Lake Russell. The southern-most nick point or outlet was at the head of present-day Ohop valley. The second of these outlets is at the eastern end of the Kirby Channel, located approximately ¾ mile east of the northeastern corner of the study area. Once this outlet was exposed, the sudden opening resulted in a catastrophic flooding event that flowed westward and carved the Kirby Channel. After eroding the channel, deposition of coarse grained soils occurred. As the flow volume decreased, deposition occurred in narrower and narrower bands of sand and gravel, which are visible in the LiDAR topographic maps such as Figure 4-1.

Three geologic cross-sections were prepared based on the borehole logs collected while installing the seven new wells, as well as other existing information. The vertical relationships of the deposits are presented in three cross-sections. Figure 4-2 shows the cross-section locations and Figures 4-3 through 4-5 show the cross-sections.

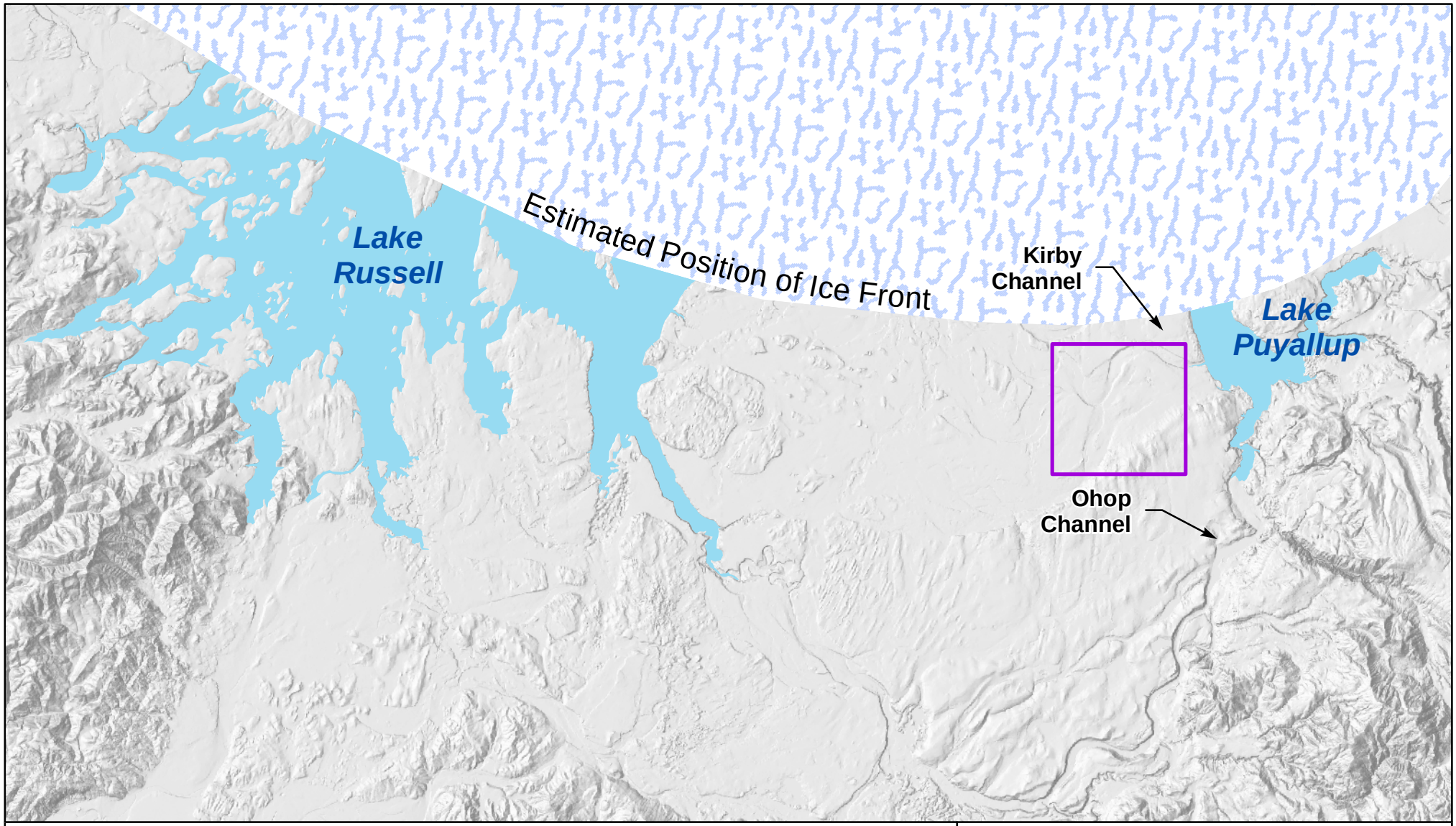
The cross-sections include a depiction of the water table (or potentiometric surface where confined). This representation of the water table is based on groundwater data for the wells that are shown in each section and is not meant to match the groundwater flow maps exactly (Section 4.3.3).

4.2.2 Synoptic Water-Level Data

Water levels in the Graham Study monitoring wells responded to heavy precipitation in the winter of 2005/2006, particularly in response to heavy rains that occurred from mid-December 2005 through January 2006. The responses varied from less than 2 ft in MW-7 to over 35 ft in FR-3-2. Nine of the 15 wells in the monitoring network experienced changes of over 20 ft during the monitoring period. The average change in all the wells was 20.3 ft. The wide variation in the magnitude of groundwater elevation change is likely due to a number of hydrogeologic factors, such as:

- Variations in the aquifer hydraulic conductivity and thickness could affect the ability of the aquifer to transmit water. The drilling observations conducted during monitoring well construction suggest widely varying soil conditions and thus a wide variation in hydraulic conductivity.

- Differences in confinement (aquifer storage) could affect the magnitude of the water level response to recharge. The relative elevations of the top of the water table and



Graham Goundwater Study Area

0 5 Miles

0 25,000 Feet

N

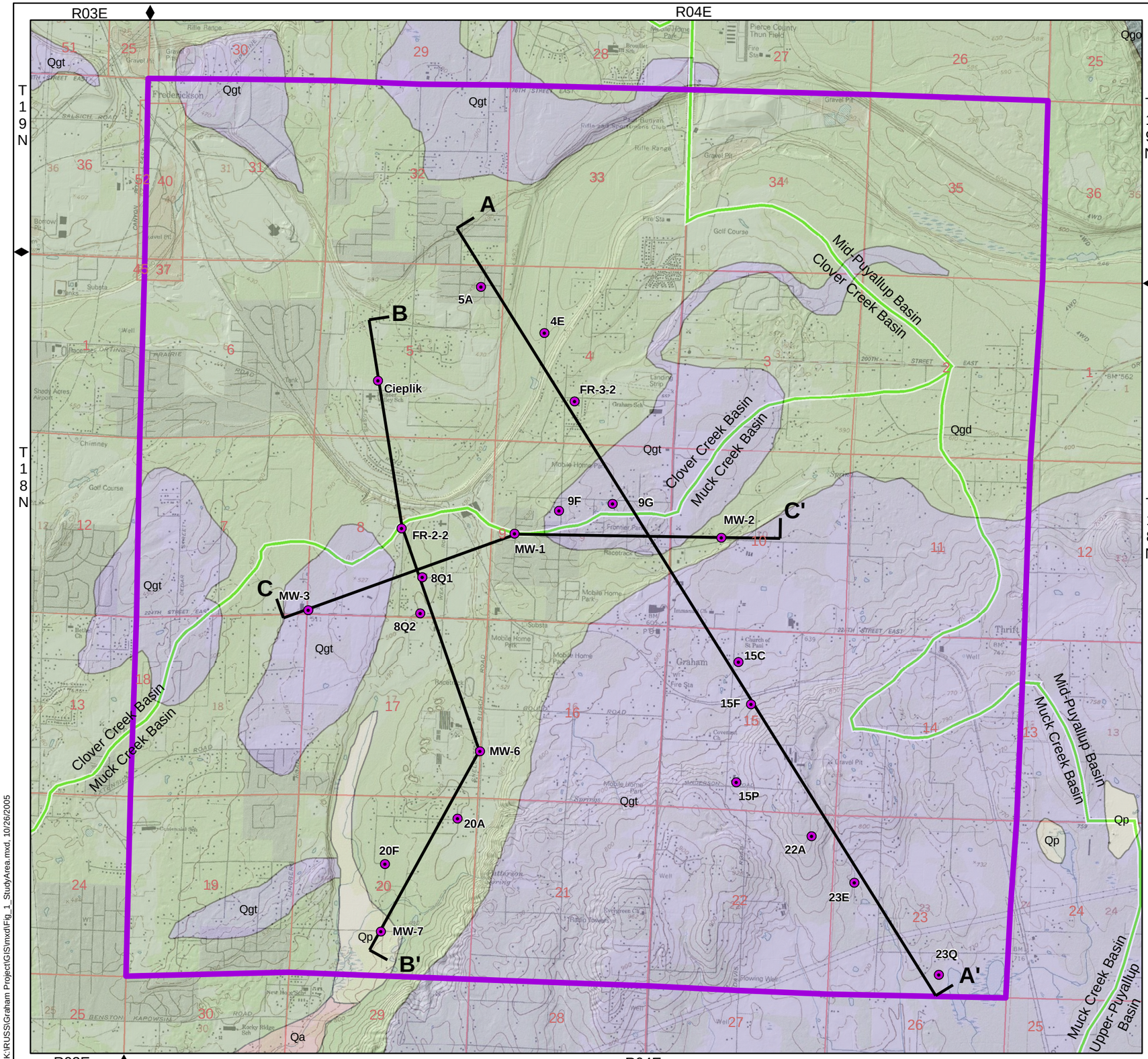
FIGURE 4-1
DEPICTION OF LAKE PUYALLUP AND LAKE RUSSELL

Graham Groundwater Study

FIGURE 4-2

STUDY AREA GEOLOGY

Graham Groundwater Flooding Study



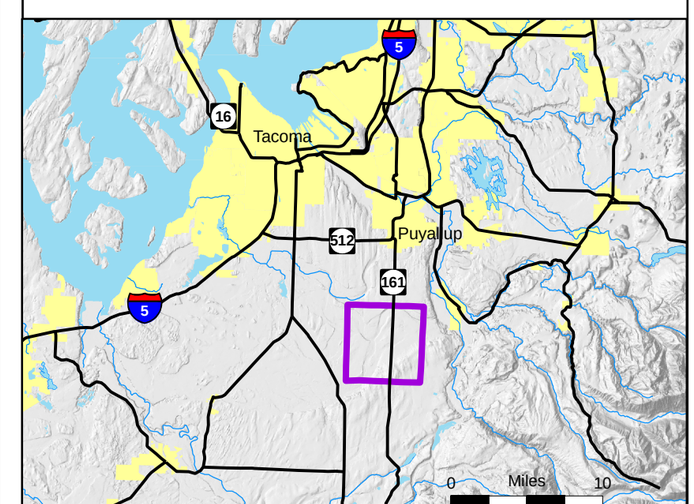
Study Area
Basin Boundaries
Hydrogeologic Cross-Sections
Cross-Section Wells

Geologic Units*

- Qp - Peat deposits
- Qa - Alluvium
- Qgd - Continental glacial drift
- Qgt - Continental glacial till

*1:100,000-Scale Digital Geology of Washington State
Washington State Department of Natural Resources
Division of Geology and Earth Resources

Background Images:
USGS 7.5' Topo of Frederickson, WA 1994
LiDAR Hillshade from 2003 LiDAR (www.pugetsoundlidar.org)

