FINAL REPORT

GROUNDWATER FLOODING EVALUATION

FREDERICKSON, PIERCE COUNTY, WASHINGTON

Prepared for
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Significant non-riverine flooding has occurred recently throughout Pierce County, blocking roads and access to adjacent homes and businesses. This type of flooding is not associated with rivers over-flowing their banks, but rather the rise of groundwater above the land surface in low-lying areas. Because of the slower rate of groundwater movement, non-riverine flooding can occur long after storms have passed and can persist for weeks or months. On behalf of Pierce County, URS has performed an investigation of non-riverine flooding at an area near Frederickson, Pierce County.

The study area is located in an un-incorporated area of central Pierce County near Frederickson and includes the Boeing Frederickson plant, the Port of Tacoma Industrial Park and numerous residential developments. Flooding has occurred within the past 5 years at two locations within the study area: a pond adjacent to 192nd Street East and two ponds near 204th Street East and the Fir Meadows residential area. Flood events have lasted from several days to several months and have resulted in road closures. Photos of 192nd Street East taken during flooding and non-flooding events are included in this Executive Summary.

The URS study has been performed in two stages and includes

- Historical data compilation and review,
- Installation of five groundwater monitoring wells,
- Excavation of an exploratory test pit and installation of a temporary piezometer,
- Implementation (by County personnel) of a groundwater level monitoring program and
- Development of a mathematical relationship between precipitation and groundwater levels.

A predictive equation utilizing the relationship between monthly precipitation and groundwater levels has been developed to estimate groundwater levels adjacent to 192nd Street East. This predictive equation incorporates the preceding water years' (October 1 to September 30) precipitation total and a running 3-month precipitation amount.

Under current conditions, the low-lying segment of 192nd Street East floods when the groundwater levels at that location reach 380 feet above mean sea level (amsl). For an average preceding water year precipitation of 42 inches, a 3-month precipitation total above 24 inches is predicted to raise the groundwater level to 380 feet at 192nd Street East in approximately 2 months time. (For example, if the cumulative October, November, and December precipitation exceeded 24 inches, it is predicted that water in the pond will rise above the road by the following February). The recurrence interval for this 3-month precipitation scenario (following an average water year) was estimated at approximately 10 years. As the preceding water year's precipitation total increases above 42 inches, the 3-month precipitation amount predicted to cause flooding is correspondingly reduced.

Recurrence intervals for 2 to 50 year water year precipitation amounts and 2 to 500 year 3-month precipitation totals, along with predicted groundwater levels, were determined for the 192nd Street East location. For an average preceding water year's precipitation (42 inches), the 100-year recurrence of the 3-month precipitation corresponds to the groundwater level of 383 feet. The 200-year recurrence corresponds to the groundwater level of 384 feet.

Until a long-term solution is implemented, the predictive equation is useful as a warning tool for each potential flooding season and for delineating areas likely to be flooded under various

precipitation scenarios. The 2-month lag time between the precipitation and predicted flooding can be used to prepare for emergency response measures, such as sandbagging the low-lying segment of 192nd Street East.

Long-term solutions include a water handling system to keep groundwater levels below 380 feet or raising the elevation of 192nd Street East. Water handling would involve collecting water near 192nd Street East (via pumps or drains) and conveying the water to a discharge location (either infiltration to the subsurface or discharge to an existing surface water body). A 3-dimensional groundwater flow model predicted that a pumping rate of approximately 300 gallons per minute (gpm) would be necessary to maintain a groundwater elevation of 380 feet along approximately 2,200 linear feet of 192nd Street East if the surrounding groundwater level reached 383 feet. This pumping would have to be continued as long as the surrounding groundwater level exceeded 380 feet, possibly for as long as 5 to 6 months.

Another potential solution to the periodic flooding of 192nd Street East is to raise the elevation of the approximately 2,250 linear foot segment of low-lying (elevation 380 feet) road adjacent to the pond. Using an average previous water year total, a groundwater level of 383 feet is predicted for a 100-year recurrence of the 3-month precipitation total of 30.38 inches. It is estimated that approximately 12,500 cubic yards (cy) of fill material would be required to raise the road surface from 380 feet to 383 feet.

Elevation of the roadway to 384 feet to provide an additional 1-foot margin of safety would require reconstruction of an additional 100 linear feet of roadway (2,350 feet total). The 384-foot surface elevation corresponds to a predicted 200-year recurrence of the 3-month precipitation total of 32.22 inches, following an average water year's precipitation. It is estimated that approximately 18,800 cy of fill material would be required to raise the road surface from 380 feet to 384 feet.

Top: View to east of western edge of flooding along 192nd Street East during spring 1997 flooding.

Bottom: Same view taken in summer 1998.

Top: View to west of flooding segment of 192nd Street East and failed barrier wall.

Bottom: Same view taken in summer 1998.

1.1 BACKGROUND

Significant non-riverine flooding has occurred within the last 5 years in numerous areas throughout Pierce County, in some cases blocking roads and causing damage to adjacent homes and businesses. These late winter and early spring events differ from the common understanding of floods, where flowing water surges over a river bank due to a recent storm or rapid snow melt, inundates adjacent areas, and then rapidly recedes as the water moves downstream. Rather, non-riverine flooding results from the rise of groundwater above the surface in low-lying areas and can occur at locations far removed from any rivers or streams.

Without a system (pumps, conveyance) to move the water away from the location where it appears, it will remain on the surface until it evaporates or groundwater levels decline and it re-infiltrates into the ground. Because of the slow rate of groundwater movement, groundwater levels respond more slowly to precipitation than rivers do, and the non-riverine flooding can occur long after storms have passed and can persist for weeks or months. Roads and structures adjacent to the locations where the groundwater appears can be blocked for long periods and damaged by the standing water.

On behalf of the Pierce County Public Works Department, Division of Storm and Surface Water Management (County), URS has performed an investigative study of this type of flooding which has occurred recently in an area near Frederickson in central Pierce County, Washington (Figure 1).

1.2 REPORT OBJECTIVES

The URS investigative study to date has consisted of two separate efforts. The initial work was conducted in 1998 by URS (then Woodward-Clyde) and included a review of existing technical reports for the area; site reconnaissance; and interviews with area residents, public officials, and businessmen. The results of this initial work were presented to the County in a Technical Memorandum (Woodward-Clyde, 1998). Based on the recommendations included in the 1998 Technical Memorandum, the County authorized URS to conduct supplemental work using historical data to determine the weather patterns likely to cause the flooding and estimate the return period of future events. The supplemental work consisted of the following tasks:

- Additional hydrologic and climatic data compilation and review;
- Installation of five groundwater monitoring wells;
- Implementation (by County personnel) of a groundwater level gauging program;
- Excavation of an exploratory test pit and installation of a temporary piezometer;
- Data evaluation.

This report presents a summary of the initial work; the results of the supplemental investigation; development of an equation relating precipitation to groundwater levels; and a discussion of potential solution options, data gaps and appropriate follow-on work.

2.1 STUDY AREA DESCRIPTION

2.1.1 Location

The study area for this investigation is located in an un-incorporated area of central Pierce County near the community of Frederickson and Pierce County's Thun Field (Figure 2). The area is approximately bounded by 176th Street East on the north and Highway 161 on the east, and includes the Boeing Frederickson plant, the Port of Tacoma Industrial Park, and numerous residential developments.

2.1.2 Topography

The most recent advance and retreat of continental glacial ice, the Vashon Glaciation, which ended approximately 12,000 years ago, has significantly shaped the surface topography of central Pierce County. This glacial ice sheet is estimated to have been nearly 1,500 feet thick over the study area, and was responsible for depositing a wide assortment of sediments and creating large landforms (Brown and Caldwell, 1984). Significant topographic features in the area remaining from the Vashon Glaciation include large former streamflow channels which are discernable on topographic maps, aerial photographs, and from the ground.

A high velocity stream of meltwater flowing westward from glacial Lake Puyallup, (formerly located in the current Puyallup River valley) eroded these large stream channels during the glacial retreat. As the glacier retreated to the north, the location of the meltwater streams also shifted to the north, abandoning the previous channels. The surface elevations of these meltwater channels tend to decrease to the north, resulting in a sequential, step-down pattern. Former meltwater stream channels in central Pierce County include the South Tacoma Channel, the Clover Creek Channel, the Kirby Channel, and the Muck Creek Channel.

The topography of the study area is dominated by the presence of the Kirby Channel, which meanders roughly east-to-west through the study area. Although perennial and ephemeral ponds are located in low-lying areas of the Kirby Channel, there are no streams or rivers present. Low-lying areas of the Kirby Channel where flooding events have recently occurred are shown on Figure 3.

Upland areas on either side of the Kirby Channel are generally level, with a steep slope separating the upland areas from the floor of the Channel. The approximate boundary of the surface drainage for the flood locations in the Kirby Channel was determined using U.S. Geological Survey (USGS) topographic maps and is included on Figure 3. The delineated surface drainage basin is approximately 6,400 acres and the southeastern boundary approximately corresponds with the boundary of the Clover Creek drainage basin.

The streams nearest to the study area are Clover Creek (located within the Clover Creek meltwater channel) and Muck Creek. Clover Creek begins at a spring approximately 1/2 mile north of 176th Street East and flows westward to Steilacoom Lake and then onto Puget Sound. Muck Creek, which also flows westward to Puget Sound, begins at Patterson Spring several miles south of the study area. The northward flowing Puyallup River is located approximately 5 miles east of the study area. There are perennial and ephemeral ponds and wetlands present

within the study area which may receive some local surface water runoff, but do not have surface water outlets.

2.2 GEOLOGY

The subsurface geology of the study area also reflects the advance and retreat of the continental glacial ice, which produced a progressional sequence of sedimentary deposits with distinctive physical characteristics. The uppermost several hundred feet of these deposits are composed of three general glacial units. The deepest is a coarse sand and gravel unit deposited by the advancing continental ice sheet (Advance Outwash). This glacial unit is overlain by a dense, intermediate layer of silt, sand, and gravel (Vashon Till) which in turn is covered with an upper unit of coarse gravel and sand deposited during the northward retreat of the ice (Recessional Outwash). The Vashon Till was reworked and compacted by the great thickness of the over-riding glacial ice, resulting in a very dense, low permeability material. The Steilacoom Gravel is a specific Recessional Outwash unit that was deposited by the meltwater streams from glacial Lake Puyallup which formed the Kirby Channel. The streamflow through the channel may have been significant enough to erode away the Vashon Till in some areas, and the recessional Steilacoom Gravel may extend from the surface to the Advance Outwash.

2.2.1 Hydrogeology

There are two aquifers separated by the Vashon Till present within several hundred feet of the surface in the study area. The uppermost aquifer is a localized unconfined aquifer in the Recessional Outwash unit (Steilacoom Gravel), perched above the Vashon Till. This aquifer produces ephemeral springs along eroded ridges, and some shallow, residential water wells are completed in this unit.