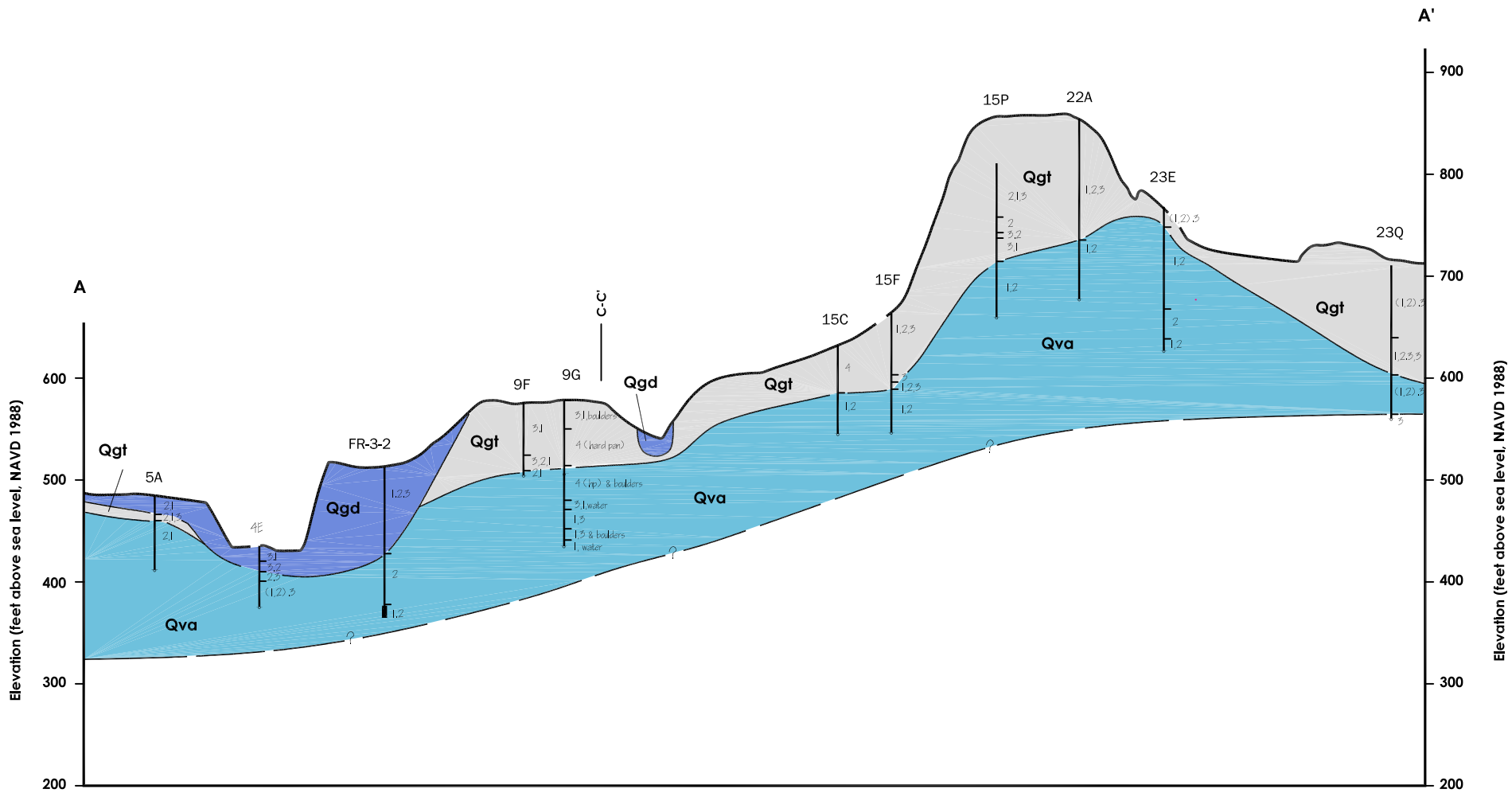


0 0.5 Miles
0 3,000 Feet
1:36,000

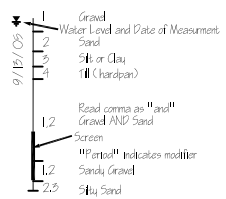
N W E S

PgG

K:\RUSS\Graham Project\GIS\mxd\Fig_1_StudyArea.mxd, 10/26/2005



LEGEND



Water Table

Qgd Vashon Glacial Drift

Qgt Vashon Till

Qva Vashon Advance Outwash

Horizontal Scale in Feet
0 1500 3000

0 75 150
Vertical Scale in Feet

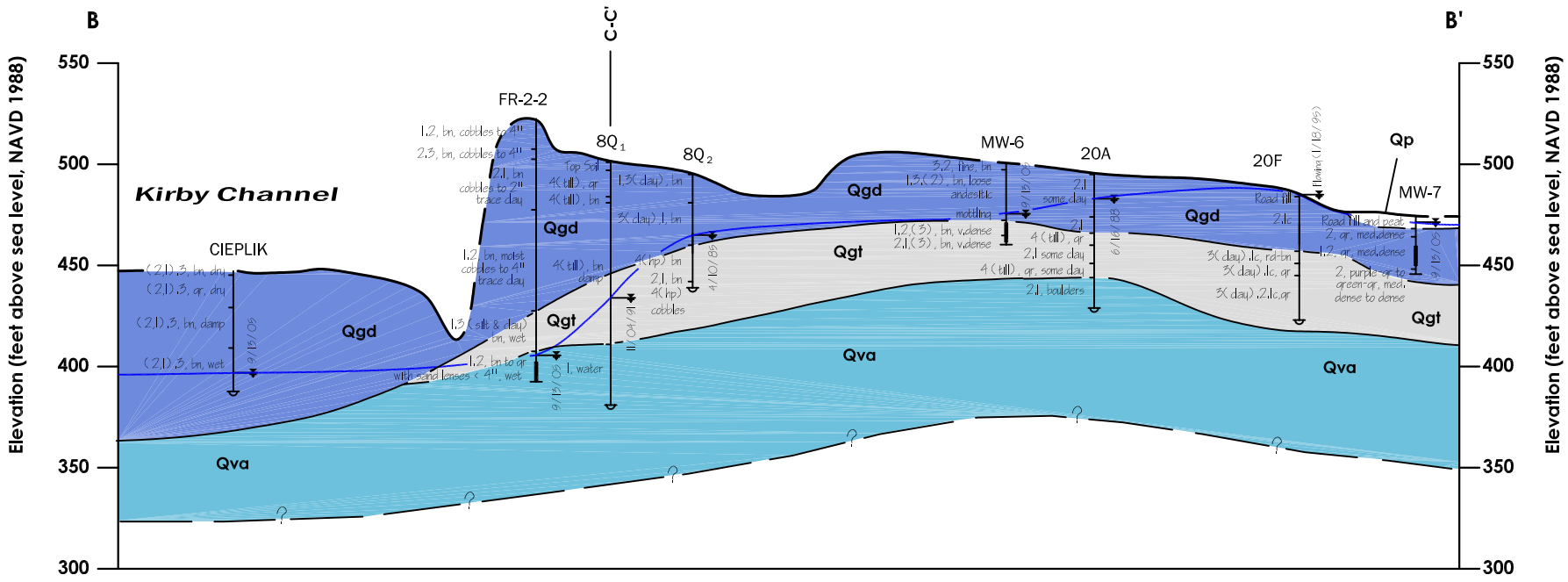
Vertical Exaggeration is 20 Times

FIGURE 4-3
GRAHAM AREA
A-A' HYDROGEOLOGIC CROSS-SECTION

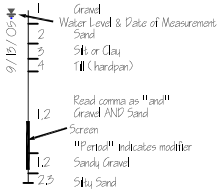
GRAHM GROUNDWATER STUDY
JOB JP0405 A-A'_XSEC.dwg

Pierce County Public Works & Utilities Water Programs

PgG



LEGEND



Water Table

Qp Peat

Qgd Vashon Glacial Drift

Qgt Vashon Till

Qva Vashon Advance Outwash

Horizontal Scale in Feet
0 1250 2500

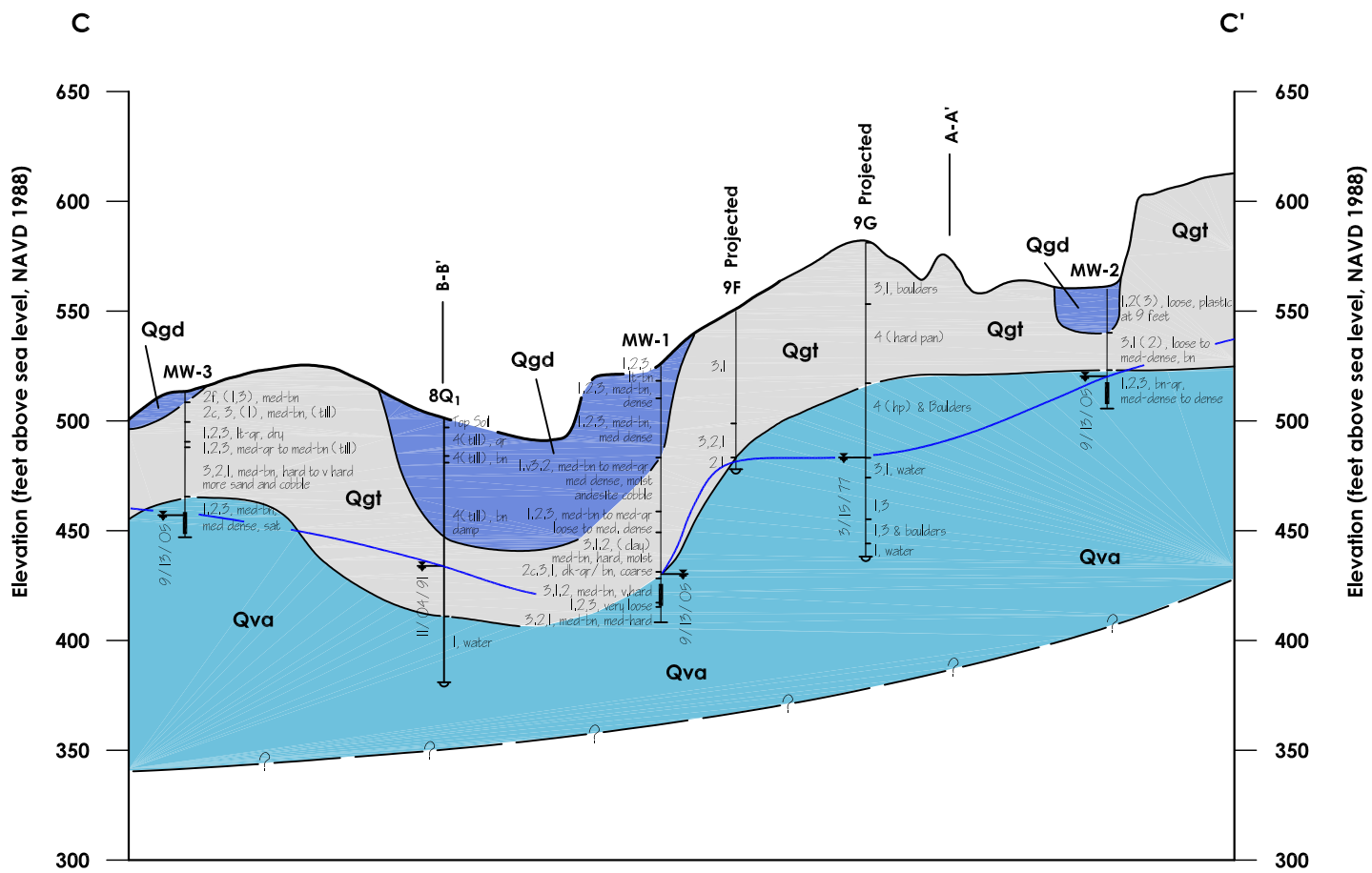
Vertical Exaggeration is 30 Times

FIGURE 4-4
GRAHAM AREA
B-B' HYDROGEOLOGIC CROSS-SECTION

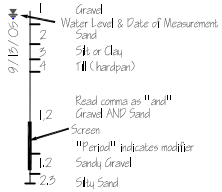
GRAHM GROUNDWATER STUDY
JOB JP0405 B-B'_XSEC.dwg

Pierce County Public Works & Utilities Water Programs

PgG



LEGEND



Water Table

Qgd Vashon Glacial Drift

Qgt Vashon Till

Qva Vashon Advance Outwash

Horizontal Scale in Feet

0 1250 2500

Vertical Exaggeration is 30 Times

FIGURE 4-5
GRAHAM AREA
C-C' HYDROGEOLOGIC CROSS-SECTION

GRAHM GROUNDWATER STUDY

JOB JP0405 C-C'_XSEC.dwg

Pierce County Public Works & Utilities Water Programs

PgG

the bottom of confining units indicate that varying degrees of confinement likely exist in the Graham Study area.

- The thickness and permeability of the overlying glacial till could affect the amount and timing of recharge.

The timing of the responses also changes depending on the location of the wells with respect to a groundwater flow line. Groundwater flow lines occur perpendicular to the groundwater elevation contours and indicate the general flow direction of groundwater as it travels from high elevation (recharge area) to lower elevations (discharge area).

Figure 4-6 shows the hydrographs for all wells in the study based on the manual measurements that were made once per month. It appears that wells located closer to recharge areas generally responded relatively quickly to precipitation events. Three general "groups" of groundwater responses are observed in the Graham monitoring wells depending on their location in the groundwater flow field:

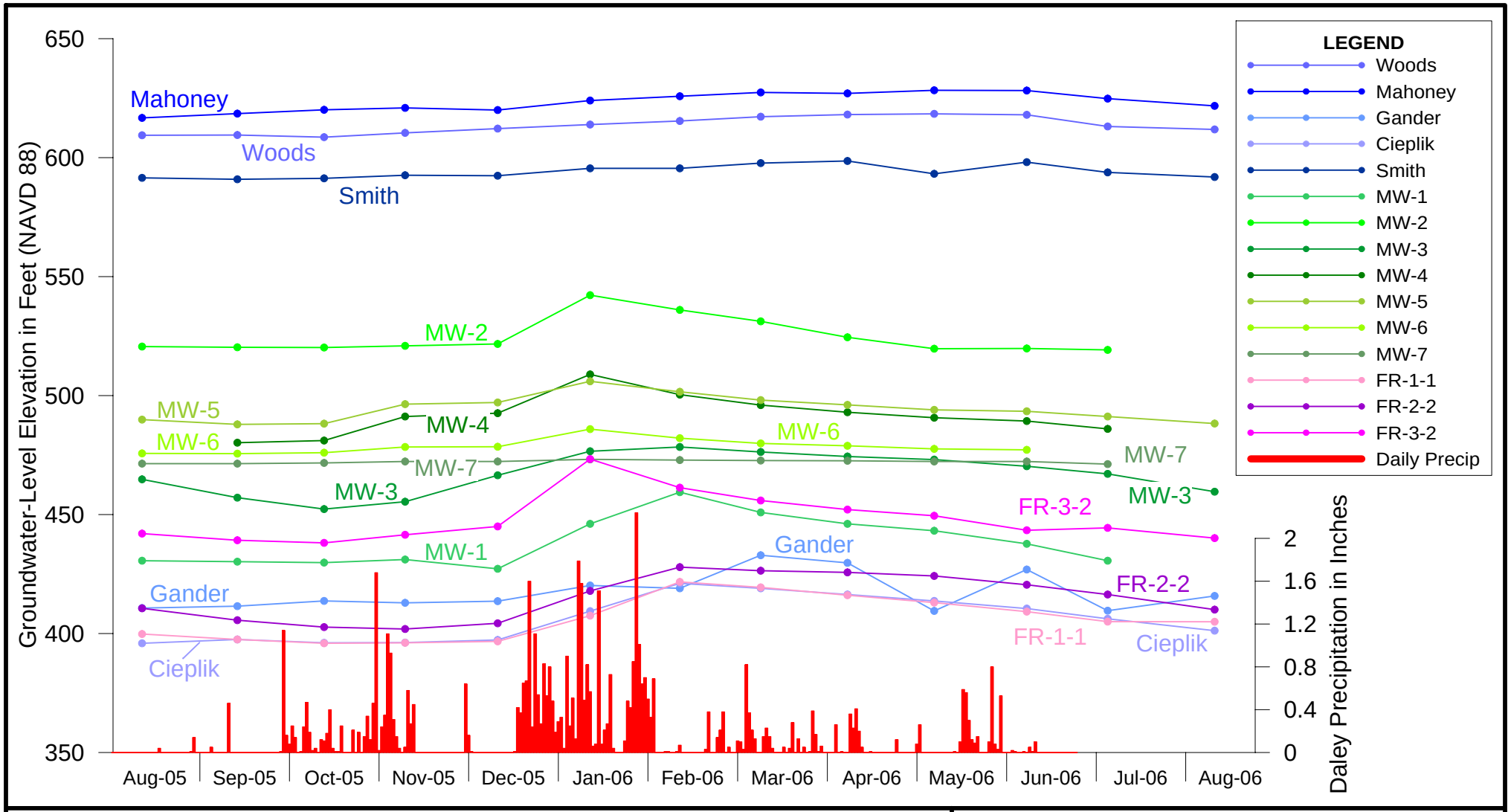
1) Wells located near the steep gradient in groundwater levels off the north slope of Graham Hill (Mahoney, Woods, Smith, and MW-7) have only responded moderately to the heavy precipitation. The maximum increase in these wells was less than 10 ft.