Below the Vashon Till is a more regional aquifer within the Advance Outwash deposits, which may be confined in some areas by the till. Deeper private residential wells and local public water supply system wells are completed within this aquifer. The base of the Advance Outwash corresponds with the top of the low permeability, non-glacial deposits present at an elevation of approximately 200 feet above sea level.

This general relationship between these two aquifers in the study area has been altered by the erosional effects of the meltwater streams that formed the Kirby Channel. In the upland areas outside the Kirby Channel, the low-permeability Vashon Till is at, or close to, the surface with a thin veneer of Recessional Outwash deposits present in some areas and a surficial soil cover. Seasonal perched groundwater may be present locally on the till within the outwash deposits. The deeper advance outwash aquifer is separated from the local perched system by the Vashon Till in the upland areas above the Kirby Channel.

Within the Kirby Channel, the Vashon Till may have been removed by erosion in some areas and the upper Steilacoom Gravel aquifer would be in direct contact with the deeper Advance Outwash aquifer. This would result in a direct hydraulic connection between these two aquifers in the Kirby Channel. Perennial and ephemeral ponds in low-lying areas of the Kirby Channel are likely surface expressions of the Steilacoom Gravel aquifer, and may also indicate areas where the two aquifers could be in hydraulic contact.

A pond of perched water on low-permeability soil would tend to be ephemeral, forming in the winter or spring from runoff and disappearing in the summer due to evaporation and slow infiltration. It appears that the pond adjacent to 192nd Street East is in hydrologic connection with the shallow groundwater system; therefore, the level of the pond fluctuates with the level of the groundwater.

Thus, groundwater within the Kirby Channel may receive recharge from both the upper Steilacoom Gravel aquifer and the lower, possibly confined Advance Outwash aquifer. The recharge to groundwater in the Kirby Channel from the upper aquifer would be controlled by the topography of the upland surface drainage basin, estimated at approximately 6,400 acres (Figure 3). The recharge area of the lower aquifer may extend well beyond the boundary of the surface drainage basin.

The key point in the relationship between these two aquifers is the hydraulic connection that may occur in some areas of the Kirby Channel due to the lack of the intervening Vashon Till. Under normal precipitation conditions, the groundwater flow between the two aquifers is downward from the upper aquifer to the lower aquifer (Hart-Crowser, 1997). This downward flow would be greatly increased in areas where the low-permeability Vashon Till does not separate the aquifers and impede the flow. This would result in lowered groundwater levels in the upper aquifer as water drains to the lower aquifer.

Under elevated precipitation conditions, however, the downward gradient may be reversed and not only would water not drain from the upper aquifer to the lower aquifer, it may actually flow upward from the lower aquifer into the upper aquifer. This effect would be magnified in areas where the low-permeability till is not present to impede the flow. Thus, some areas of the Kirby Channel may act as groundwater discharge areas for the deeper aquifer, causing the water level in the upper aquifer to rise, possibly above the ground surface. The adjacent Clover Creek Channel to the north was reported by Brown and Caldwell to be a groundwater discharge area, but the water is conveyed downstream by Clover Creek. There are no flowing streams in the Kirby Channel and any water that reaches the surface will remain there until it evaporates or re-infiltrates into the ground.

Deeper (greater than 300 feet) regional confined aquifers are also present in the study area within older glacial deposits. The City of Tacoma-Frederickson water supply well, located just north of 192nd Street East and the perennial pond, is completed within one of these deeper, regional aquifers. It is doubtful that these deeper aquifers have a significant influence on the groundwater flooding events.

2.3 PRECIPITATION

Precipitation data between March 1941 and December 2000 was obtained for this report. Data from 1941 through July 2000 was taken from the McMillin Reservoir (#455224) gauge, while data from the McChord Air Force Base was used for August through December 2000. The McMillin Reservoir station is located on the Puyallup River approximately 5 miles northeast of the study area, and McChord Air Force Base is located approximately 10 miles west. These data are included in Appendix A and include both calendar (January 1 to December 31) and water year values for the time period of record. A water year spans the time period between October 1 and September 30. For example the 1995–1996 water year extends from October 1, 1995 to September 30, 1996.

The average calendar year precipitation measured at the McMillin Reservoir was 41.88 inches, with the maximum annual value of 62.88 inches occurring in the calendar year of 1996. The minimum calendar year precipitation was 22.07 inches measured in 1952.

The average water year precipitation at the reservoir was 42.16 inches/year, with the recorded water year precipitation levels ranging from 25.11 inches in 1944 to 60.4 inches in 1997. Most of the precipitation occurs between November and April, with very little precipitation occurring in the summer.

Flow data for the Puyallup River at the Orting station and snowfall at Mount Rainier were also obtained for the time period between 1990 and 1999. These data are included in Appendix A.

2.3.1 Land Use

Speransky (1999) analyzed land use changes within the surface drainage area delineated for the study area between 1960 and 1985 based on a review of aerial photography. Speransky reported a steady increase in development in during this time period from approximately 30 percent developed (which includes residential, commercial, and industrial activities) in 1960 to approximately 57 percent developed in 1985. The percentage of developed land (residential, commercial, and industrial) within the same area in 1995 was estimated at 64 percent, using Pierce County Surface Water Program maps.

Current land use in the study area includes commercial and industrial development (the Boeing Frederickson Site and the Port of Tacoma Industrial Park), relatively dense residential subdivisions (Fir Meadows), isolated homes and open land (both forested and grass). The trend in the study area is toward more commercial and industrial development (primarily at the Port of Tacoma Industrial Park) and residential subdivisions distributed throughout the area.

Previous reports have estimated an evapotranspiration rate for the study area to be between 15 and 21 inches per year (GeoEngineers, 1990a; Hart-Crowser, 1997). Both of these values are based on previous work done by the Washington State University Cooperative Extension Service and are associated with undeveloped, fully forested areas. (GeoEngineers also reported an evapotranspiration rate of 8 inches per year for developed, non-forested property.)

Land use plays an important role in determining the amount of groundwater recharge of an area by affecting the evapotranspiration and surface runoff rates. Removal of forested areas will increase the amount of rainfall that reaches the ground surface due to decreased rates of interception and evapotranspiration. In most areas, an increase in urbanization and impermeable surfaces (pavement, rooftops) results in increased surface water runoff, elevated peak discharges from streams following storm events, and decreased recharge to groundwater.

However, there are no streams or rivers in the study area to convey surface water runoff out of the area. Based on discussions with County personnel, storm water runoff at existing commercial and industrial sites and new residential developments in the study area is generally directed to on-site infiltration galleries or ponds. The trend in the study area toward commercial, industrial, and residential land use will increase the amount of precipitation that is infiltrated into the ground and will increase groundwater recharge. New development also may increase groundwater recharge by releasing water imported through piped water supply systems to the ground via excess irrigation, septic systems, and other water usage. However, this irrigation water is added into the groundwater reservoir at a time when the water levels are low, in the

summer time. While seasonal fluctuations of groundwater levels generally reflect the lowest values in the summertime, a significant lag time can be observed. So elevated water levels resulting from fall/winter/spring precipitation can persist well into the summer. Although the contribution for excess irrigation may be relatively small, in wet years it may be enough to exacerbate a flooding problem.

Thus, precipitation in 1965 that would have resulted in no impacts in the study area could result in substantial flooding in 1995, as increased development has raised the percentage of precipitation that recharges groundwater, and added roads and buildings that can be impacted by the flood water.

2.3.2 Historic Flooding Events

The most recent flooding event in the study area occurred in March 1999 at the pond adjacent to 192nd Street East (Tacoma News Tribune, 1999). Significant winter flooding was also documented along 192nd Street East in the late winter and early spring of 1996 and 1997 (Hart-Crowser, 1997). The flooding in all 3 years covered the road with water and prevented its use. The road was blocked in March 1999 for 5 days, in 1997 for 5 months (January through June), and in 1996 for 3 months (January to April).

The ephemeral ponds located near 204th Street East and Eustis Hunt Road also expanded past their normal boundaries during the 1997 event. A video taken by County personnel at the western-most pond illustrated the rise of the groundwater above the surface. Water south of Fir Meadows was visible bubbling several inches above the ground and was capable of raising the grass and upper soil layer.

Both of these ponds expanded northward past 204th Street East. The western-most pond reached the Fir Meadows residential area, where the water ponded in a major intersection and caused some damage to adjacent residences. Despite the reported presence of an infiltration gallery near the intersection, the water remained in the intersection for several months. The eastern-most pond also extended northward, and dissipated slowly during the spring and early summer. No damage was reported from this pond.

Written reports documenting flooding events prior to 1996 in the area were not available; therefore, area residents and businessmen were interviewed to try to determine the date and severity of previous flooding events in the area. Randles Sand and Gravel has been operating since the mid-1950s east of the intersection between 192nd Street East and Canyon Road. Mr. Dave Randles recalled that flooding similar to the 1996–1997 events occurred at some time in the early 1970s.

Discussions also were held with Mr. Ray Richmond, a long-time local resident whose property includes the western-most ephemeral pond near 204th Street East that spilled into the Fir Meadows residential area in 1997. Mr. Richmond estimated that the size of the pond on his property in 1972 was similar to that reached in 1996 and again in 1997.

Photographs of both flooding and non-flooding events taken along 192nd Street East between 1997 and 1999 are included in Appendix B.

2.3.3 Previous Investigations

Previous investigations in the area can be divided into four general categories:

- Regional studies on soils, geology, and groundwater that include the study area
- Site-specific studies concerning groundwater at the current Boeing Frederickson plant
- Site-specific studies for development of commercial properties at the Port of Tacoma Industrial Park
- Studies focused on the flooding issues in the study area

The soil survey for Pierce County describes the soil in low-lying depressional areas in the Kirby Channel near Frederickson as Dupont muck, a poorly drained organic soil (U.S.D.A., 1979). Other soils within the Kirby Channel are dominated by the Spanaway gravelly sandy loam, a moderately permeable soil composed primarily of glacial outwash and volcanic ash. Soils in the upland areas of the study area include the Everett sandy gravelly loam and the Kapowsin gravelly loam. Both of these soils are well drained, with the Kapowsin gravelly loam typified by a very low permeability substratum that can perch water during the rainy season.

The study area was also included in the Clover/Chambers Creek Geohydrologic Study conducted for the Tacoma-Pierce County Health Department (Brown and Caldwell, 1984). This report concluded that two distinct groundwater systems are present in the Clover/Chambers Creek drainage area: a shallow (less than 300 feet deep) system termed Layer A that is composed of recent glacial deposits and a deeper system (greater than 400 feet) below the non-glacial material (Layer B) that separates the two systems. The shallow aquifers of interest in the study area are all located within Layer A, which is not lithologically differentiated in the Brown and Caldwell report.