2) Wells located in the lowland area between the Graham Hills and the Kirby Channel (MW-2, MW-4, MW-5, and MW-6) had a more immediate response to precipitation. These wells show a moderate to strong response to both the November and mid-December/January precipitation events, and all three show a decline in February while the other monitored wells continue to rise.

3) Wells located near the Kirby Channel and farthest from the recharge area (MW-1, MW-3, FR-1-1, FR-2-2, FR-3-2, Gander, and Cieplik) all responded significantly (over 20 ft in all wells) to the mid-December/January precipitation, but little response occurred during the November precipitation.

Detailed observations of the data are presented below:

- Groundwater levels in MW-7, located near the southwestern corner of the study area, appeared to follow a different pattern from the other wells in the study. Groundwater levels in MW-7 did not appear to respond to the precipitation events. One possible explanation is that the well taps the aquifer very close to the ground surface. In this case, since the aquifer appears to be close to the ground surface, little head change is needed to cause discharge to the ground surface. MW-7 is located near a wetland. Once the groundwater level rises to the ground surface, it discharges to the wetland. After the groundwater reaches the ground surface, water levels in MW-7 can no longer increase because the water simply spreads out into the wetland.



This plot was originally produced in color. Black & white copies may not convey the intended information.

Pierce County
Public Works & Utilities
Water Programs

FIGURE 4-6
SUMMARY OF MONTHLY (SYNOPTIC) GROUNDWATER LEVELS

BROWN AND CALDWELL
Environmental Engineers & Consultants

PgG

GRAHAM GROUNDWATER STUDY

- MW-3 experienced a 12-ft decline in water levels during the fall of 2005. The cause of this apparent decline is not clear. One possible explanation is that a nearby pumping center could have been pumping at the time the data was collected.

- Other wells also exhibited groundwater-level declines during the fall of 2005. These declines in FR-1-1 (4 ft), FR-2-2 (8 ft), and FR-3-2 (4 ft) appear to be reasonably associated with normal seasonal fluctuation in groundwater elevations.

- The Gander and Mahoney wells showed water levels rising about 3 ft during the fall of 2005. It is possible that this increase is an artifact of the pumping schedule for these domestic wells. If the August and September measurements were affected by recent pumpage, and if the October measurement was not, there would be an apparent increase in groundwater elevation. The Gander well also experienced declines in water levels in May and July 2006. These apparent low levels are likely associated with pumping.

- Five of the wells (FR-3-2, MW-2, MW-4, MW-5, and MW-6), located on the sloping plane between Graham Hill and the Kirby Channel, experienced peak groundwater levels in January 2006. These peaks correspond closely to the high rainfall experienced in December and January. Other wells experienced groundwater level peaks that were delayed relative to the winter precipitation event. These wells (MW-3, MW-1, Gander, FR-2-2, Ceiplik, and FR-1-1) experienced peaks in February and March 2006. In general, the wells with the higher groundwater head elevations responded more quickly to rainfall than those wells with lower groundwater elevations. This may indicate that the five wells located between Graham Hill and the Kirby Channel experienced "mountain-front recharge," which can quickly provide runoff water to the groundwater system.

- The three domestic wells located close to the base of Graham Hill had smaller responses to rainfall compared to the other wells. This could be because these wells are located on Vashon Till, which tends to resist infiltration more than the recessional outwash deposit.

4.2.3 Groundwater Contours and Basin Boundaries

Figures 4-7 through 4-10 show groundwater elevation contours in the Graham Study area in October 2005, February 2006, May 2006, and July 2006, respectively. As shown in these figures, the general pattern of groundwater flow (flow direction and gradient magnitude) is to the northwest from Graham Hill. Groundwater flows from areas of high elevations (recharge areas) to areas of lower elevations (discharge areas). Therefore, groundwater that recharges in the Graham Hill area generally flows northwesterly, crossing into the Clover Creek basin toward the Kirby Channel. A

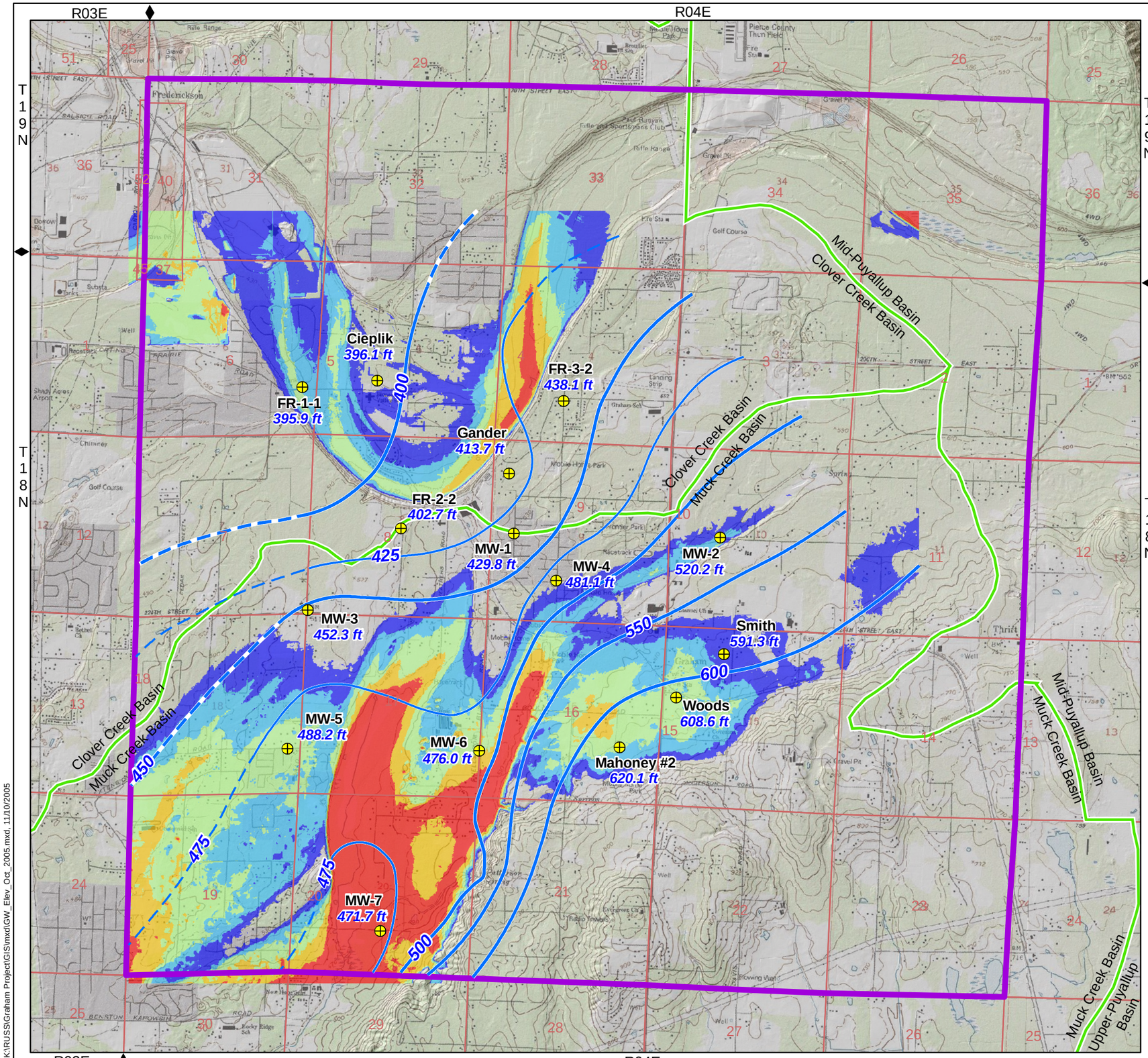


FIGURE 4-7

GROUNDWATER ELEVATION ON OCTOBER 13, 2005

Graham Groundwater Flooding Study

Study Area

Basin Boundaries

Monitoring Well with Groundwater Elevation in Feet (NAVD88)

Groundwater Elevation Contours (Dashed Were Infered)

Estimated Depth to Groundwater

- < 10 ft
- 10 - 20 ft
- 20 - 30 ft
- 30 - 40 ft
- 40 - 50 ft

Background Images:
USGS 7.5' Topo of Frederickson, WA 1994
LiDAR Hillshade from 2003 Lidar (www.pugetsoundlidar.org)

0 0.5 Miles

0 3,000 Feet

1:36,000

N S E W

Pierce County Public Works & Utilities Water Programs

PgG

K:\RUSS\Graham Project\GIS\mxd\GW_Elev_Oct_2005.mxd, 11/10/2005

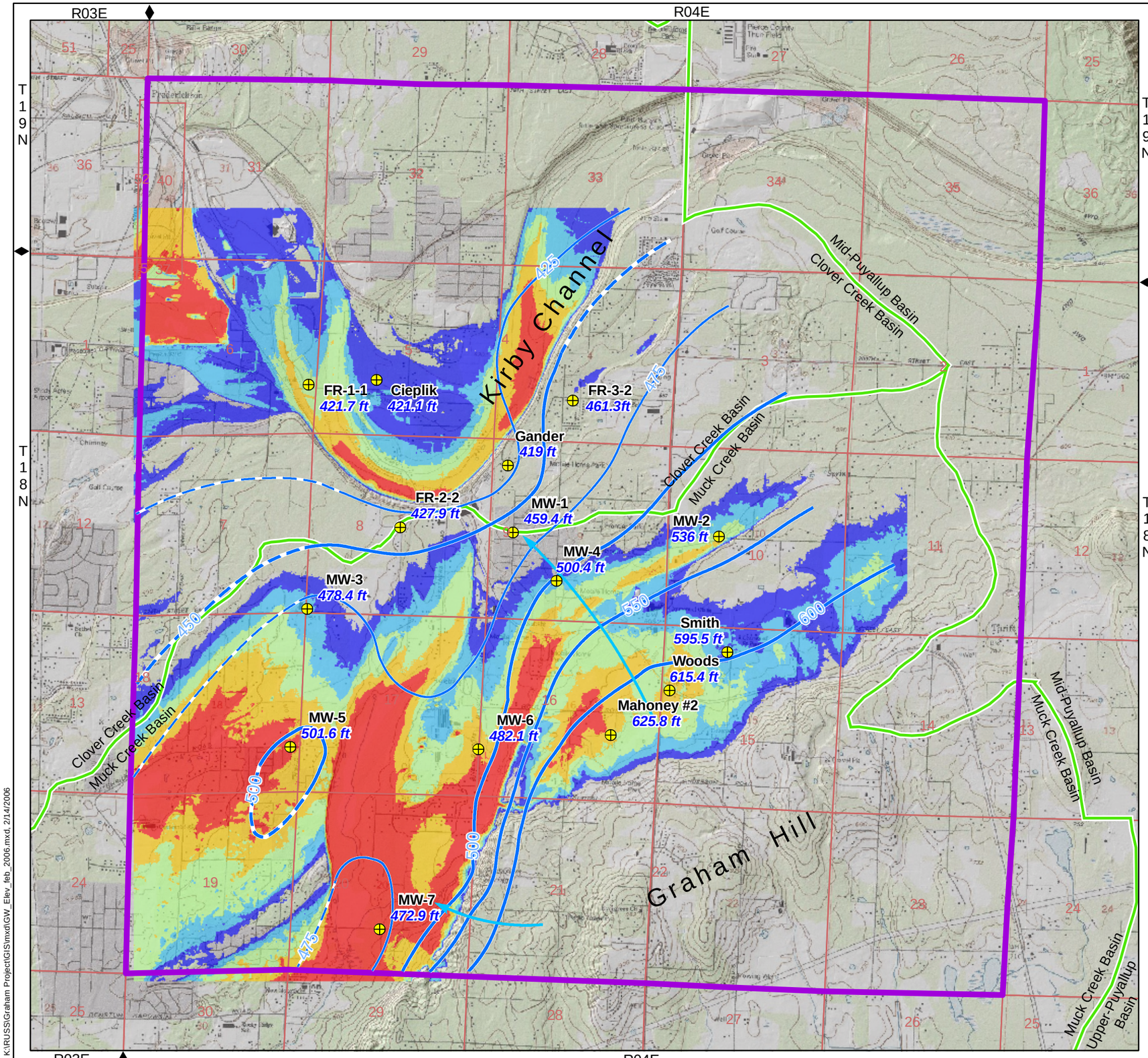


FIGURE 4-8

GROUNDWATER ELEVATION ON FEBRUARY 13, 2006

Graham Groundwater Flooding Study

Study Area

Basin Boundaries

Monitoring Well with Groundwater Elevation in Feet (NAVD88)

Groundwater Elevation Contours (Dashed Were Infered)

Groundwater Flow Direction

Estimated Depth to Groundwater

- < 10 ft
- 10 - 20 ft
- 20 - 30 ft
- 30 - 40 ft
- 40 - 50 ft

Background Images:
USGS 7.5' Topo of Frederickson, WA 1994
LiDAR Hillshade from 2003 Lidar (www.pugetsoundlidar.org)

0 0.5 Miles

0 3,000 Feet

1:36,000

N W E S

Pierce County Public Works & Utilities Water Programs

PgG

K:\RUSS\Graham Project\GIS\mxd\GW_Elev_feb_2006.mxd, 2/14/2006

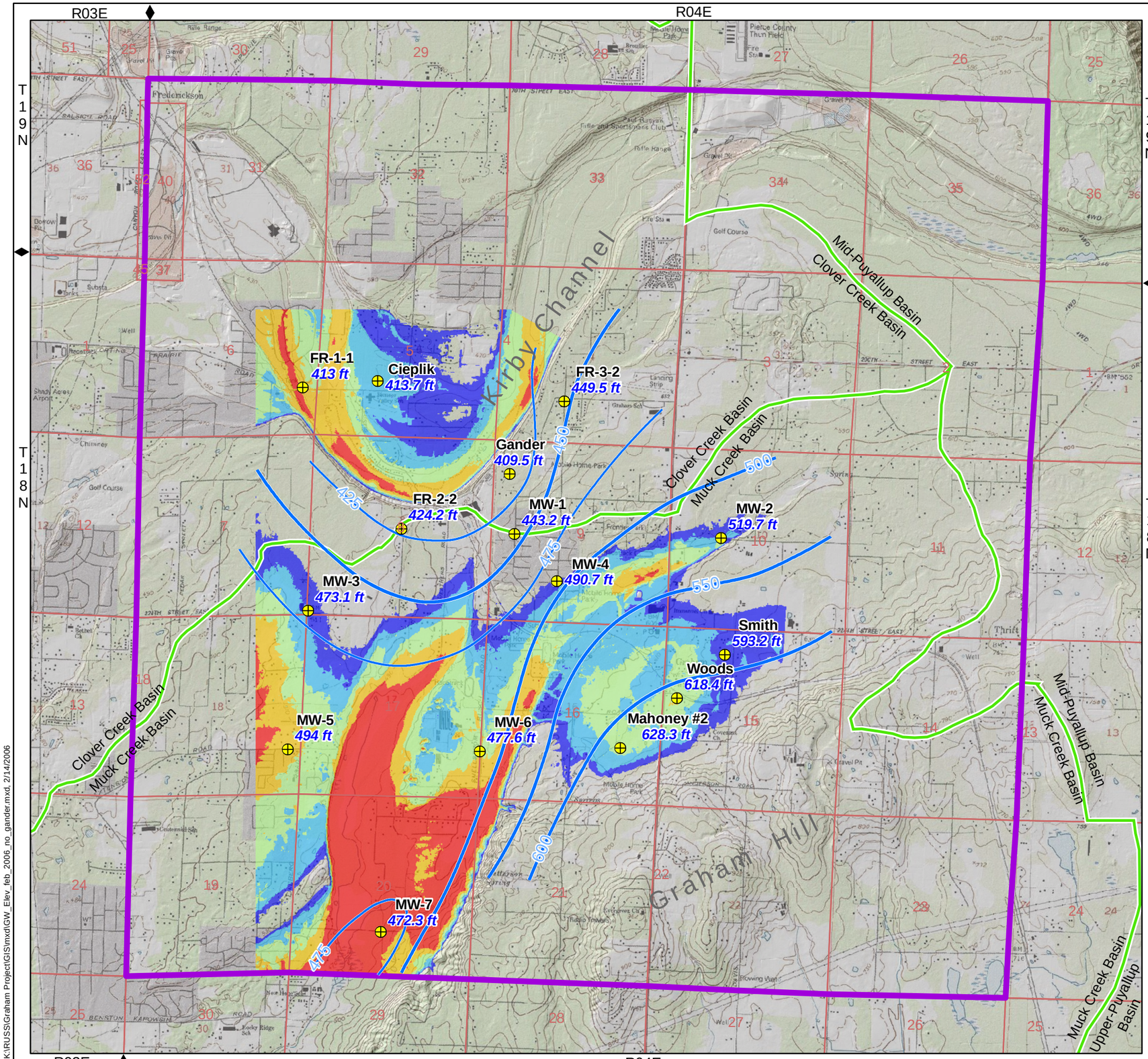


FIGURE 4-9

GROUNDWATER ELEVATION ON MAY 12, 2006

Graham Groundwater Flooding Study

- Study Area
- Basin Boundaries
- Monitoring Well with Groundwater Elevation in Feet (NAVD88)
- Groundwater Elevation Contours (Dashed Were Infered)
- Groundwater Flow Direction

Estimated Depth to Groundwater

- < 10 ft
- 10 - 20 ft
- 20 - 30 ft
- 30 - 40 ft
- 40 - 50 ft

Background Images:
USGS 7.5' Topo of Frederickson, WA 1994
LiDAR Hillshade from 2003 Lidar (www.pugetsoundlidar.org)

0 0.5 Miles

0 3,000 Feet

1:36,000

N W E S

PgG

K:\RUSS\Graham Project\GIS\mxd\GW_Elev_feb_2006_no_gander.mxd, 2/14/2006

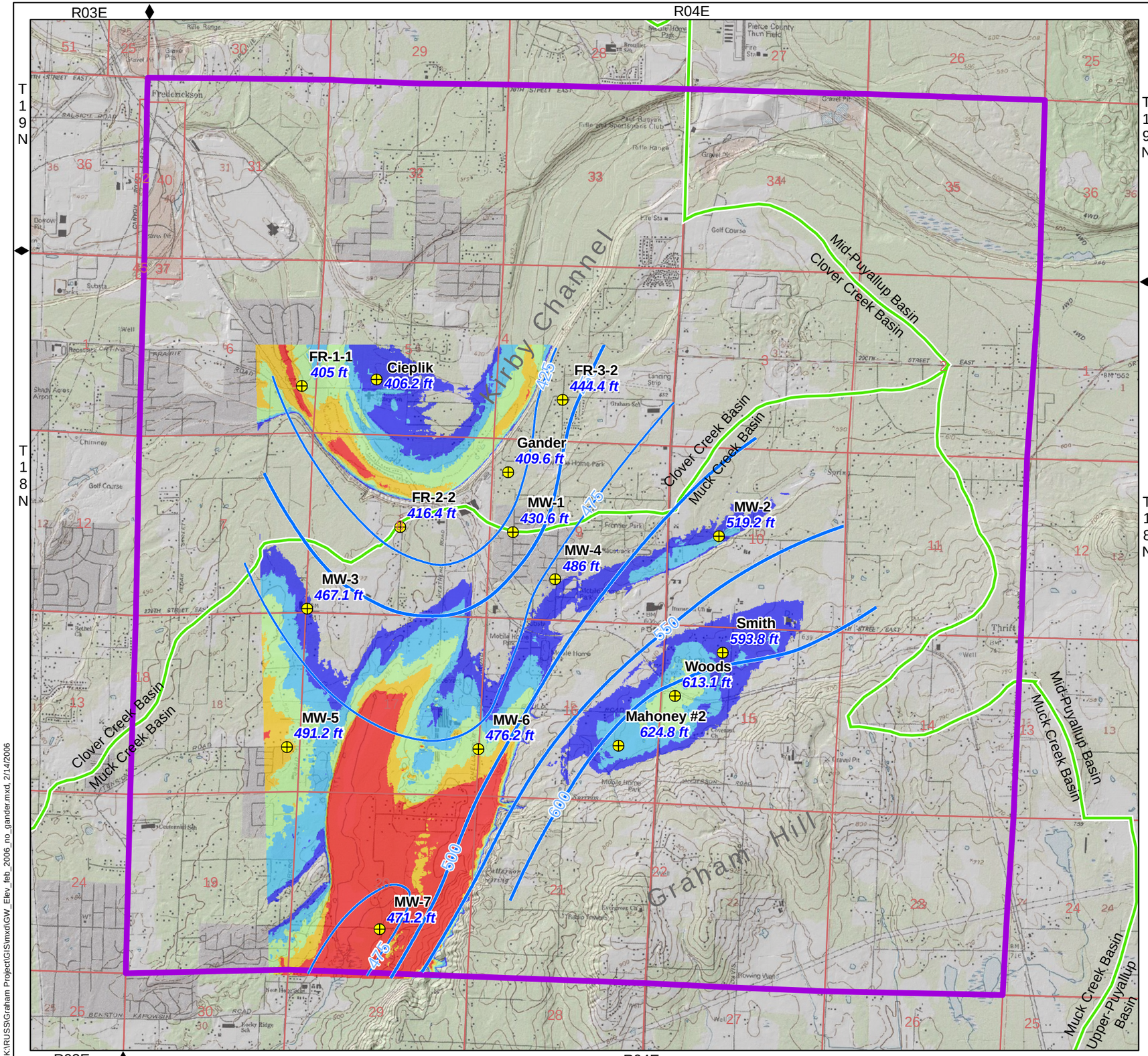


FIGURE 4-10

GROUNDWATER ELEVATION ON JULY 11, 2006

Graham Groundwater Flooding Study

Study Area

Basin Boundaries

Monitoring Well with Groundwater Elevation in Feet (NAVD88)

Groundwater Elevation Contours (Dashed Were Infered)

Groundwater Flow Direction

Estimated Depth to Groundwater

- < 10 ft
- 10 - 20 ft
- 20 - 30 ft
- 30 - 40 ft
- 40 - 50 ft

Background Images:
USGS 7.5' Topo of Frederickson, WA 1994
LiDAR Hillshade from 2003 Lidar (www.pugetsoundlidar.org)

0 0.5 Miles

0 3,000 Feet

1:36,000

N W E S

PgG

K:\RUSS\Graham Project\GIS\mxd\GW_Elev_feb_2006_no_gander.mxd, 2/14/2006

smaller component of groundwater that recharges in the Graham Hill area flows westerly toward MW-6 and MW-7, staying in the Muck Creek basin.

The well monitoring data collected in Phase II appear to confirm the preliminary groundwater flow map (Phase I), which was prepared based on review of well drillers' logs. The preliminary map showed a data gap in the southwestern portion of the study area. The data from the new monitoring wells reduces the uncertainty regarding flow directions, especially in the southwest portion of the study area. Also, Phase I data indicated that the crest of Graham Hill was coincident with a groundwater divide, whereby groundwater beneath the northwestern portion of the hill flowed northwesterly. This divide is not shown in Figures 4-7 through 4-10 because no monitoring wells were installed for the purpose of refining its position.

The magnitude of the groundwater gradient in the Graham study area is generally high, indicating a steep flow field. The gradient is the driving force that causes groundwater to flow from areas of high elevation to areas of lower elevation. In the Graham study area, the groundwater elevation change (head loss) is about 150 ft over approximately 1 mile. This groundwater gradient is relatively high and the gradient suggests that the upper aquifer in the Graham Study area is generally lower permeability. This is based on the hydrogeologic principal that lower permeability aquifers require higher driving forces to push water through (as compared to high permeability aquifers). Also, fine-grained soils were observed in the borings completed for this project. Fine-grained soils are generally less permeable than sandy or gravelly soils.

The groundwater flow direction did not change significantly over the course of the monitoring period. As shown in Figure 4-7 through 4-10, the wells with the highest groundwater elevations are always the three domestic wells located in sections 15 and 16 at the base of Graham Hill. The lowest groundwater elevations are consistently in the Kirby Channel as monitored by FR-1-1 and the Cieplik well.[2] Three of the four maps indicate flow from groundwater elevations of over 600 ft to groundwater elevations of between 400 and 425 ft. Only the October 2005 map (Figure 4-7) indicates groundwater elevations below 400 ft in FR-1-1 and the Cieplik well.[3]

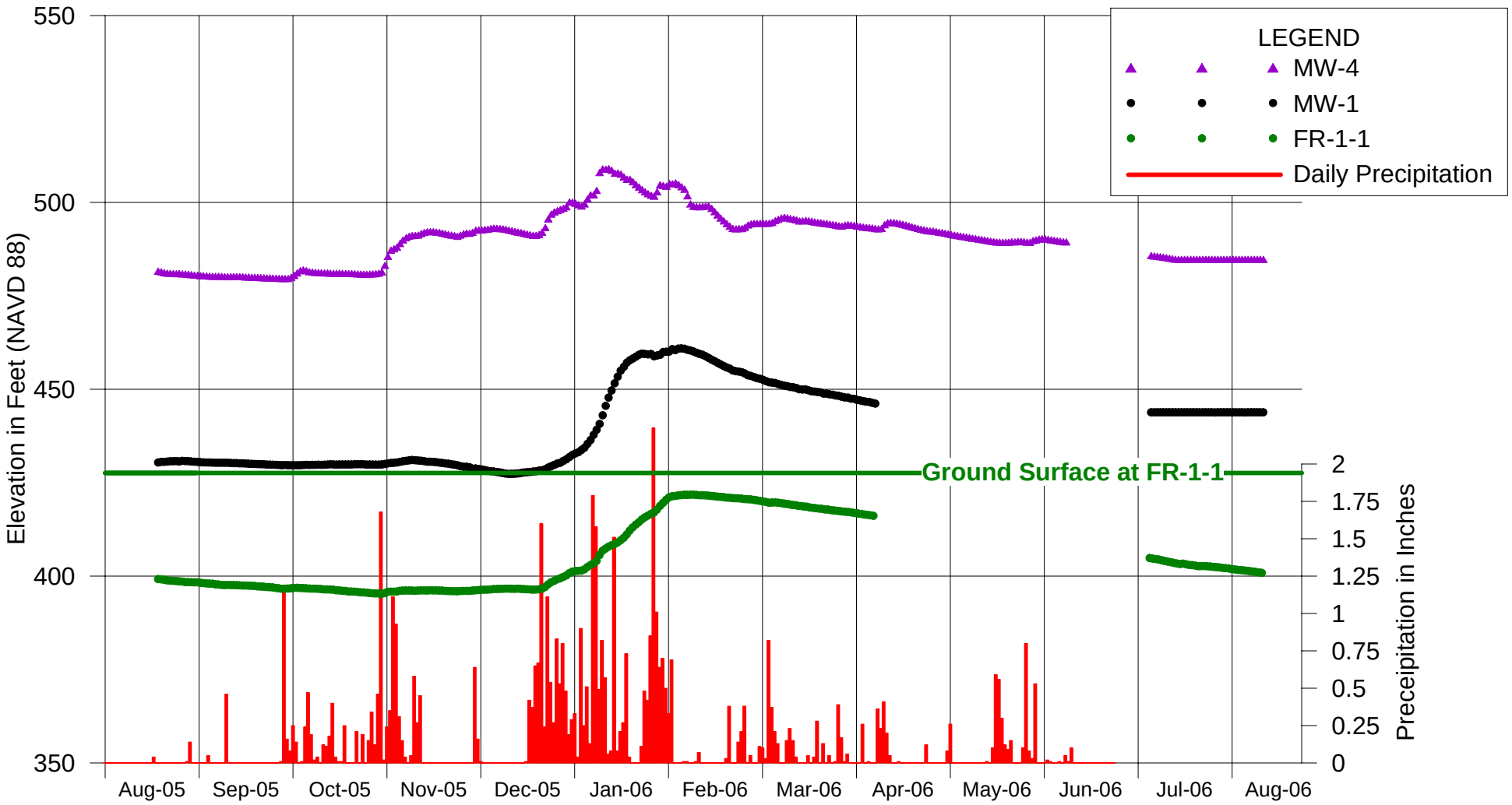
4.2.4 Depth to Groundwater

Figures 4-7 through 4-10 also show the estimated depth to groundwater based on the monthly snapshot water-level data. The groundwater response to precipitation for the winter of 2005/2006 has been considerable. The maps show significantly larger areas where groundwater is shallower in winter months compared with fall and spring months. There are large areas where the depth to

---

[2] Groundwater elevation in the Gander well drops below these on two occasions—likely a result of recent or concurrent pumping at the time of groundwater level data collection.