Numerous site-specific reports have also been issued on the nearby Boeing Frederickson plant, primarily focused on groundwater contamination remaining from pre-Boeing activities at the property. Prior to Boeing's purchase of the site, it was the location of an explosives manufacturing and processing plant for nearly 40 years. Nearly 60 groundwater monitoring wells were installed between 1987 and 1995, with approximately half of these being subsequently abandoned (Conestoga Rovers, 1999) Numerous groundwater monitoring and modeling programs were conducted at the site during these years (Earth Consultants, 1989; AGI, 1990, 1991, 1993, and 1994a; Harding Lawson, 1994 and 1995).

Site-specific studies of other commercial properties within the study area include a draft Environmental Impact Statement for a proposed power generating station (Pierce County, 1980). This report includes a photograph of the pond adjacent to the current location of 192nd Street East, although the date that the photo is taken is not reported. It is difficult to determine the elevation of the water in the pond when the photo was taken, but it appears that the water would have reached 192nd Street East (which had not yet been constructed). A geotechnical and a groundwater report were prepared for a sand and gravel quarry near the 192nd Street East pond. (GeoEngineers, 1990a and 1990b). The reports for the quarry stated that there is no significant surface water runoff from the quarry, the pond level represents the shallow water table, and the two uppermost aquifers in the area are in hydraulic connection.

Previous investigations have also been conducted specifically on the seasonal flooding within the study area. Hart-Crowser conducted an assessment of the 1996 and 1997 flooding events at the

pond adjacent to 192nd Street East for the Port of Tacoma (Hart-Crowser, 1997). Hart-Crowser reported that the flooding appeared to be caused by late winter/early spring groundwater levels in the shallow aquifer within the Kirby Channel rising sufficiently high to cover lower elevation topographic areas with water. The rise in water level was reported to be associated with the previous water years precipitation, which recharges the shallow aquifer in the Kirby Channel at a rate greater than the groundwater can flow out of the aquifer (Hart-Crowser, 1997).

The 1996 and 1997 flooding was not attributed by Hart-Crowser to individual precipitation events, but rather to cumulative precipitation that infiltrated to the groundwater and raised the water level. Hart-Crowser predicted that water year (October 1 to September 30) precipitation totals above 52 inches will cause flooding in the same water year at 192nd Street East. Hart-Crowser also reported that a 2-year average of water year precipitation above 49 inches may also be correlated with flooding.

The recurrence interval for a single water year precipitation level of 52 inches was estimated by Hart-Crowser at approximately 28 years, and the recurrence interval of two successive years of 49 inches precipitation was estimated at approximately 100 years.

Speransky performed a statistical evaluation of the groundwater and precipitation data for the study area using groundwater data from wells at the Randles Quarry and the Boeing Frederickson plant (Speransky, 1999). Linear regression analyses were used to determine a mathematical relationship between precipitation and groundwater levels. The analyses were performed on both water year and quarterly (beginning in November) precipitation totals.

While the total water year precipitation displayed the best correlation with groundwater levels, the quarterly correlation was determined to be more useful in predicting flooding events. The well with the best correlation ($r^2 = 0.815$) between groundwater and both seasonal and quarterly precipitation was the Randles well RMW-1. Speranky's regression equation for well RMW-1 was:

$$\textit{groundwater elevation (ft)} = 364.01 + 0.494 * (\textit{quarterly precipitation - inches})$$

The groundwater elevation is predicted in feet and the quarterly precipitation units are inches. Speransky reported a 2-month time lag between the quarterly precipitation totals and the groundwater response in well RMW-1. Thus, the groundwater level in March predicted by the equation is determined primarily by the precipitation for the previous November, December, and January. Speransky also reported that groundwater levels in the Frederickson area are influenced by two aquifers: a shallow, unconfined aquifer and a deeper, confined aquifer.

3.1 SUPPLEMENTAL WORK

3.1.1 Historic Data Compilation

To advance our understanding of hydrogeologic conditions and the relationship between groundwater levels and precipitation, additional historic water level data for groundwater monitoring wells in the study area were obtained from technical reports on file at the Washington State Department of Ecology and the Tacoma Public Library. Reports obtained during this supplemental review included two annual groundwater monitoring reports for the Boeing Frederickson site (AGI, 1994b and 1996), and a hydrogeologic assessment of a property adjacent to 192nd Street East (GeoEngineers, 1992). There are also numerous private residential water wells and small public water supply wells in the area, but stratigraphic logs, construction details, and reliable water level data were generally not available for these wells.

The locations of selected groundwater monitoring wells with the most extensive historical data and best distribution within the study area are shown on Figure 4. Available lithologic logs and well construction diagrams for these wells are included in Appendix C.

3.1.2 Well Installation and Groundwater Monitoring

Although numerous monitoring wells are present at the Boeing Frederickson plant and Port of Tacoma Industrial Park, no monitoring wells were available south and east (upgradient) of these areas. As part of the supplemental investigation, five monitoring wells (FR-1-1, FR-2-2, FR-3-1, FR-3-2, and FR-4-1) were installed by the County at four locations in the study area to provide a wider distribution of water level data. These locations are shown on Figure 5.

The wells were advanced to maximum depths ranging from 25 to 150 feet below ground surface (bgs). Wells FR-3-1 and FR-3-2 are adjacent wells that have screened interval depths of 15 to 25 feet bgs and 134 to 144 feet bgs, respectively. All five wells were installed using an air rotary drilling rig with pneumatic hammer and were constructed of 2-inch-diameter Schedule-40 PVC and machine-slotted PVC screen. Well construction diagrams and lithology for the new monitoring wells are included in Appendix C.

Upon completion of the monitoring well installation, County personnel implemented a regular water level gauging program. The gauging program consisted of measuring water levels in the newly installed wells (FR-1-1, FR-2-2, FR-3-1, FR-3-2, and FR-4-1), in the existing Port of Tacoma wells (PZ-1, PZ-4, and P.O.T. Well) and in the Randles Sand and Gravel wells (RMW-1 and –3). The water level in the pond along 192nd Street East was also monitored using a staff gauge installed for that purpose. (A verbal agreement between the County and Boeing was made to share water level data collected at the Boeing Frederickson plant with the County in exchange for the County data. Apparently this agreement has not been implemented between County and Boeing Field staff. No data are currently available). The monitoring wells and pond were measured weekly during the winter and monthly in the summer. The locations of these wells included in the monitoring program are included on Figure 5.

County personnel surveyed the elevations of the top-of-casing point of each newly installed County well and the base of the staff gauge at the 192nd Street East pond. The elevations of the well casings for the Port of Tacoma and Randles wells were taken from previous reports.

Groundwater elevations at the monitoring wells were determined by subtracting the measured depth-to-water from the elevation of the top of the well casing. The elevation of the pond was obtained by adding the measurement on the staff gauge to the known elevation of the base of the gauge. Following collection, the data were tabulated and hydrographs and water-level contour maps were prepared.

3.1.3 Test Pit Excavation and Piezometer Installation

In December 1999, an exploratory test pit was excavated and a temporary piezometer was installed in the excavation near the intersection of 67th Avenue East and 201st Street East in the Fir Meadows residential area. This intersection was flooded in the spring of 1996 and 1997, blocking traffic and causing some minor damage to adjacent residences.

It was unknown if the 1996 and 1997 flooding resulted from surface water runoff from higher elevation areas within Fir Meadows that perches on the surface or if it is an expression of the shallow groundwater table that has risen above the ground surface (or a combination of the two). The 1968 Road and Drainage Plan (RDP) for Fir Meadows indicates an infiltration gallery just north of the intersection, but no information was available on the gallery's construction or current operating condition.

The objective of the test pit exploration was to observe the subsurface stratigraphy at the intersection and determine if there is an interval of high permeability subsurface material above the shallow groundwater table into which runoff entering the intersection area can be infiltrated. If the water flooding the intersection was determined to be surface runoff, the stratigraphic information could be useful in evaluating the feasibility of installing an infiltration system to eliminate ponding. The temporary piezometer was installed to provide data on the presence and depth of shallow groundwater at the intersection and to provide the ability to monitor the depth to groundwater at the intersection during future flooding events. These data could indicate if water that ponded in the intersection in the future was runoff from other areas or groundwater that had risen above the land surface.

The test pit was located within the county right-of-way on the eastside of the intersection. A tracked excavator, operated by county personnel, advanced the test pit to a total depth of approximately 13.5 feet. The test pit location and stratigraphy observed in the test pit sidewalls is described on the attached test pit exploration log (Appendix C). The excavated material was placed adjacent to the open excavation and returned to the excavation immediately upon completion of the piezometer installation. The temporary piezometer was constructed of 2-inch diameter schedule 40 polyvinyl chloride (PVC) with 5 feet of slotted screen at the bottom. The piezometer was cut flush with the surface, labeled, and capped. The temporary piezometer was included in the groundwater level gauging program after installation.

4.1 RESULTS

4.1.1 Historical Groundwater Data

Historical water level data for eight monitoring wells and the pond adjacent to 192nd Street East are shown on Figure 6. The locations of these wells are included on Figure 4 and the data are included in Appendix C. Intermittent monthly groundwater data for the Randles wells (RMW-1 and -3) and the pond are available from early 1990 through the end of 1995. Water level data for wells at the Boeing Frederickson site (14-A, 11-C, BMW-4, -10, and -14) are continuous from January 1993 through December 1995. Data for the deep City of Tacoma well are continuous from January 1995 through February 1999.

Groundwater data for the 1995-1997 time period when two major flooding events occurred were not available for any of the shallow groundwater monitoring wells, with the exception of a single measurement taken by Hart-Crowser in April 1997.

Previous studies in the area have reported that groundwater levels in the shallow unconfined aquifer respond quickly to precipitation, with the lowest level noted in the autumn and the highest levels present in late winter and early spring (AGI, 1992; Hart-Crowser, 1997). A similar trend was observed in the data for the study area groundwater monitoring wells. Annual variations in water levels ranged from 8 to 12 feet between August 1992 and July 1993 at the Boeing Frederickson site, and from 9 to 13 feet between January and October 1990. Water elevation in the perennial pond adjacent to 192nd Street East varied 2.5 feet between January and October, 1990 (AGI, 1992) although the data for the pond was intermittent.

4.1.2 Water Level Gauging Program

The water level gauging program began in February 1999, with measurements taken on a weekly basis until May 1999. From May until November 1999 the measurements were taken monthly, and then weekly until May 2000. Monthly measurements were then resumed. Measurements at P.O.T. well were discontinued in June 1999 and PZ-1 was dry from June 1999 until February 2000. No water was measured in well FR-3-1 and the water level in the pond was below the bottom of the staff gauge from June 1999 until March 2000. By April 2000 the water level in the pond was once again below the level of the staff gauge. The water level elevations in the pond and monitoring wells are shown on Figure 7, and the water level data are included in Appendix C. No data from the Boeing Frederickson plant were available for inclusion in the water level gauging program.