[3] The suggestion that groundwater elevations are usually above 400 ft in the Kirby Channel is somewhat misleading and reflects the timing of maps presented in this report. These two wells, located in the channel, experienced groundwater elevations below 400 ft in the last five months of 2005 (August through December). Since October groundwater levels were generally the lowest during the monitoring period in the study area, it was chosen as the month to present in map form.



Although the data loggers were set to collect data every hour, only one point in every 24 points collected are presented in this plot. Therefore these plots represent daily data collection. This simplification does not affect the presentation of the data.

FIGURE 4-11
DAILY WATER LEVEL ELEVATIONS FOR SELECTED WELLS (Transducer Data)

BROWN AND CALDWELL
Environmental Engineers & Consultants

PgG

GRAHAM GROUNDWATER STUDY

groundwater was less than 10 feet during February 2006 (Figure 4-8). These are the areas where winter-season groundwater - level increases could cause or exacerbate flooding.

Compared to the summer and fall of 2005, groundwater levels during the winter of 2005/2006 period have increased substantially due to large winter precipitation events. Groundwater level rises of up to 30 ft have been observed in some wells and the estimated depths to groundwater have decreased over substantially large areas.

While the precipitation pattern during the winter of 2005/2006 was unusually concentrated in January and February, we believe the response in groundwater heads is typical. Continued monitoring could provide additional insight into how unusual this past winter was.

4.2.5 Lag Time

Continuous Data (FR-1-1, MW-1, MW-4)

Transducers were deployed in FR-1-1, MW-1, and MW-4 in mid August 2005. These wells were chosen because they fall approximately along a flow line with MW-4 at the upgradient end and FR-1-1 at the downgradient end. The data, along with precipitation, are presented in Figure 4-11. The following observations are provided based on these data.

- The three wells show slightly declining groundwater levels in the fall of 2005. The magnitude of the decline is similar for the three wells.

- The three wells show strong response to the heavy precipitation experienced during the 2005/2006 winter. MW-1 experienced the largest response (30 ft) between late October 2005 and February 7, 2006; groundwater levels in MW-4 increased 28 ft between late October 2005 and January 14, 2006; and FR-1-1 experienced an increase of 26 ft between late October and February 11, 2006.

- Responses to the October/November 2005 precipitation event are varied. MW-4 responded to the October/November event the most. It experienced an increase of about 6 ft; MW-1 responded with a slight increase of about 1 ft; and FR-1-1 did not respond at all.

- The wells' responses to both precipitation events (October/November 2005 and December 2005/ January 2006) share a common feature. MW-4 responds quickly and is very spiky; MW-1 responds more slowly and the response is more subdued than MW-4; and FR-1-1's response is slowest, much more subdued than the other two wells, and attenuated in magnitude.

The data presented in Figure 4-11 allows us to estimate the lag time between recharge in the upgradient portion of the site to discharge in the downgradient portion. As indicated in Section 3.2.5, this analysis is based on three assumptions: 1) the three instrumented wells are located along a single flow line, 2) the groundwater level data in the two downgradient wells reflect groundwater inflow to the well location as opposed to recharge that is occurring at the well location, and 3) data from MW-4 represent upland recharge and data from FR-1-1 represent lowland (Kirby Channel) discharge.

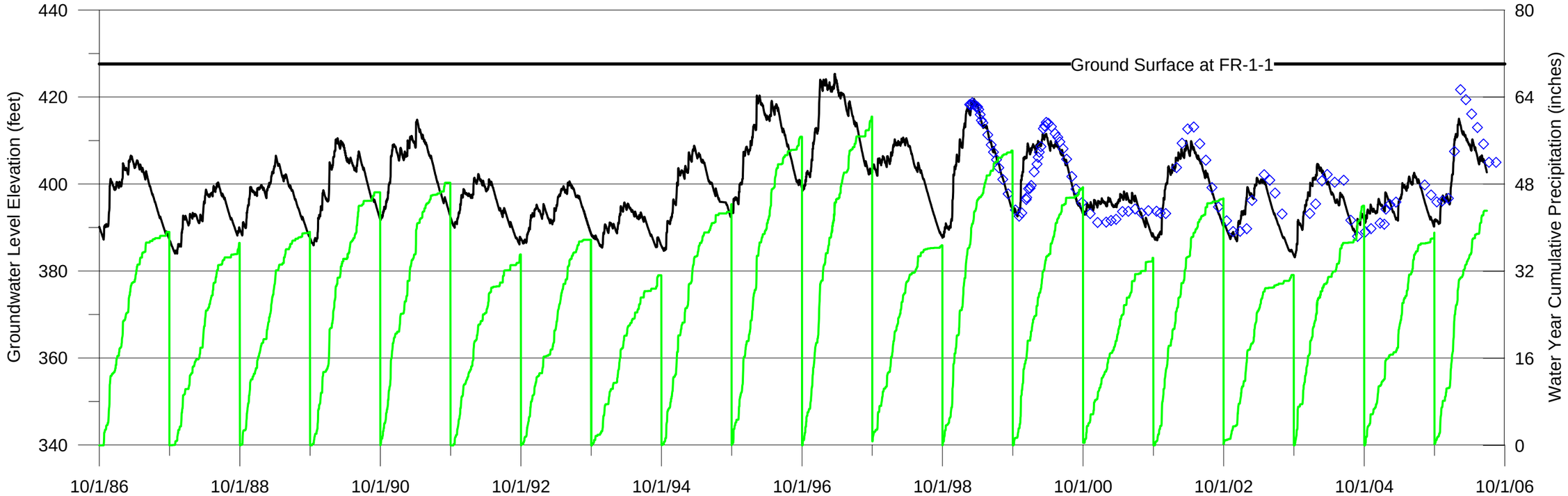
Based on our evaluation of the arrival of peak groundwater levels in the three wells, it appears that the lag time from recharge near Graham Hill (simulated by groundwater levels in MW-4) to discharge in western portion of the Kirby Channel (simulated by groundwater levels in FR-1-1) is about 26 days, or about 350 ft per day. The lag time (i.e., the time required for groundwater recharge to affect groundwater discharge) is not equivalent to the time it would take for a particle of water to travel within the subsurface.[4] Rather, the lag time is primarily determined by the time it takes for the groundwater head to travel, which it is typically much faster than the rate of water movement.

4.2.6 Precipitation and Antecedent Precipitation Index (API)

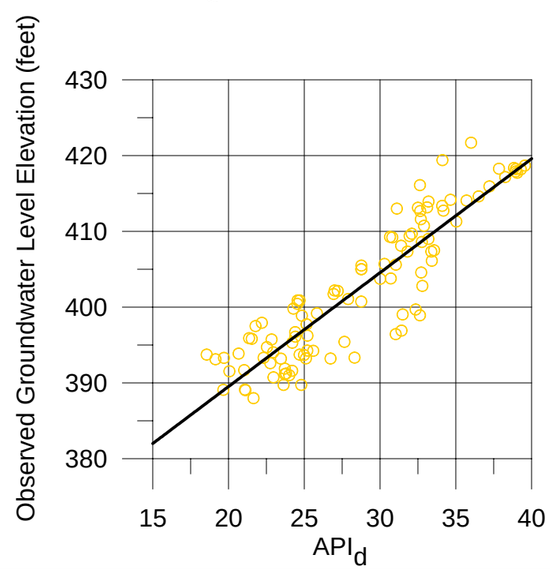
The results of the API analysis are presented on Figures 4-12, 4-13, and 4-14 showing the API for FR-1-1, FR-2-2, and FR-3-2, respectively. These plots present the comparison between the observed groundwater elevations in each well to those calculated using the API method. The simulated groundwater levels appear very consistent with the observed values except that simulated levels for the 2005/ 2006 winter season appear to be slightly lower.[5] The plots suggest that the rainfall that occurred in the 1996 water year (1996/1997 winter season) caused the highest groundwater levels in the area. For this reason, simulations completed for the regional infiltration pond are based on rainfall during that winter season (considered to be the rainiest in recent times).

[4] The travel time for a particle of water, or seepage velocity, is based on the porosity of the soil and on the hydraulic conductivity and gradient of the aquifer.

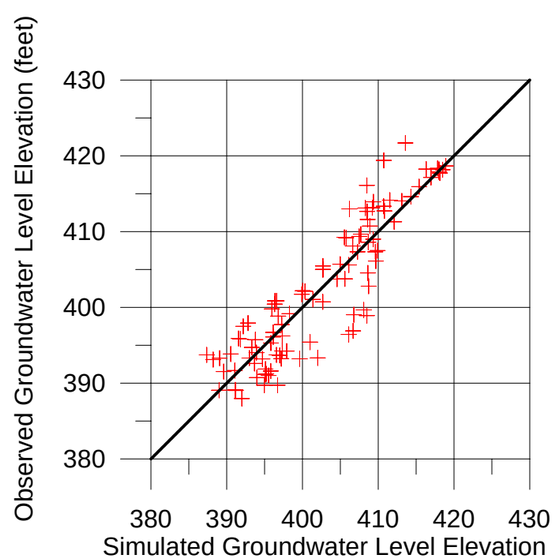
[5] This slight underestimate of groundwater levels may be associated with the pattern of rainfall that occurred during the 2005/2006 winter season. From mid-November to mid-December 2005, there was essentially no rainfall followed by a period of concentrated rainfall.



Correlation Between Observed Groundwater Elevation and API_d



Correlation Between Observed Groundwater Elevation and Simulated Groundwater Elevation



Simulated Groundwater Elevation
Observed Groundwater Elevation
Water Year Cumulative Precipitation at McMillan Reservoir
Line/Scatter Plot 5
Fit 1: Linear

$API_d = API_{d-1}*C + PPT_d$

Simulated Water Level = $S*(API_d)+ I$

API_d = Antecedent Precipitation Index for day d

API_{d-1} = Antecedent Precipitation Index for day d-1

C = decay coefficient

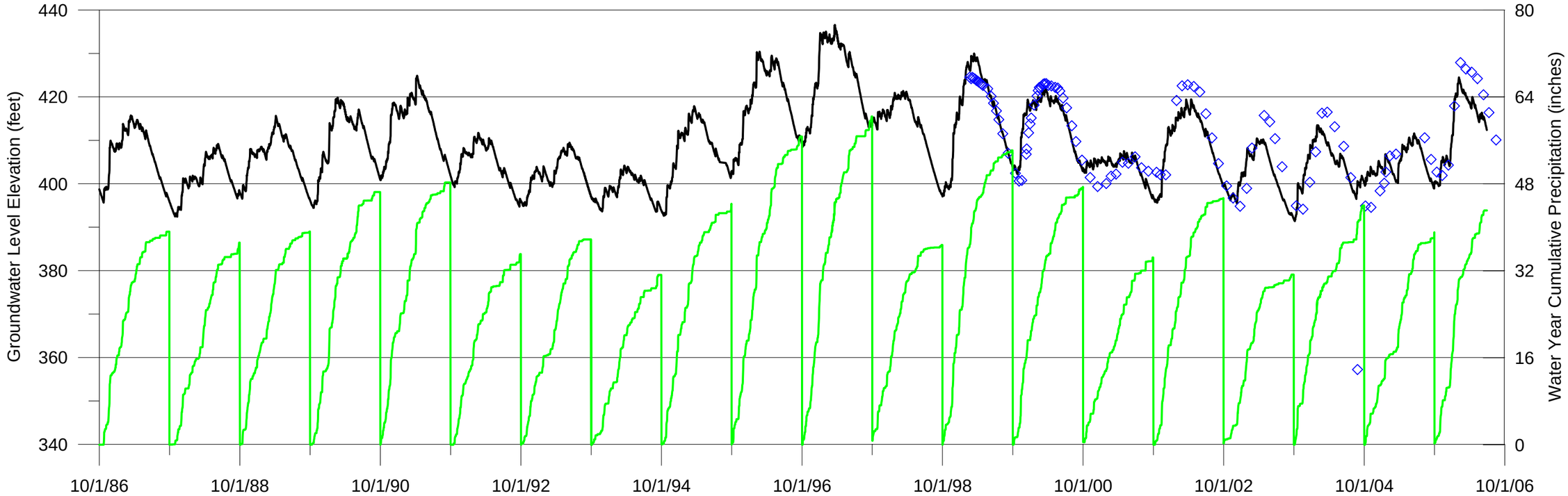
PPT = precipitation for day d

S = slope of correlation line between observed water level and API_d

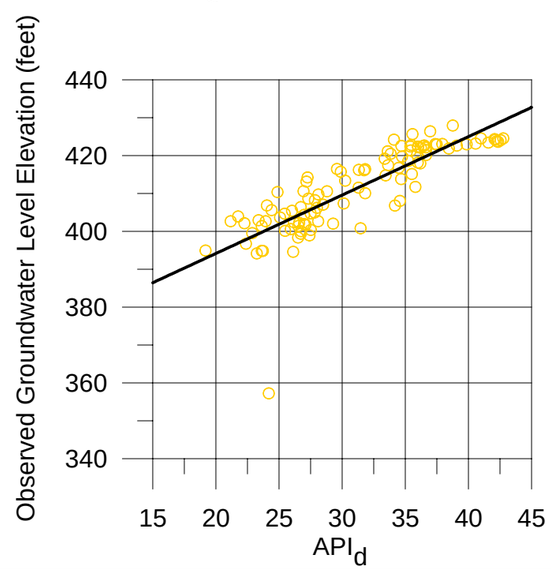
I = intercept of correlation line between observed water level and API_d