Groundwater in the study area occurs at elevations ranging from approximately 366 to 459 feet above mean sea level with the highest elevations occurring in the south and southeast segments of the study area and the lowest elevations occurring in the northwest. Potentiometric surface contour maps for wet season (mid-March) and dry season (early November) are presented in Figures 8 and 9 respectively. The groundwater flow direction was generally to the northwest during both wet and dry seasons; however, the flow gradient did vary between the seasons. In spring 1999, the flow gradient was approximately 0.009 feet per foot and was relatively consistent throughout the watershed. In fall 1999, the flow gradient ranged from approximately

0.013 feet per foot in the eastern portion of the watershed to approximately 0.004 feet per foot in the western portion of the watershed.

Seasonal water level fluctuations ranged from approximately 8 feet at Well FR-4-1 (located in the northeastern portion of the study area) to approximately 26 feet at Well FR-1-1 (located in the south-central portion of the watershed). In both cases higher water level elevations occurred during the winter and early spring months, with the lowest groundwater levels occurring in late summer and autumn.

4.1.3 Test Pit Excavation and Temporary Piezometer Installation

The test pit was situated adjacent to the intersection in the County right-of-way and advanced to a depth of 13.5 feet. Once below the finer-grained, compacted surface material, the subsurface lithology encountered consisted of coarse gravel with some silt and sand. Gravel with interstitial clay was encountered at approximately 12 feet bgs, which may be indicative of a low-permeability layer. No groundwater was observed in the test pit during excavation. The temporary piezometer was installed to a depth of approximately 13 feet, with 5 feet of slotted screen at the bottom.

The temporary piezometer was included in subsequent water level monitoring measurements. No groundwater was measured in the temporary piezometer between December 1999 and May 2000 and no ponding occurred in the intersection.

Based on the observation of the test pit sidewalls, the depth interval between 1 and 11 feet bgs appears to be of sufficient permeability to allow infiltration of surface water (provided that this interval is not saturated with groundwater). As no ponding occurred in the intersection between December 1999 and May 2000, it is not yet known if ponding is the result of surface water collecting in a low-lying area or the rise of the groundwater table above the ground surface.

A comparison of the surface contours at Fir Meadows with the 1968 RDP indicates that the existing surface contours do not match drainage patterns described in the RDP. The RDP indicates that surface drainage from the intersection was originally designed to flow southward to the current athletic field. There were reports from Fir Meadows residents that an infiltration gallery had at one time been installed in the athletic field, but that subsequent improvements to the field had raised the surface elevation above adjacent areas in the development. The current drainage pattern is opposite that shown on the RDP as water from the athletic field drains to the intersection. The intersection also receives drainage from the ditches adjacent to the roads in the southern half of the Fir Meadows development.

4.1.4 Groundwater/Precipitation Relationship

There have been five reported flooding events in the project area since 1942 (the first year precipitation data were collected at the McMillin Reservoir). These events occurred in the early 1950's, early 1970's, 1996, 1997 and 1999 (Hart-Crowser, 1997, TNT, 1999). While little is known about the flooding in the 1950's and 1970's, the events in the 1990's have been better documented.

The flooding events appear to be the result of groundwater levels rising above the ground surface of topographically low areas in response to precipitation. While the flows in the Puyallup River

and snow fall at Mount Rainier reflect the precipitation trends observed for the McMillin Reservoir and may recharge groundwater near the study area, they have not been directly correlated to groundwater flooding within the study area.

The groundwater surfaces at two locations within the study area: the perennial pond adjacent to 192nd Street East, and two ponds near 204th Street East. Once on the surface, the water from the perennial pond blocks access to 192nd Street East while the water from the ephemeral ponds near 204th Street East flows northward and impacts nearby residential areas. The development of a predictive equation for groundwater levels based on precipitation could be useful in predicting future flood events and developing short-term and permanent flood mitigation measures.

While the Hart-Crowser estimate of the cumulative water year precipitation amount (52 inches) that will result in flooding appears to be well correlated with flooding events at 192nd Street East, the use of a water year precipitation total to predict late winter/spring flooding is not particularly useful. The water year runs from October 1 to September 30, so by the time the water year total is known, the flooding would have already occurred.

Speransky's equation relating quarterly precipitation totals with groundwater levels appeared to be more useful as a predictive tool. To evaluate the equations' usefulness, the equation was slightly modified to use a running 3-month total of precipitation and the predicted groundwater level was plotted monthly against measured water levels in RMW-1. The 2-month time lag between the end of the precipitation period and the predicted groundwater level reported by Speransky was maintained. For example, the monthly precipitation values for October, November, and December (of any year) are used to predict the groundwater level the following February. Then, November, December, and January data are used for the March prediction, and so on through the time period of interest. This was done for the time period between 1990 and 2000, during which intermittent water level data in well RMW-1 were available and three flood events occurred. It must be noted that only one data point was available for the 1995 through 1997 time period, when two major flood events occurred.

The monthly groundwater levels predicted by the modified equation matched the measured water levels in RMW-1 fairly well when precipitation levels were within the normal range. The effectiveness of the modified equation was visually evaluated by comparing known and predicted water level elevations graphically. However, Speransky's equation appeared to under-predict groundwater levels during elevated precipitation periods. This is most likely due to the re-calculation of the groundwater level for each month using the same beginning water level elevation of 364.01 feet for each prediction. In periods of low or normal precipitation, it is likely that the groundwater levels declined sufficiently over the 2-month lag time to meet this condition as groundwater moved laterally and downward from the shallow groundwater aquifer. However in periods of elevated precipitation (such as water years 1995-1996 and 1996-1997), the water level may not decline sufficiently and the equation will under-predict the resultant monthly groundwater levels.

To account for the lack of sufficient groundwater level decline in above-average precipitation years, a trial and error adjustment was made to the 364.01 value depending on the previous water years' total precipitation. For water years with less than the average water year value of 42 inches of precipitation, no adjustment was made. For water years above 42 inches of precipitation, a percentage of the water year total was added to the 364.01 value for each

monthly water level prediction. Five percent of the previous water years' total was used for the months June through November and seven percent was used for the months of December through May.

Thus for months where the previous water years' total was less than 42 inches the equation was:

*Predicted groundwater elevation (ft) = 364.01 +0.494 * (quarterly precipitation-inches)*

For months where the previous water years' total exceeded 42 inches two equations were used:

Predicted groundwater elevation - feet (June to November)

*= [364.01 + 0.07 * (quarterly precipitation-inches)] +0.494 * (quarterly precipitation-inches)*

Predicted groundwater elevation - feet (December to May)

*= [364.01 + 0.05 * (quarterly precipitation-inches)] +0.494 * (quarterly precipitation-inches)*

A plot of predicted (using the modified Speransky equation) and measured groundwater levels in well RMW-1 between 1990 and 2000 is presented in Figure 10. These data are also presented in tabular form in Appendix C. Unfortunately, there were no data available for the monitoring wells in the area during the 1996 and 1997 flood events, with the exception of a single data point taken by Hart-Crowser in March, 1997.

Some variation between the measured and predicted groundwater levels can also be attributed to the discrepancies in dates. The precipitation values are always reported for the end of the month, while the water level data may have been collected at any time during the month.

It is known that the water level in the pond rose above 192nd Street East in the 1996, 1997, and 1999 flood events, although regular groundwater data is available only for 1999. The historical data indicates that the water level in RMW-1 is in general agreement with the level in the pond, with some variation perhaps due to intermittent surface water discharge to the pond from nearby properties. A conservative 2-foot offset was used for extrapolating water levels in RMW-1 to the pond adjacent to 192nd Street East.

The elevation of the lowest segment of 192nd Street East near the pond is approximately 380 feet. Therefore, predicted groundwater elevations in well RMW-1 near 378 feet are approximately indicative of the pond raising above the road. This condition was met in 1999 in both the predicted and measured groundwater data. The lack of measured groundwater elevation data during the 1996 and 1997 flood events prevents confirmation of these values.

The modified Speransky equation can thus be used to determine what precipitation patterns will produce a water level above 378 feet in well RMW-1 and corresponding flooding at 192nd Street East. Since the equation uses both 3-month and the previous water year's totals, both must be used in the calculation.

For an average preceding water year precipitation total of 42 inches, it is estimated that a 3-month precipitation total exceeding 24 inches will result in the water level in the pond crossing

192nd Street East within approximately 2 months time. For example, if the cumulative October, November, and December precipitation exceeds 24 inches it is predicted that the water in the pond will rise above the road by the following February.

The U.S.G.S. frequency analysis program utilizing the log-Pearson Type III distribution was used to estimate the recurrence intervals for water year and 3-month cumulative precipitation totals. The recurrence interval for a running 3-month cumulative precipitation total was estimated by selecting the highest of the twelve values for each year. The frequency analyses are included with the precipitation data in Appendix A.

The recurrence interval of a 3-month precipitation total of 24 inches was estimated at approximately 10 years. This was the amount of precipitation in any 3-month time period that is estimated to produce flooding at 192nd Street East with an average (42 inches) precipitation total for the previous water year. As the precipitation total for the previous water year increases, the total 3-month precipitation estimated to produce flooding decreases. For every 1-inch increase in the previous water years' total above 42 inches, the 3-month precipitation total that is predicted to correspond with flooding is reduced by approximately 0.15 inches.

Using the recurrence intervals estimated for water year and 3-month precipitation totals and the predictive equation, the estimated groundwater levels at the pond that would occur in response to the different precipitation magnitudes were determined. Table 1 shows the predicted groundwater levels near the pond for 2-year through 50-year water year precipitation amounts with the pond projected to cross the road when the water level exceeds 380 feet. As illustrated by Table 1, a 3-month cumulative precipitation total of at least 24.04 inches following water years with average (42 inches) or greater precipitation totals will result in predicted flooding of 192nd Street East.

The length of time that the water remains over the road is a function of the longer-term precipitation data, and no mathematical relationship to predict this has yet been determined. Although no data are available, the 1996 and 1997 events reportedly lasted significantly longer than the 1999 event. This is most likely due to the previous water years' precipitation totals. The water year precipitations prior to the 1996 flood and 1997 event were 44.33 inches and 56.71 inches prior, respectively, while the water year precipitation prior to the 1999 event was only 36.75 inches.

4.2 POTENTIAL 192ND STREET EAST FLOODING SOLUTIONS

Solutions for reducing the damage and inconvenience caused by groundwater flooding at 192nd Street East can be separated into three general categories:

- No infrastructure changes – only monitoring and emergency response
- Conveying water away from the area via pumps or drains
- Raising the elevation of 192nd Street East roadway

The first two of these categories require continued monitoring of precipitation and groundwater levels and use of the predictive groundwater level equation. Additional groundwater data are necessary to confirm that the predictive equation is valid for accurately predicting groundwater levels. (The current equation was developed using the existing data set that is under-represented in high precipitation years).