FIGURE 4-12
FR-1-1 GROUNDWATER ELEVATIONS
(OBSERVED AND SIMULATED)

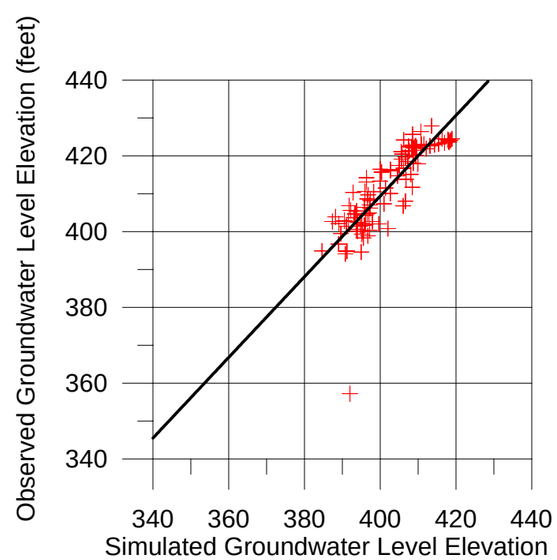
BROWN AND CALDWELL
Environmental Engineers & Consultants
PgG



Correlation Between Observed Groundwater Elevation and API_d



Correlation Between Observed Groundwater Elevation and Simulated Groundwater Elevation



Simulated Groundwater Elevation
Observed Groundwater Elevation
Water Year Cumulative Precipitationat McMillan Reservoir

$API_d = API_{d-1}*C + PPT_d$

Simulated Water Level = $S*(API_d)+ I$

API_d = Antecedent Precipitation Index for day d

API_{d-1} = Antecedent Precipitation Index for day d-1

C = decay coefficient

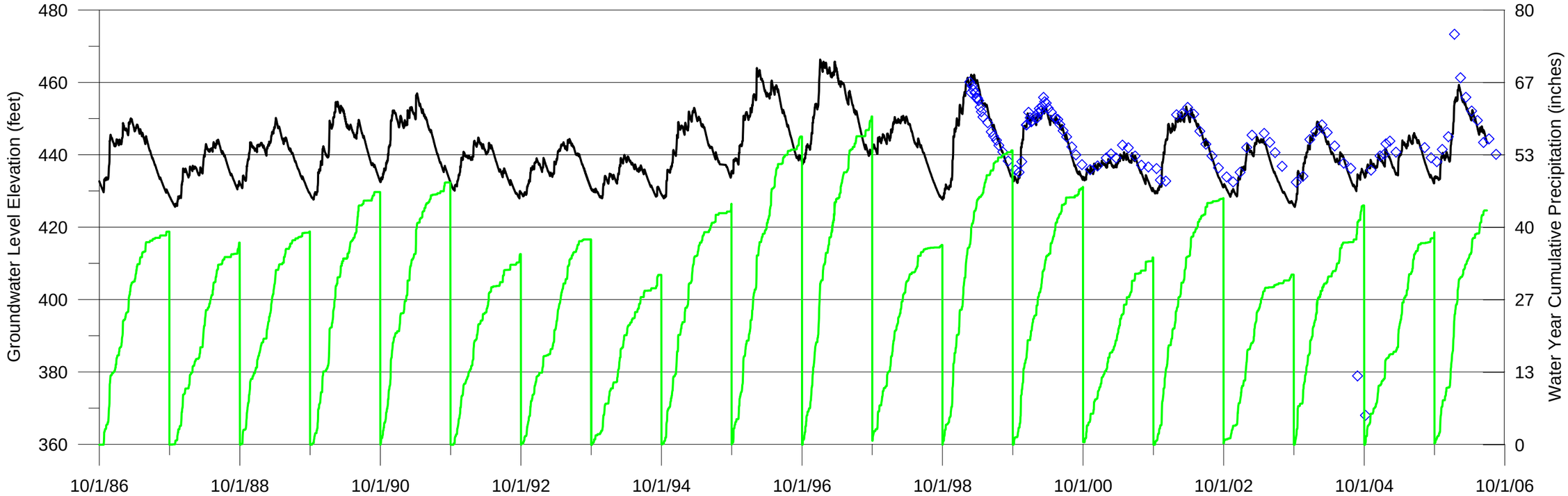
PPT = precipitation for day d

S = slope of correlation line between observed water level and API_d

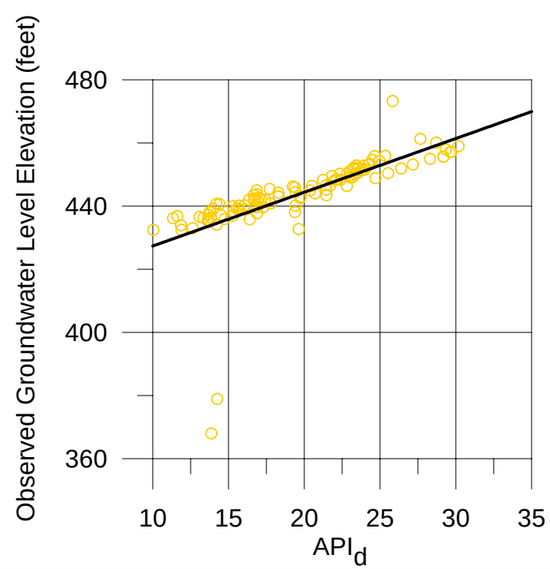
I = intercept of correlation line between observed water level and API_d

FIGURE 4-13
FR-2-2 GROUNDWATER ELEVATIONS
(OBSERVED AND SIMULATED)

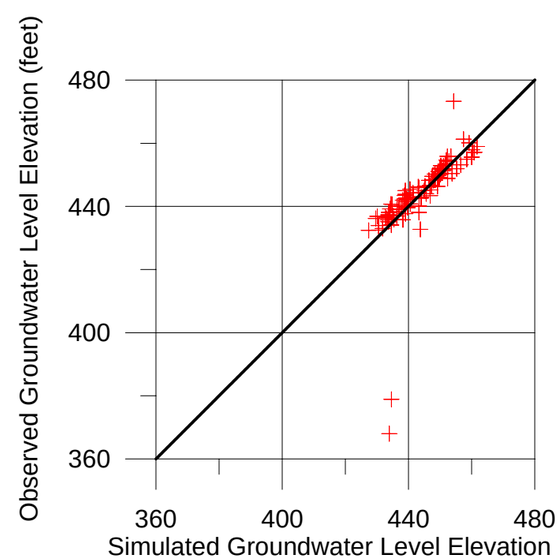
BROWN AND CALDWELL
Environmental Engineers & Consultants
PgG



Correlation Between Observed Groundwater Elevation and API_d



Correlation Between Observed Groundwater Elevation and Simulated Groundwater Elevation



Simulated Groundwater Elevation
Observed Groundwater Elevation
Water Year Cumulative Precipitationat McMillan Reservoir

$API_d = API_{d-1}*C + PPT_d$

Simulated Water Level = $S*(API_d)+ I$

API_d = Antecedent Precipitation Index for day d

API_{d-1} = Antecedent Precipitation Index for day d-1

C = decay coefficient

PPT = precipitation for day d

S = slope of correlation line between observed water level and API_d

I = intercept of correlation line between observed water level and API_d

FIGURE 4-14
FR-3-2 GROUNDWATER ELEVATIONS
(OBSERVED AND SIMULATED)

BROWN AND CALDWELL
Environmental Engineers & Consultants
PgG

5. PROPOSED REGIONAL INFILTRATION POND

5.1 DESCRIPTION

Pierce County's Muck Creek Basin Plan proposed a large regional infiltration pond (CIP 12NF-XXX) to reduce the potential for future flood damage in the Graham area. The proposed pond would be located in a natural depression located about one-half mile northwest of the intersection of Meridian and 224th Street. A large portion of the Graham area currently drains to the proposed pond location. The Muck Creek Basin Plan indicates that surface ponding occurs at this location during large storm events, but flooding of adjacent developed areas has not been reported to date (Pierce County Public Works and Utilities, 2003). Water Programs staff has not observed any off-site flooding around the proposed pond location (H. Schmidt, 2006).

Based on preliminary modeling, the basin plan estimated that the proposed pond would need a surface area of about 11 acres and a depth of 12 ft to dispose of runoff from a 100-year event. The preliminary pond capacity of about 120 acre-ft was estimated based on an assumed drainage area of 2,440 acres and an infiltration rate of 0.5 inch per hour ((Pierce County Public Works and Utilities, 2003).

Water Programs refined the preliminary pond sizing after the basin plan was completed. Water Programs used the Western Washington Hydrology Model (WWHM) Version 2.5f to evaluate pond performance based on two alternative pond volumes (2.5 and 5.5 acre-ft) and three infiltration rates (2, 10, and 30 inches per hour). The pond volumes simulated by Water Programs are much smaller that the 120 acre-ft cited in the basin plan because Water Programs' model assumed a much smaller drainage area (835 acres vs. 2,440 acres) and much higher infiltration rates (2 to 30 inches per hour vs. 0.5 inch per hour). .

5.2 DRAINAGE AREA CHARACTERISTICS

The Muck Creek Basin Plan indicated that the proposed pond location receives drainage from about 2,440 acres. However, after the basin plan was completed, Water Programs conducted a more detailed analysis and found that the drainage area is about 835 acres. Table 5-1 summarizes the drainage area characteristics used in the County's WWHM (H. Schmidt, 2006).

Table 5.1. Drainage Basin Land Use Characteristics (provided by Pierce County)

Predeveloped Land Use:	
Land Use	Acres
Till Forest	731
Outwash Forest	21
Saturated Pasture	83
TOTAL	835

Estimated Fully Developed Land Use:	
Land Use	Acres
Till Grass	585
Outwash Grass	21
Saturated Pasture	83
Impervious	146
TOTAL	835

The WWHM was used to estimate the maximum flow volumes to the proposed infiltration pond under existing and future land uses, based on the drainage area characteristics listed above the 48-year period of record (1948-1996) over which the continuous simulation is run. Table 5-2 lists the estimated maximum volumes that would drain to the regional infiltration pond under the future (full build-out) scenario.

Table 5.2. Maximum Flow Volumes Estimated for the Proposed Regional Infiltration Pond

Maximum Volumes	acre-ft
1-day max volume	98.12
3-day max volume	215.08
7-day max volume	316.54

The WWHM model was run several years ago. It is possible that the drainage area conditions could have changed since then, due to new development and highway drainage system improvements.

5.3 POTENTIAL IMPACTS ON FLOODING PROBLEMS

Using the MODFLOW groundwater modeling code, a two-dimensional, transient, groundwater flow model was developed to simulate changes in groundwater levels beneath the proposed infiltration pond. The model simulates daily impacts from focused recharge under 1996 precipitation conditions (worst-case scenario). Daily runoff rates to the proposed infiltration pond were calculated for the site using the WWHM and provided to PGG for the recharge input to the groundwater model.

The MODFLOW model uses the Recharge Boundary Condition to simulate infiltration of runoff water collected by a 300-ft by 300-ft infiltration pond. The maximum infiltration rate was assumed to be 2 in/hr (4 ft/day). This is the low end of the range used by Pierce County in its WWHM modeling of the proposed pond. For days when the daily runoff rates exceed 2 in/hr, the extra water is assumed to be stored above ground and infiltrated through the pond bottom at the maximum rate until all the stored water is infiltrated. A graph of the 1996 runoff rates and the simulated infiltration rates is shown in Figure 5-1.