4.2.1 Monitoring and Emergency Response

By monitoring the precipitation monthly, the running 3-month total can be maintained and at the end of each September the preceding water year total can be determined. Once the water year total is known, the 3-month cumulative precipitation predicted to cause flooding can be determined from Table 1. When the 3-month totals approach or reach the value from Table 1, flooding along 192nd Street East can be anticipated within 2 months. When the flooding will occur in those 2 months depends upon when the bulk of the precipitation fell within the 3-month monitoring period. If the November, December, and January totals exceed the predicted amount that will cause flooding and most of the precipitation fell in November, the flooding can be expected to occur sooner than if most rain fell in January.

Thus, the precipitation data and predictive equation can provide a warning that flooding may occur in the near future and emergency response measures (such as sandbagging the road) can be implemented. The equation can also be used for zoning purposes to delineate areas that would be flooded under different precipitation scenarios. This information could also be useful in preventing future development in areas highly susceptible to flooding. Figure 11 shows the area that would be inundated when the water level reaches an elevation of 383 feet (100-year recurrence). This recurrence interval corresponds to 3-month precipitation totals and a previous water year precipitation total of less than 42 inches. This is the approximate elevation that the flood water reached during the 1996/97 flood event.

Approximately 2,250 feet of 192nd Street East is covered when the water elevation reaches 383 feet. Keeping the roadway clear of water would thus require nearly 4,500 linear feet of sandbags. Given that the precipitation patterns that produce flooding at 192nd Street East may also cause flooding in other areas of Pierce County, placing and maintaining a sandbag wall for this distance along the roadway may be a significant drain on County personnel and resources.

4.2.2 Water Conveyance

Previous reports note that the area near 192nd Street East appears to be a discharge location for both local and regional groundwater aquifers (Speransky, 1999). Flooding occurs when water levels in these aquifers exceed the elevations of surface structures, such as 192nd Street East and adjacent commercial enterprises. A system to prevent the groundwater from reaching the elevations that cause flooding would consist of three components:

1. Water collection
2. Water conveyance
3. Water discharge

The water collection system could consist of either pumps installed in shallow, large-diameter wells or gravity drains installed at the proper elevation. The surface elevation of the pond at 192nd Street East during the flood event in 1997 was measured at 383 feet (Hart-Crowser, 1997). Hart-Crowser also estimated that the pond covered approximately 25 acres to an average depth of 5 feet. Using these values, approximately 40 million gallons of water were present on the surface and 24 millions gallons of that were above the level of the road (assuming the road was covered with 3 feet of water). But the water in the pond is connected to the aquifer and simply

removing (with pumps or gravity drains) 40 million gallons of water will not eliminate the pond, as water removed will be replaced by the aquifer.

An estimate of the pumping rate required to maintain the groundwater level below the elevation of the road (380 feet) during the 1997 flood event was made using Visual Modflow, a 3-dimensional groundwater flow modeling package. The model was constructed using the aquifer parameters and flooding extent reported by Hart-Crowser (1997). Input parameters and the groundwater modeling results are included in Appendix D. The model predicted that a total pumping rate of approximately 300 gallons per minute (gpm) would be required to maintain a groundwater elevation of 380 feet along approximately 2,200 linear feet of 192nd Street East during a flood event when the surrounding groundwater level reached 383 feet. The installation of three wells along 192nd Street (each pumping approximately 100 gpm) would provide maximum drawdown immediately adjacent to the road. The pumps would have to be engaged while the surrounding water levels were below 380 feet and pumping would be required the entire time that the surrounding water level exceeds 380 feet. In the spring 1997 flooding the water remained above 380 feet for several months, while in the 1999 flooding 380 feet was exceeded for only several days.

Regardless of the type of water collection system used (pumps or gravity drains), a conveyance system will be required to move the water from the flood area to a discharge location. The conveyance system could consist of open ditches or surface or buried piping. The size of this conveyance system would depend on the volume of water to be moved and the distance from the flooded area to the discharge location. A collection and conveyance system utilizing gravity to move the water would eliminate the need for pumps and electrical power. However, given the location of the flooding in a topographically low area, a gravity system could require extensive deep trenching to reach the discharge location.

Any water handling solution to the flooding would also require a discharge location for the water generated by the pumping or gravity drains. Possible discharge locations could include infiltration back into the ground at some undeveloped downgradient (west/northwest) location or discharge into a surface water body. Infiltration back into the ground could occur at a location where a sufficient un-saturated interval remains between the surface and water table even under high-precipitation conditions. Identifying such a location would be a key task of a feasibility study.

Discharge to surface water bodies could also occur, but could raise significant permitting requirements and require a demonstration that the discharged water would not cause downstream impacts. Clover Creek is present approximately 1 mile north of 192nd Street, Muck Creek is approximately 5 miles south, and the Puyallup River is approximately 6 miles east of the pond.

The design of the water collection, conveyance and discharge system for the area adjacent to 192nd Street East is beyond the scope of this report.

4.2.3 Elevating 192nd Street East

Another potential solution to the periodic flooding of 192nd Street East is to raise the elevation of the low-lying road segment in the area adjacent to the pond. Under existing conditions, water begins to cover 192nd Street East when the water level elevation reaches 380 feet. The existing elevation of the segment of 192nd Street near the pond is shown on Figure 12.

Based on the results of the predictive modeling presented in Table 1, a pond elevation of 383 feet is predicted for an average water year and a 100-year recurrence of the 3-month cumulative precipitation total. The approximately 2,250 linear foot segment of 192nd Street East that is flooded when water levels reach 383 feet is included on Figure 12.

Elevation of the approximately 2,250-foot segment of low-lying roadway surface to 383 feet would provide flooding protection for a predicted 100-year recurrence of a 3-month precipitation total. This would require the use of approximately 12,400 cy of fill material, assuming a 30-foot wide road surface and a 3:1 (horizontal to vertical) slope to the ditch. Compensatory storage will not be needed after the roadway material is imported. The maximum pond level is reached based on the head in the shallow groundwater system and is independent of material placed in the low-lying area.

Elevation of the roadway to 384 feet to provide a 1-foot margin of safety would require reconstruction of an additional 100 linear feet of roadway (2,350 feet total). The 384-foot surface elevation corresponds to a predicted 200-year recurrence of the 3-month cumulative precipitation total, following an average water year's precipitation total (Figure 12). This scenario would require use of approximately 18,800 cy of material, assuming a 30-foot wide road surface and a 3:1 (horizontal to vertical) slope to the ditch.

There are several businesses located northwest of the pond that lie within the 383 foot surface contour. Reportedly, access to these businesses was disrupted during the 1996/7 floods. If the surface of 192nd Street East is raised to 383 or 384 feet, the access roads from 192nd Street East to these business structures should also be raised to prevent future access problems. As far as protection of the existing structures, the predictive equation coupled with continued groundwater and precipitation monitoring should provide sufficient warning of flooding that sandbag walls or other protective measures can be implemented.

5.1 CONCLUSIONS

Seasonal flooding occurs in the study area as the result of groundwater levels rising above the ground surface, generally in winter and early spring. Two locations where significant problems have been reported from this flooding are within the Kirby Channel near the pond adjacent to 192nd Street East and at the Fir Meadows residential area near 204th Street East. Recent flooding events have occurred in 1996, 1997, and 1999. Once at the surface, the duration of the flooding has been documented to last from several days to several months.

The monitoring program carried out on the newly installed county monitoring wells and existing wells suggests that the groundwater at the two flooding locations in the Kirby Channel is present within the same shallow aquifer system. This shallow aquifer system responds quickly to precipitation. There are no surface water outlets from the study area and all precipitation that falls in the approximately 6,400-acre study area that is not lost to evapotranspiration ultimately recharges the shallow aquifer.

In the low-lying areas of the Kirby Channel, the shallow aquifer may be in hydrologic connection with a deeper, confined aquifer where the aquitard usually present between these two aquifers has been eroded away. The hydrologic connection between these two aquifers could have a significant impact on the duration of flooding events. Work previously conducted at the study area estimated that nearly 95 percent of discharge from the upper shallow aquifer is downward to the deeper aquifer. During high-precipitation years, this downward gradient may be reversed, eliminating a significant discharge outlet for the shallow aquifer.

The two flooding locations may correspond to areas where the two aquifers are in hydraulic connection. Other locations within the study area may also be subject to this unified-aquifer condition, but not identified because no infrastructure is present in the vicinity to receive damage from flood events. As development continues within the study area additional flooding areas may be identified based on citizen complaints.

Under current conditions, flooding of 192nd Street East occurs when the groundwater levels at that location reach 380 feet amsl. Previously reported estimates that 52 inches of water year precipitation will produce flooding of 192nd Street East in the same water year appears to remain valid. The water year precipitation for 1998–1999 was 54.19 inches, and the pond at 192nd Street East flooded the road for several weeks in January 1999. The recurrence interval of this water year precipitation total has been estimated at approximately 15 years.

However, the use of water year precipitation totals are not necessarily useful in predicting flood events as the flooding of the road will have already occurred before the total water year precipitation is known. An equation correlating recent 3-month precipitation totals, and the previous water years' total with shallow groundwater levels near 192nd Street East was developed for this report as a more timely predictive tool. This equation indicates that for an average (42 inches) preceding water year total, groundwater levels will reach 380 feet (and flooding of 192nd Street East will occur) when a 3-month precipitation total exceeds 24 inches, with an approximately 2 month lag time. The recurrence interval of this 3-month precipitation amount was estimated at approximately 10 years.

As the preceding water years' total increases above 42 inches, the 3-month precipitation amount predicted to be necessary to cause flooding is correspondingly reduced. For every 1-inch

increase in the previous water years' total above 42 inches, the 3-month precipitation total that is predicted to correspond to flooding is reduced by 0.15 inches.

Until a long-term solution is implemented, the predictive equation can be used as a warning tool for each potential flooding season. The water year total will be known at the beginning of each October and the 3-month precipitation total predicted to cause flooding that winter can be estimated using the equation. Monthly precipitation monitoring can provide a warning that flooding of 192nd Street East may be imminent once the predicted 3-month total is approached or exceeded. The two-month lag time between the precipitation and predicted flooding can be used to prepare for emergency response measures, such as sandbagging the low-lying segment of 192nd Street East. The equation can also be used for zoning purposes to delineate areas that would be flooded under different precipitation scenarios. This information could also be useful in preventing future development in areas more susceptible to flooding.

Potential long-term solutions to the periodic winter/spring flooding of 192nd Street East include:

- Water handling to keep the groundwater level below the flood elevation (380 feet)
- Raising the elevation of 192nd Street East above the flood elevation

Water handling would involve collecting (via pumps or drains) water near 192nd Street East and conveying the water to a discharge location (either infiltration to the subsurface or discharge to an existing surface water body). A 3-dimensional groundwater flow model predicted that a pumping rate of approximately 300 gpm would be necessary to maintain a groundwater elevation of 380 feet along approximately 2,200 linear feet of 192nd Street East if the surrounding groundwater level reached 383 feet. These were conditions observed during the 1997 flood event. A series of pumps could be installed along 192nd Street East to maximize drawdown at the road while minimizing the amount of pumped water. It would be necessary to operate the pumps for the entire time that the surrounding water level exceeds 380 feet, which in previous flood events has ranged from days to months.

A conveyance system (open ditches or buried piping) would then be required to move the water from the flood area to a discharge location. The size of this conveyance system would depend on the volume of water to be moved and the distance from the flooded area to the discharge location. Possible discharge locations could include infiltration back into the ground at some other location or discharge into a surface water body. Infiltration back into the ground would require a location where a sufficient unsaturated interval remains between the surface and water table even under high-precipitation conditions. Discharge to surface water bodies could also occur, but could raise significant permitting requirements and require a demonstration that the discharged water would not cause downstream impacts. The design of a water collection, conveyance and discharge system capable of preventing flooding of 192nd Street East is beyond the scope of this report.

Another potential solution to the periodic flooding of 192nd Street East is to raise the elevation of the approximately 2,250 linear foot segment of low-lying (elevation 380 feet) road adjacent to the pond. A groundwater level of 383 feet is predicted for a 100-year recurrence of the 3-month precipitation total of 30.38 inches (using an average previous water year total). This would require the use of approximately 12,400 cy of fill material, assuming a 30-foot wide road and a 3:1 (horizontal to vertical) slope to the ditch.

Elevation of the roadway to 384 feet to provide an additional 1-foot margin of safety would require reconstruction of an additional 100 linear feet of roadway (2,350 feet total). The 384-foot surface elevation corresponds to a predicted 200-year recurrence of the 3-month precipitation total of 32.22 inches, following an average water year's precipitation. The 384-foot scenario would require the use of approximately 18,800 cy of fill material, also assuming a 30-foot wide road and a 3:1 (horizontal to vertical) slope to the ditch.

The findings and conclusions documented in this report have been prepared in a manner consistent with the level of care and skill normally exercised by members of the environmental science profession currently practicing under similar conditions in the area, and in accordance with the Exhibit and General Services Agreement executed between Pierce County and URS Corporation. No third party shall have the right to rely on URS opinions rendered in connection with the services or in this document without URS and Pierce County's written consent and the third party's agreement to be bound to the same conditions and limitations as Pierce County.

This report reflects our professional opinions, interpretations, recommendations, and observations of the study area conditions.

No warranty is expressly stated or implied in this report with regard to the surface or subsurface conditions of the soil or groundwater below the surface of the study area. Equations and groundwater elevation predictions were made using available water level data that is incomplete. As additional data are added, the equations and predictions should be adjusted to reflect the new data. These equations and groundwater elevation predictions were developed solely for use by Pierce County in evaluating potential solutions to periodic groundwater flooding. No other use by any other party of these equations or predicted groundwater elevations is intended.

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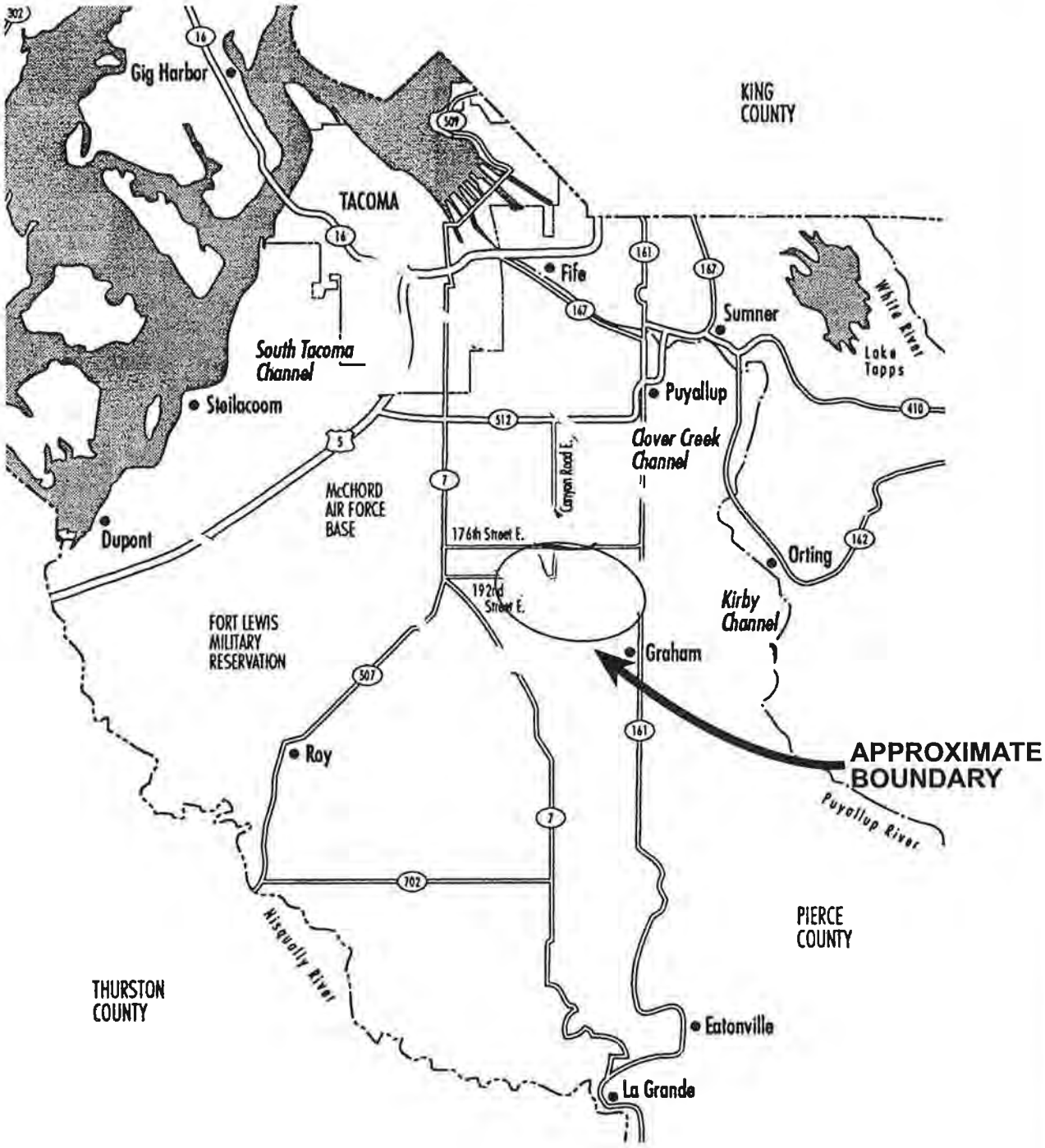
Table 1

ESTIMATED GROUNDWATER ELEVATIONS AT 192ND STREET EAST POND FOR A RANGE OF 3-MONTH AND WATER YEAR PRECIPITATION TOTALS

3-MONTH CUMULATIVE		PRECEDING WATER YEARS						
		RECURRENCE INTERVAL (Years)						
		2	AVERAGE	4	5	10	25	50
RECURRENCE INTERVAL (Years)		WATER YEAR PRECIPITATION (Inches)						
	PRECIPITATION (Inches)	41.13	42	46.21	47.76	51.37	55.33	57.93
2	18.36	375.1	377.2	378.3	378.4	378.7	379.0	379.1
5	21.87	376.8	378.9	380.0	380.2	380.4	380.7	380.9
10	**24.04**	377.9	380.0	381.1	381.2	381.5	381.8	381.9
25	26.65	379.2	381.3	382.4	382.5	382.8	383.0	383.2
50	28.53	380.1	382.2	383.3	383.4	383.7	384.0	384.2
100	30.38	381.0	383.1	384.3	384.4	384.6	384.9	385.1
200	32.22	381.9	384.0	385.2	385.3	385.5	385.8	386.0
500	34.66	383.1	385.2	386.4	386.5	386.7	387.0	387.2

Notes:
Groundwater elevation estimates are made using regression equation for well RMW-1 with 2-foot offset between well RMW-1 and pond elevation.
The groundwater elevation at which the water will cross 192nd Street East is estimated at 380 feet.
Combinations of preceding water year precipitation and 3-month cumulative precipitation predicted to result in flooding of 192nd Street East are shaded.
The groundwater elevation regression equation for well RMW-1 was determined using 1992/93 and early 1999 data.
The equation may change as additional data are collected.
This table was developed solely for use by Pierce County in evaluating flooding near 192nd Street East. No other use of these results by any other party is intended.