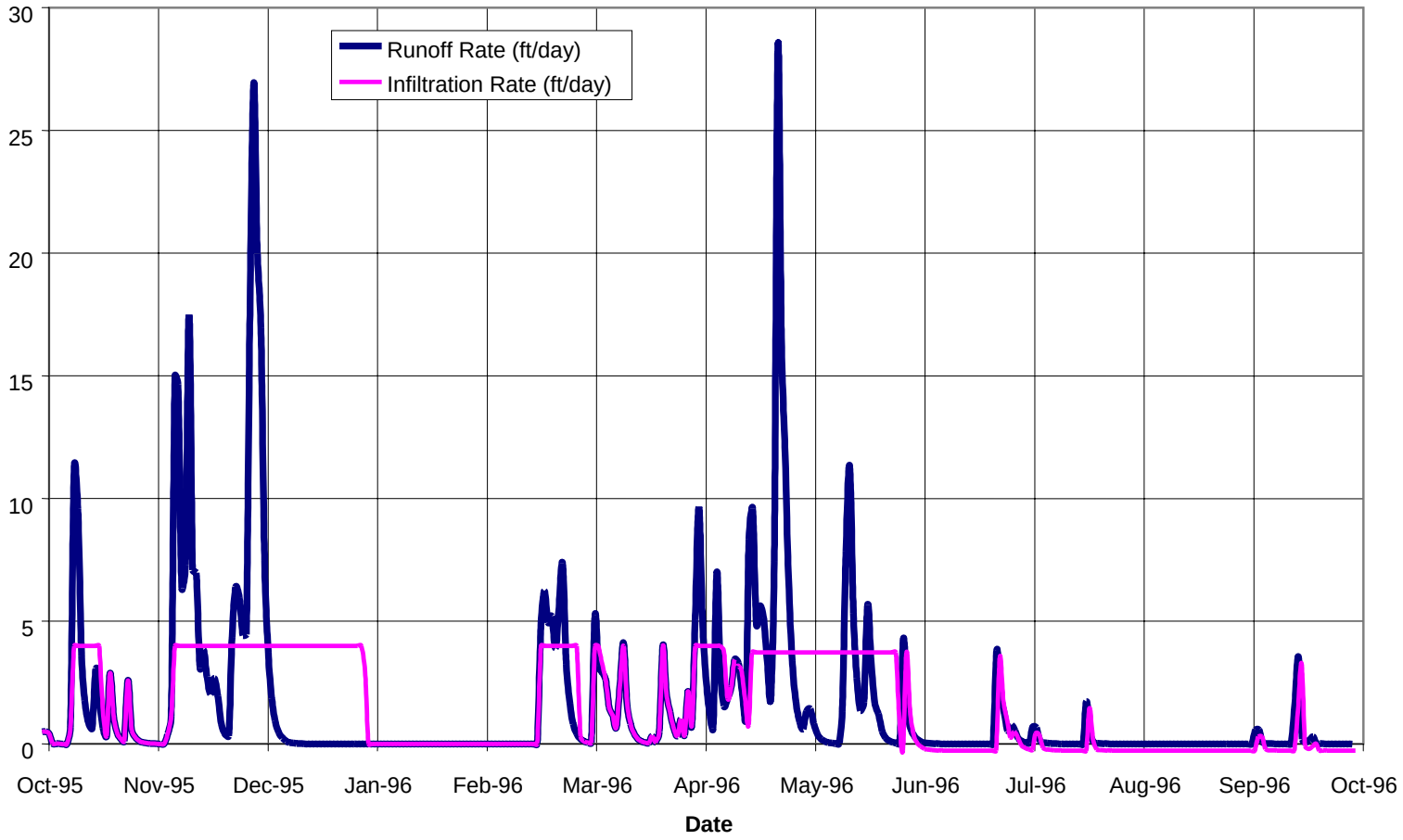


FIGURE 5-1
1996 RUNOFF RATES AND SIMULATED INFILTRATION RATES

GRAHAM GROUNDWATER FLOODING STUDY

The model was used to simulate daily changes in the groundwater table (mound height) under the 1996 water year conditions, which is considered to be a worst-case year. The model assumed a flat water table at an elevation of 500 ft (the average groundwater elevation for the area).

The MODFLOW results show that the impact of the proposed infiltration pond could vary considerably depending on the bulk hydraulic conductivity and storativity of the aquifer near the site. As discussed in Section 3.2.7, the MODFLOW model was calibrated to the measured water levels in MW-4, which is about 1,500 ft from the proposed pond site. The calibrated model yielded a K value of 40 ft per day, which is close to the average estimate based on well log information (well yield and drawdown). The calibrated storage value was 0.03 (dimensionless). Using these values indicates the potential for 60 ft of groundwater mounding to occur underneath the infiltration pond given the flow quantities estimated using the County's WWHM model. The model suggests that a groundwater-level increase of 20 ft above current groundwater levels would extend out 1,325 ft from the infiltration pond. The model results also indicate that the mound would dissipate before reaching the Kirby Channel, so the proposed pond should not affect groundwater levels or flooding beneath the Kirby Channel.

The groundwater level in MW-4 (the monitoring well closest to the proposed pond location,) rose 30 feet during December 2005 to February 2006. This shows that groundwater levels in this portion of the study area can rise quickly during wet periods. On January 14, 2006, when the highest groundwater elevations were recorded, groundwater levels at MW-4 were approximately 30 feet lower than the ground surface elevation at the proposed infiltration pond site. Based on the data from MW-4, the MODFLOW model indicated that the groundwater mound would cause flooding of the ground surface around the pond site. However, Water Programs staff has not observed flooding of streets, basements, or crawlspaces in the residential areas adjacent to the pond site. The lack of observed flooding indicates the model may be over-predicting the rise in groundwater elevations that would caused by the proposed infiltration pond (personal communication H. Schmidt, 2006).

The most likely reason for over-prediction is that the model assumes soil conditions at the proposed pond site are similar to conditions at the closest monitoring wells (MW-4 and MW-1). However, the pond site is in an area of complex soil assemblages. At the time of soil deposition, ice was still present in the area and many micro-depositional regimes existed. Soil conditions can vary considerably over short distances. For example, there could be a small buried channel (on the order of 10's of ft in size) near the proposed pond site that acts as a conduit to remove groundwater quickly and reduces the potential for groundwater mounding.

The groundwater monitoring conducted for this project suggests that the area in the vicinity of MW-4, which is close to the proposed infiltration pond, is subject to short lag times between precipitation and rising groundwater. This is a function of aquifer properties and given heterogeneities in the soil conditions, the controlling properties at the infiltration pond site may be different than they are at MW-4.

Although the MODFLOW model appears to over-estimate groundwater mounding at the proposed pond site, the measured increase in groundwater levels of about 30 feet in MW-1 and MW-4 in response to winter precipitation, suggests that greater response in the aquifer to the concentrated recharge of the proposed infiltration pond is possible. This possibility suggests the need for caution and further study. Even with the predicted high increase in groundwater levels, the model indicated that the groundwater mound would dissipate before reaching the Kirby Channel and would not exacerbate flooding in that area.

6. RECOMMENDATIONS

6.1 REVISIT BASIN PLANNING BOUNDARIES

The groundwater elevation data collected for this study shows that groundwater from the Graham area, which is currently included in the Muck Creek basin planning area, flows northwest into the Clover Creek basin planning area. The water level data indicate that the groundwater divide is about 1 to 1-½ miles southeast of the current boundary between the Muck Creek and Clover Creek basin planning areas. Pierce County may wish to consider adjusting the basin boundary line, so that the Clover Creek basin planning area includes the entire area that contributes groundwater flow to that basin. It may be advisable to adopt a county-wide policy for such situations.

6.2 INVESTIGATE SITE-SPECIFIC GROUNDWATER CONDITIONS AT PROPOSED POND SITE

The groundwater level measurements and groundwater modeling performed for this study suggest that Pierce County's proposed infiltration pond could cause a large groundwater mound to form beneath the site. The MODFLOW model results indicate that the mound could be large enough to limit infiltration rates from the pond, and potentially cause flooding of adjacent areas. The model also indicates that the mound would dissipate before reaching the Kirby Channel, so it should not exacerbate flooding in that area.

The MODFLOW model may over-estimate the potential for groundwater mounding at the proposed pond site. Site observations by County staff indicate that aquifer permeability at the proposed pond site may be considerably higher than indicated by the model.

Model results are based on groundwater conditions at a nearby well; therefore, additional site-specific information is needed to confirm that the proposed site is suitable for a regional infiltration pond, and to refine the pond design. The following actions are recommended:

- Complete at least three borings and monitoring wells at the proposed pond site. A minimum of three wells is needed to measure the gradient of the aquifer, which could affect the aquifer's ability to transport infiltrated water away from the site. While drilling, close attention should be paid to observing possible perched zones. For this reason, the borings and wells should be constructed during winter months.

- If perched groundwater is observed in a boring, complete a separate monitoring well within the perched zone to allow water level monitoring in the perched zone.

- Perform slug tests on each well to estimate the hydraulic conductivity of the aquifer.

- Monitor water levels in the wells, especially during February through April. Monitoring should be conducted with transducers.

- Use the water level data collected at the site to re-calibrate the MODFLOW model. Run the calibrated model to estimate the potential for groundwater mounding beneath the proposed infiltration pond.

The existing MODFLOW model results and County staff observations suggest that the proposed pond site may not be able to infiltrate much more water than currently flows there. If the refined MODFLOW model indicates that significant mounding could occur, Pierce County may wish to restrict future land use activities that would increase flows to the pond site.

6.3 UPDATE DRAINAGE AREA AND DESIGN FLOWS

Water Programs used the Western Washington Hydrologic Model (WWHM) to estimate surface water flows to the proposed infiltration pond. The WWHM was done several years ago. Drainage area conditions could have changed since then, due to recent development and highway drainage system improvements in the study area The WWHM should be re-run using the latest topographic and land use data for the area that drains to the proposed pond site. This will provide updated estimates of the surface water inflow volumes for the MODFLOW model, which should then be re-run to simulate the magnitude of groundwater mounding beneath the pond site.

7. REFERENCES

Buchanan-Banks, J.M. and Collins, D.S., 1994, *Map Showing Depth to Bedrock of the Tacoma and Part of the Centralia 30' X 60' Quadrangles, Washington*, USGS Miscellaneous Field Studies Map, MF-2265.

Ecology, 2001. Assessment of Surface Water and Groundwater Interchange within the Muck Creek Watershed, Pierce County. Publication No. 01-03-037.

Schmidt, Helmut, 2006. Personal communications. Pierce County Public Works and Utilities, Water Programs Division.

Pierce County Public Works and Utilities, with the assistance of CH2MHill. Muck Creek Basin Plan. Pierce County Public Works and Utilities, Water Programs Division.

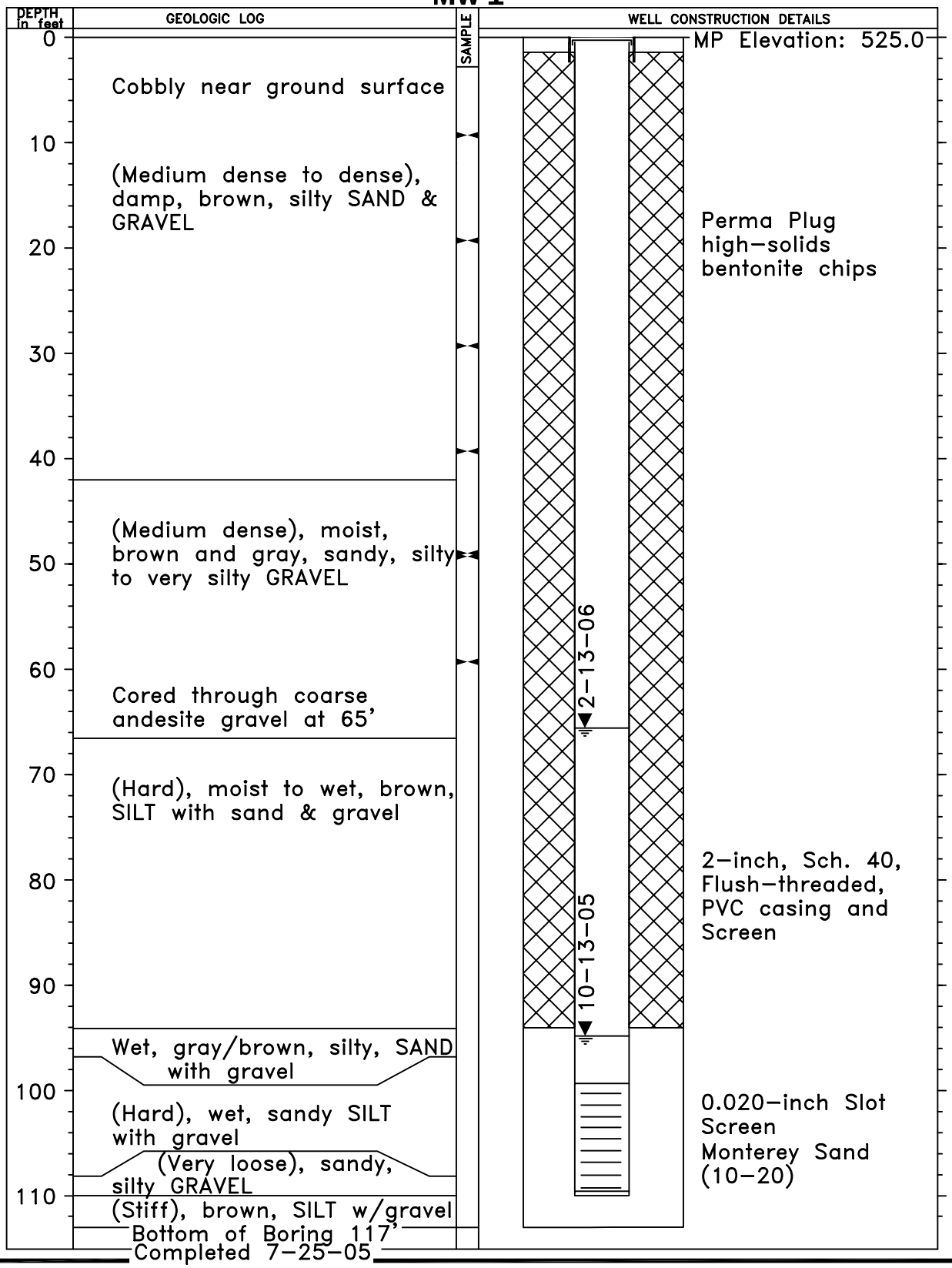
Pierce County Public Works and Utilities, with the assistance of Tetra Tech/KCM, 2003. Clover Creek Basin Plan. Pierce County Public Works and Utilities, Water Programs Division.

URS, 2001. Groundwater Flooding Evaluation, Frederickson, Pierce County, WA.