0 400

Approx. Scale in Miles

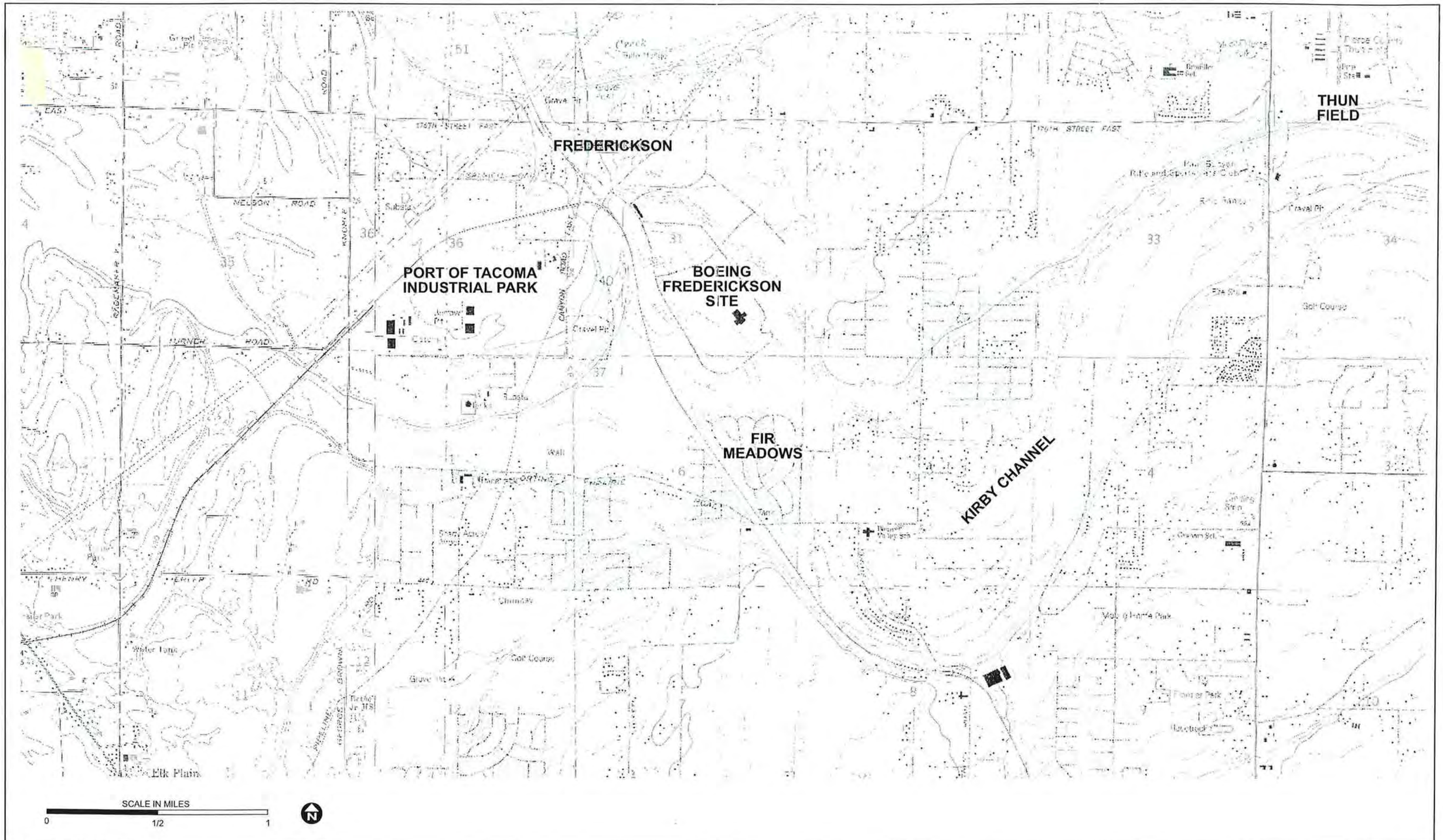
All roads

County boundary

Source: Brown and Caldwell, 1984

Frederickson Flooding Assessment	Project No. 54984009NA.04	Project Area Location	Figure 1
URS			

98/Fredickson 8/00

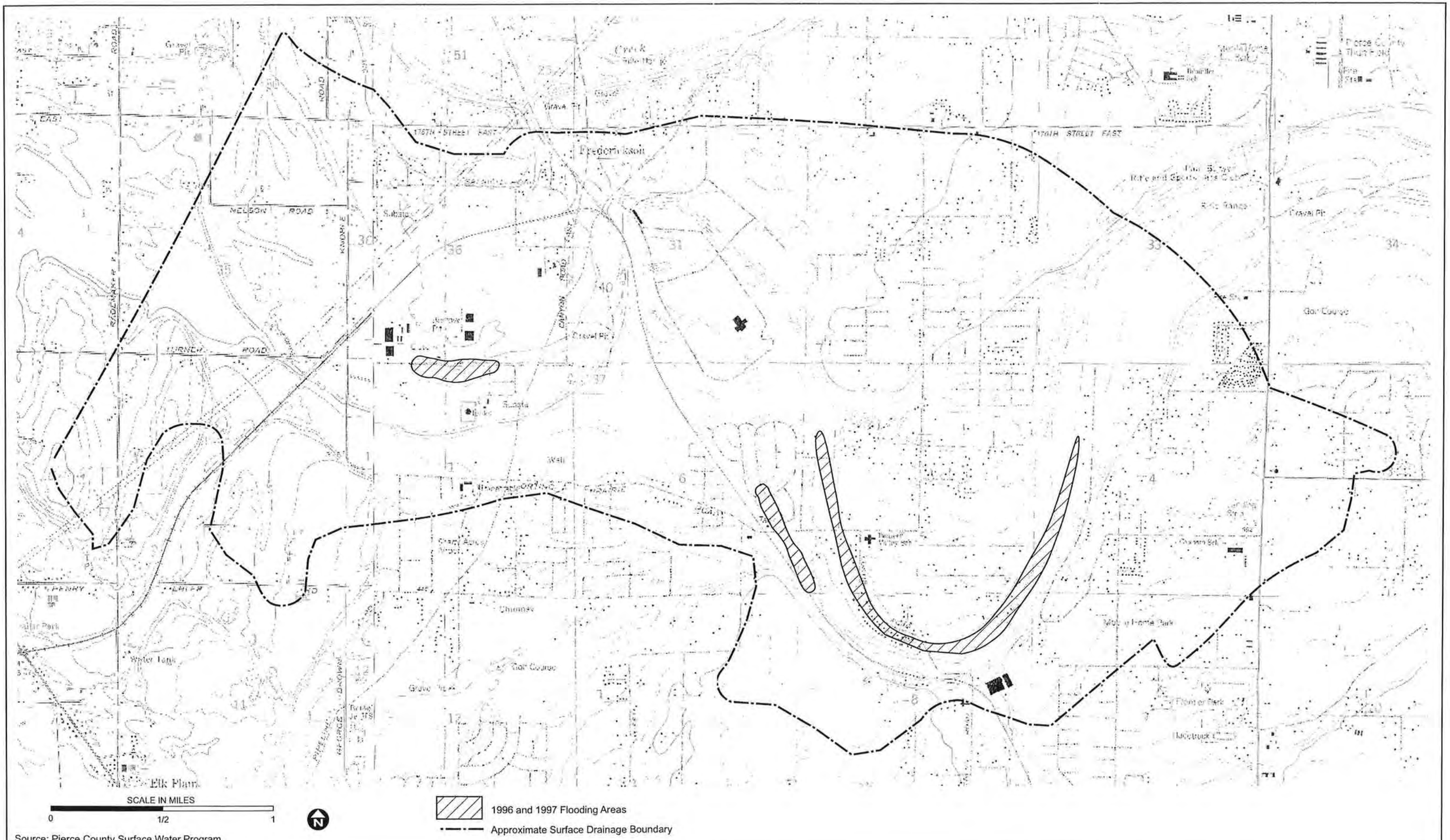


Fredrickson Flooding Assessment	Project No. 54984009NA.04
URS	

Study Area Vicinity

Figure 2

98/Frederickson 7/00



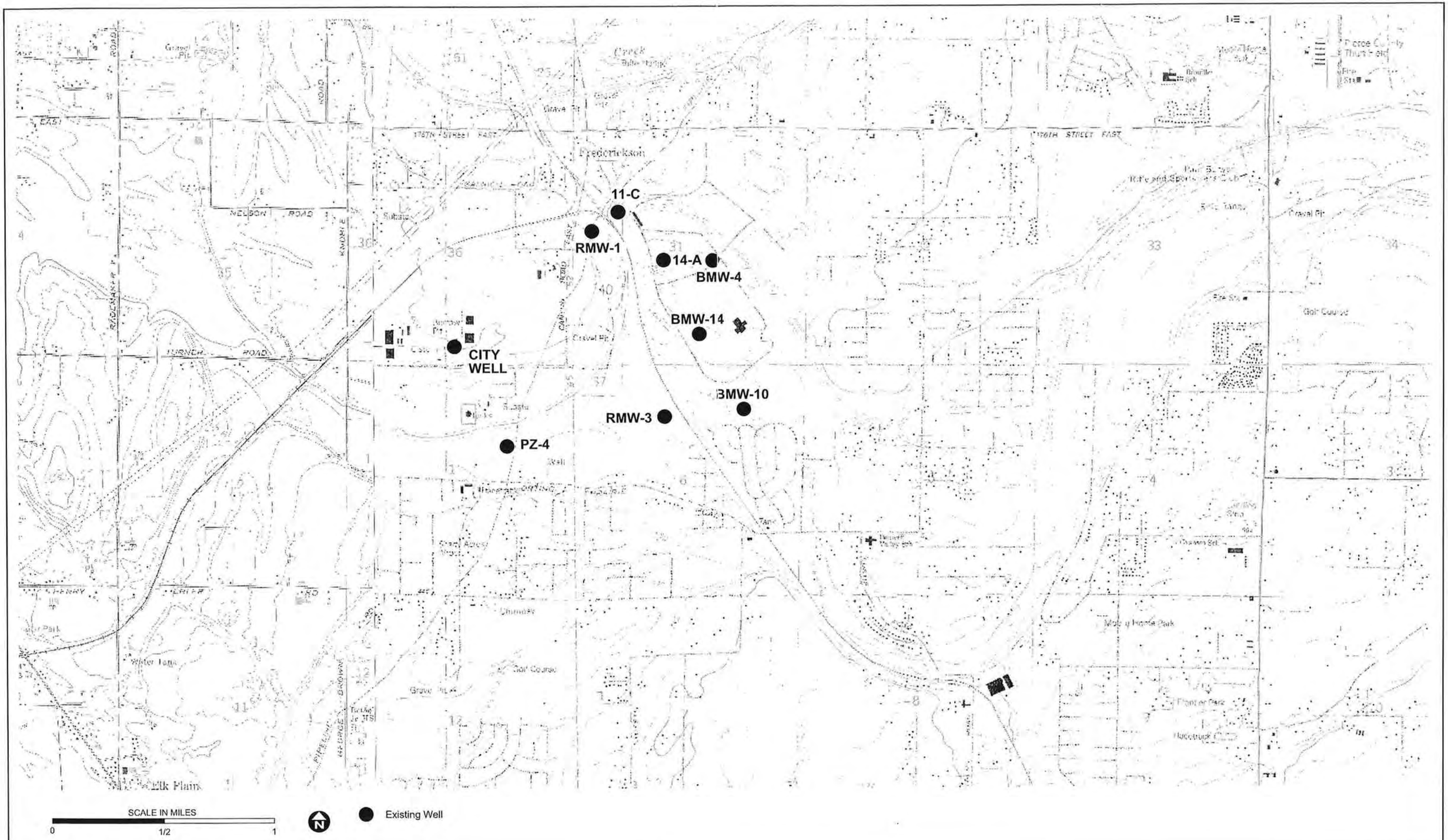
Source: Pierce County Surface Water Program