APPENDIX A

BORING LOGS

MW-1



PROJECT NAME: Graham Groundwater Study
WELL INDENTIFICATION NUMBER: MW-1 (APM-947)
LOCATION: SW¼ NW¼ SEC.9 T18N/R4E
DRILLING METHOD: Sonic
DRILLER: Steve Zimmerman
FIRM: Pro Sonic
CONSULTING FIRM: Brown and Caldwell
REPRESENTATIVE: Ada Hamilton

FIGURE A-1

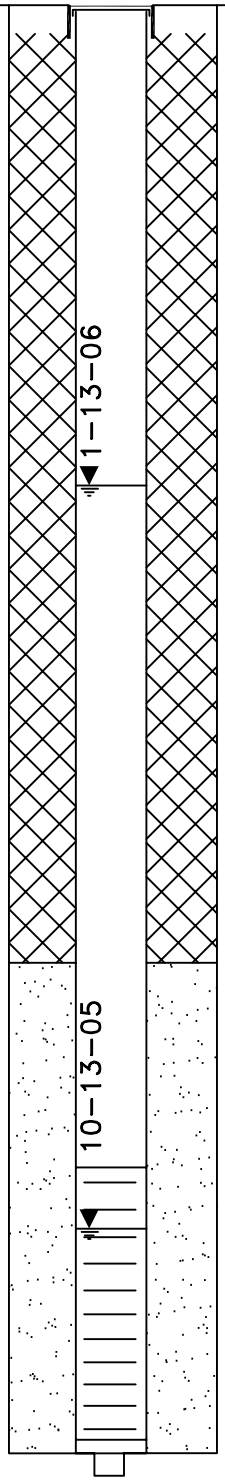
BROWN AND CALDWELL
Environmental Engineers & Consultants

Pierce County
Public Works & Utilities
Water Programs

PgG

MW-2

DEPTH in feet	GEOLOGIC LOG	SAMPLE	WELL CONSTRUCTION DETAILS
0			MP Elevation: 559.9
5	Loose to medium dense, damp to wet, brown, silty sandy GRAVEL		Quick Grout high–solids bentonite grout
10			
15			2–inch, Sch. 40, Flush–threaded, PVC casing and Screen
20			
25	Medium dense to dense, wet, brown, sandy, silty GRAVEL – Hard drilling no water notedz e		
30			
35			
40	Medium dense to dense, wet to saturated, brown to brownish gray, silty, SAND & GRAVEL		
45			0.020–inch Slot Screen
50			Colorado Silica Sand (10–20)
	Bottom of Boring 53' (sampled to 54.5') Completed 6–8–05		



PROJECT NAME: Graham Groundwater Flooding Evaluation
WELL INDENTIFICATION NUMBER: MW–2 (APM–160)
LOCATION: SW¼ NE¼ SEC.10 T18N/R4E
DRILLING METHOD: Hollow–Stem Auger
DRILLER: Mike Smith
FIRM: Holt Drilling
CONSULTING FIRM: Pacific Groundwater Group, Inc.
REPRESENTATIVE: Dawn Chapel
* Sample Submitted for Grain Size Analysis

FIGURE A-2

BROWN AND CALDWELL
Environmental Engineers & Consultants

Pierce County
Public Works & Utilities Water Programs

PgG

MW-3

DEPTH in feet	GEOLOGIC LOG	SAMPLE	WELL CONSTRUCTION DETAILS
0	(Medium dense to dense), damp, brown SAND		MP Elevation: 513.1
10	Damp, brown, SILT & coarse SAND		
20	Damp, gray and brown, silty SAND & GRAVEL		Hole Plug high–solids bentonite chips
30	(Hard), damp to moist, brown SILT with fine sand and gravel As above but with more sand and gravel		2–13–06 2–inch, Sch. 40, Flush–threaded, PVC casing and Screen
40			
50	(Medium dense), wet, brown, silty GRAVEL & SAND		
60			0.020–inch Slot Screen Monterey Sand (10–20) 10–13–05
70	Bottom of Boring 66.5' Completed 7–19–05		
80			
90			
100			

PROJECT NAME: Graham Groundwater Study
WELL INDENTIFICATION NUMBER: MW–3 (APM–946)
LOCATION: SW¼ SW¼ SEC.8 T18N/R4E
DRILLING METHOD: Sonic
DRILLER: Steve Zimmerman
FIRM: Pro Sonic
CONSULTING FIRM: Brown and Caldwell
REPRESENTATIVE: Ada Hamilton

FIGURE A-3

Pierce County Public Works & Utilities Water Programs

BROWN AND CALDWELL Environmental Engineers & Consultants

PgG

MW-4

DEPTH in feet	GEOLOGIC LOG	SAMPLE	WELL CONSTRUCTION DETAILS
0			MP Elevation: 547.6
10	(Loose), damp, brown, sandy GRAVEL with varying silt content		Pure Gold high–solids bentonite chips
20			
30			1–13–06
40			
50	(Dense), moist to wet, brown, silty, sandy GRAVEL		2–inch, Sch. 40, Flush–threaded, PVC casing and Screen
	Wet, gray, very silty, sandy GRAVEL		10–13–05
60	(Dense), wet, gray, silty SAND & GRAVEL		
70			0.020–inch Slot Screen Colorado Silica Sand (10–20)
80	(Medium stiff), wet, brown, SILT to (hard) CLAY with sand and some gravel		
	Bottom of Boring 85' Completed 8–17–05		
90			
100			

PROJECT NAME: Graham Groundwater Study
WELL INDENTIFICATION NUMBER: MW–4 (APM–948)
LOCATION: SE¼ SW¼ SEC.9 T18N/R4E
DRILLING METHOD: Sonic
DRILLER: Steve Zimmerman
FIRM: Pro Sonic
CONSULTING FIRM: Brown and Caldwell
REPRESENTATIVE: Ada Hamilton

FIGURE A-4

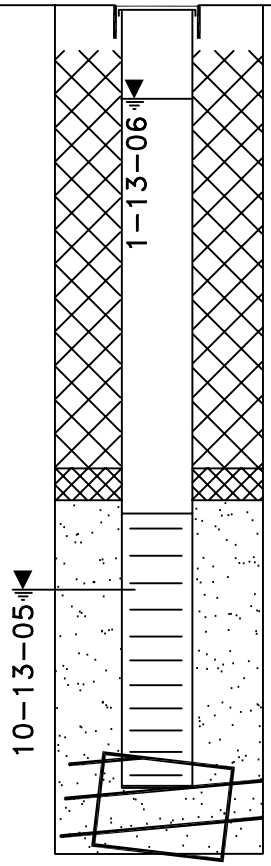
BROWN AND CALDWELL
Environmental Engineers & Consultants

Pierce County
Public Works & Utilities
Water Programs

PgG

MW-5

DEPTH in feet	GEOLOGIC LOG	SAMPLE	WELL CONSTRUCTION DETAILS
			MP Elevation: 509.4
0	Sand and Gravel FILL over Loose to medium dense, damp, fine SAND and SILT		
5	Very dense, damp, light gray, sandy, silty GRAVEL (TILL) drilling advances slowly		
10			
15	Very dense, damp to wet, brown to light gray, slightly silty, sandy GRAVEL with cobbles		
20			
25			
30	Bottom of Boring 31' Completed 6-9-05		
35			
40			
45			
50			



Quick Grout high-solids bentonite grout

2-inch, Sch. 40, Flush-threaded, PVC casing and Screen

0.020-inch Slot Screen Colorado Silica Sand (10-20)

3.5 feet of auger broke off and left in hole

PROJECT NAME: Graham Groundwater Flooding Evaluation
WELL INDENTIFICATION NUMBER: MW-5 (APM-165)
LOCATION: SE¼ SE¼ SEC.18 T18N/R4E
DRILLING METHOD: Hollow-Stem Auger
DRILLER: Mike Smith
FIRM: Holt Drilling
CONSULTING FIRM: Pacific Groundwater Group, Inc.
REPRESENTATIVE: Dawn Chapel

FIGURE A-5

Pierce County Public Works & Utilities Water Programs

BROWN AND CALDWELL Environmental Engineers & Consultants

PgG

MW-6

DEPTH in feet	GEOLOGIC LOG	SAMPLE	WELL CONSTRUCTION DETAILS
0	Damp, brown, fine sandy SILT		MP Elevation: 500.1
5	Loose, damp, brown, slightly sandy, silty GRAVEL		Hole Plug bentonite chips
10			1-13-06
15			
20	First attempt to drill this boring met refusal at 20'		10-13-05
25	Very dense, wet, gray and brown, slightly silty, fine to medium SAND & GRAVEL		2-inch, Sch. 40, Flush-threaded, PVC casing and Screen
30			
35			0.020-inch Slot Screen Colorado Silica Sand (10-20)
40	Bottom of Boring 40' Completed 6-6-05		
45			
50			

PROJECT NAME: Graham Groundwater Flooding Evaluation
WELL INDENTIFICATION NUMBER: MW-6 (APM-163)
LOCATION: NE¼ SE¼ SEC.17 T18N/R4E
DRILLING METHOD: Hollow-Stem Auger
DRILLER: Mike Smith
FIRM: Holt Drilling
CONSULTING FIRM: Pacific Groundwater Group, Inc.
REPRESENTATIVE: Dawn Chapel

FIGURE A-6

Pierce County Public Works & Utilities Water Programs

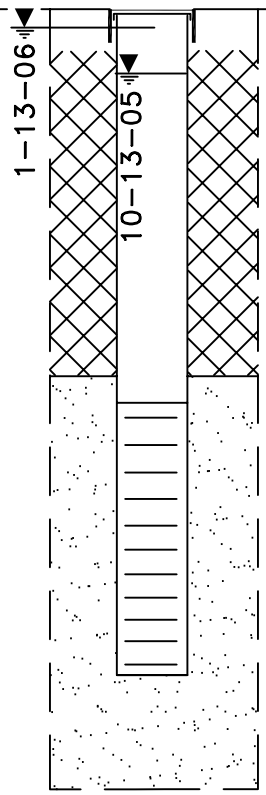
BROWN AND CALDWELL Environmental Engineers & Consultants

PgG

MW-7

DEPTH in feet	GEOLOGIC LOG	SAMPLE
0	Sandy Gravel FILL (roadbed)	
5	Soft, damp, dark brown PEAT	
10	Loose, wet, gray, fine to medium SAND	
15	Medium dense, wet, gray, sandy GRAVEL	
20		
25	Very dense, wet, green-gray, fine to medium SAND	
30	Bottom of Boring 28.5' Completed 6-6-05	
35		
40		
45		
50		

WELL CONSTRUCTION DETAILS

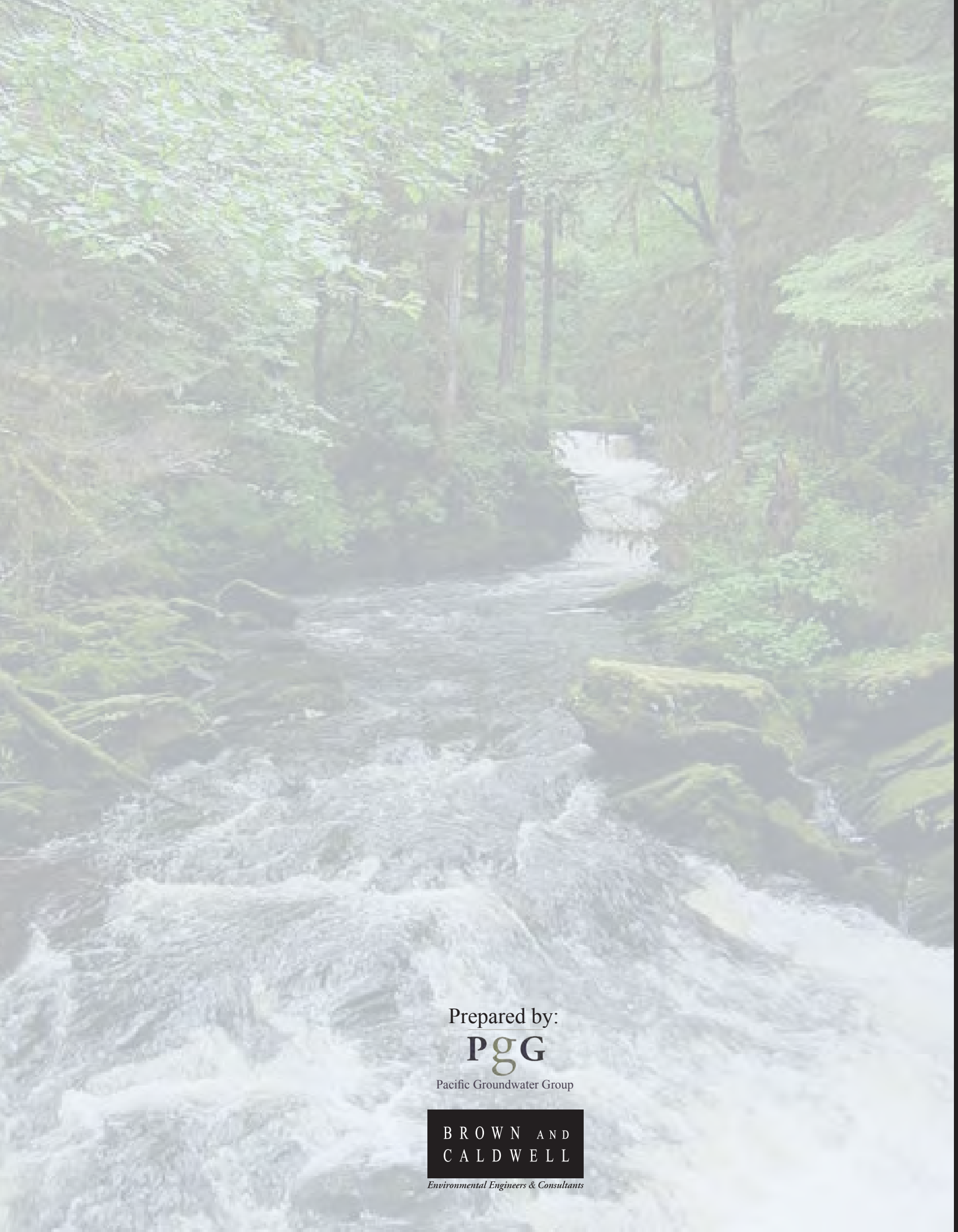


PROJECT NAME: Graham Groundwater Flooding Evaluation
WELL INDENTIFICATION NUMBER: MW-7 (APM-162)
LOCATION: WE¼ SW¼ SEC.20 T18N/R4E
DRILLING METHOD: Hollow-Stem Auger
DRILLER: Mike Smith
FIRM: Holt Drilling
CONSULTING FIRM: Pacific Groundwater Group, Inc.
REPRESENTATIVE: Dawn Chapel

FIGURE A-7

BROWN AND CALDWELL
Environmental Engineers & Consultants

PgG



Prepared by:

PgG

Pacific Groundwater Group

BROWN AND CALDWELL

Environmental Engineers & Consultants