Fredrickson Flooding Assessment	Project No. 54099000NA.04
URS	

Approximate Surface Drainage Boundary and Recent Flood Areas

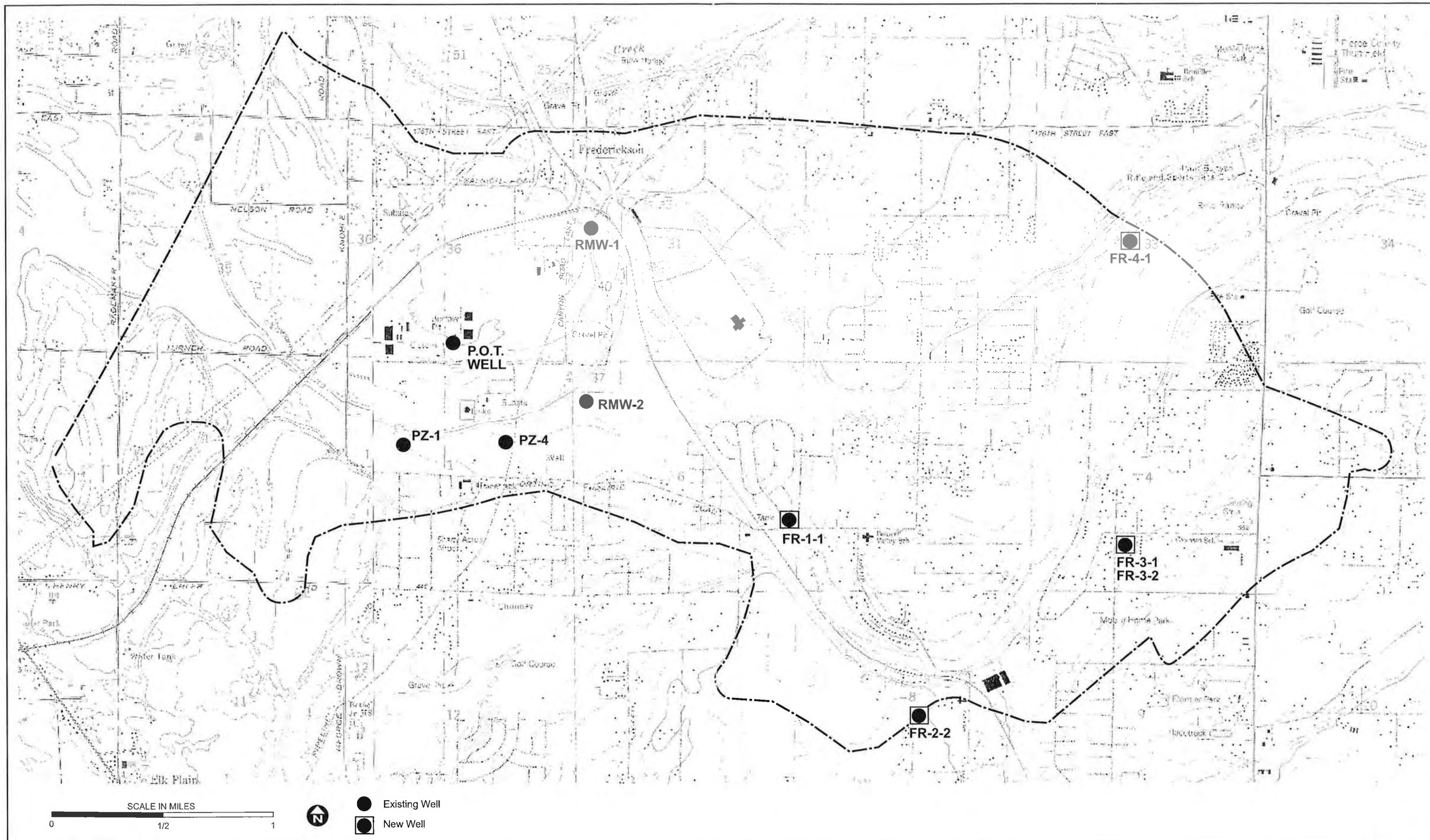
Figure 3

98/Frederickson 7/00



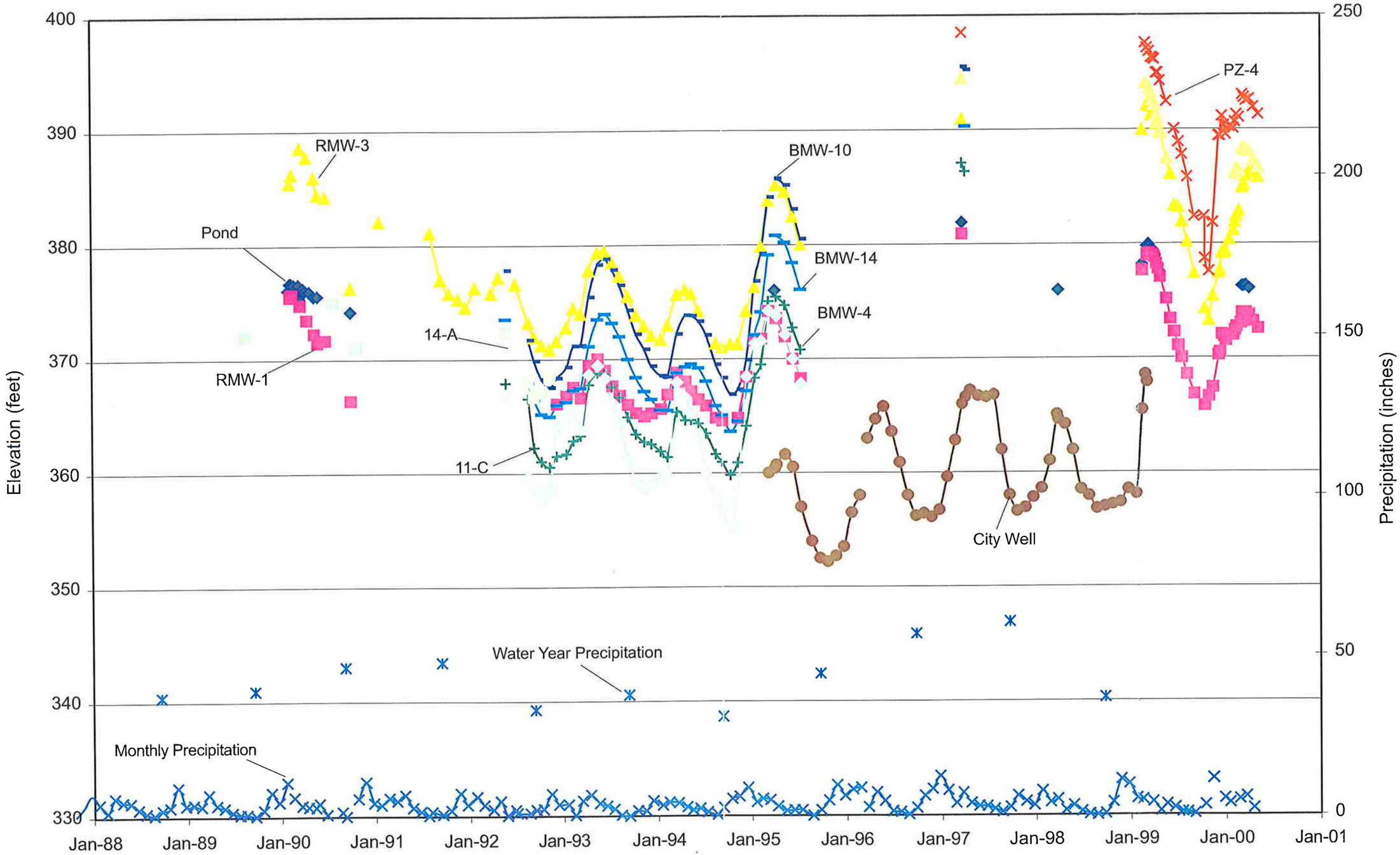
Fredrickson Flooding Assessment	Project No. 54984009NA.04	Historic Water Level Data Locations	Figure 4
URS			

98/Frederickson 7/00



Fredrickson Flooding Assessment	Project No. 54984009NA.04	New Monitoring Wells and Water Level Gauging Locations	Figure 5
URS			

98/Frederickson 7/00

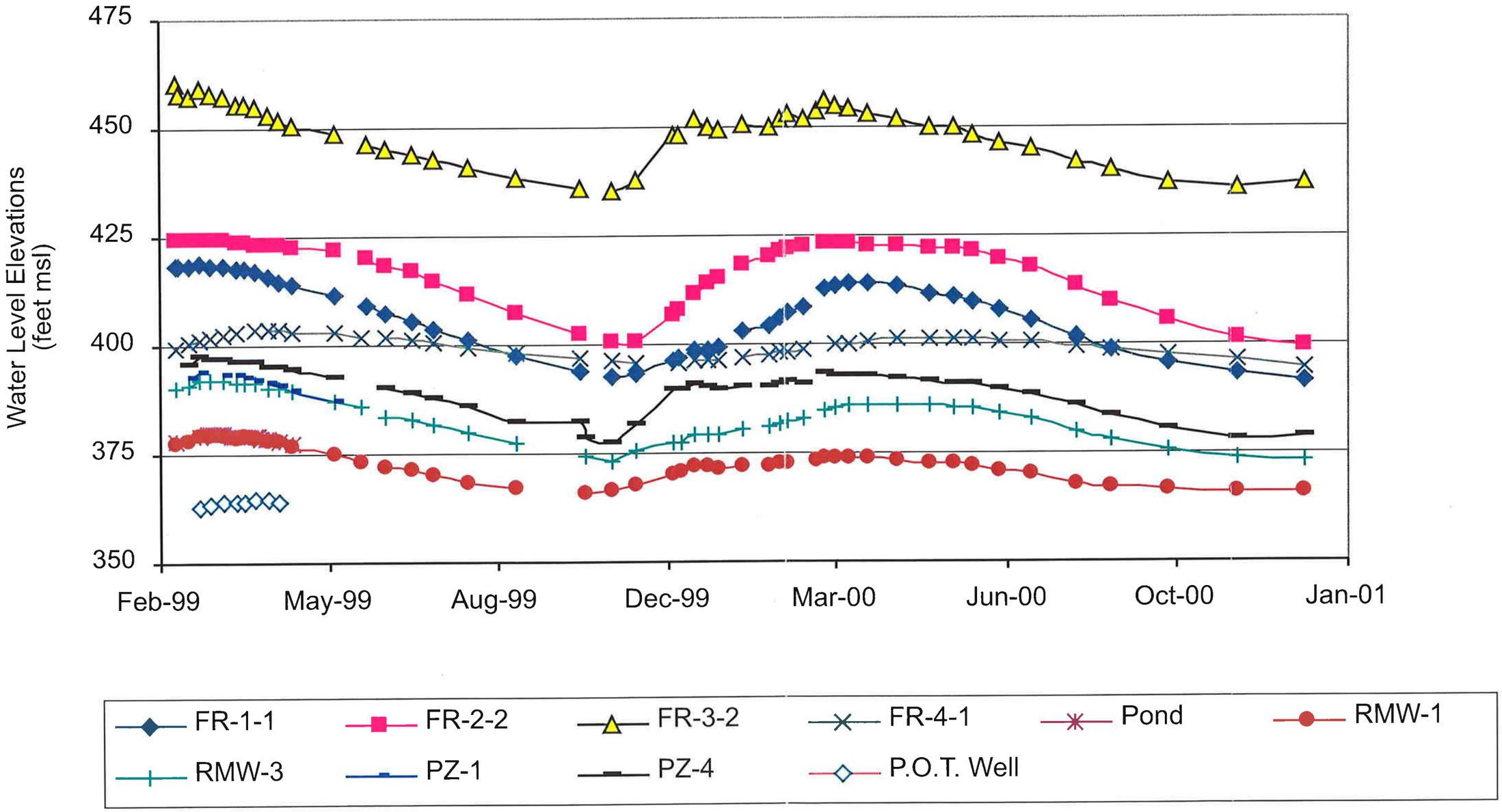


Fredrickson Flooding Assessment	Project No. 54984009NA.04
URS	

Historical Water Level Data

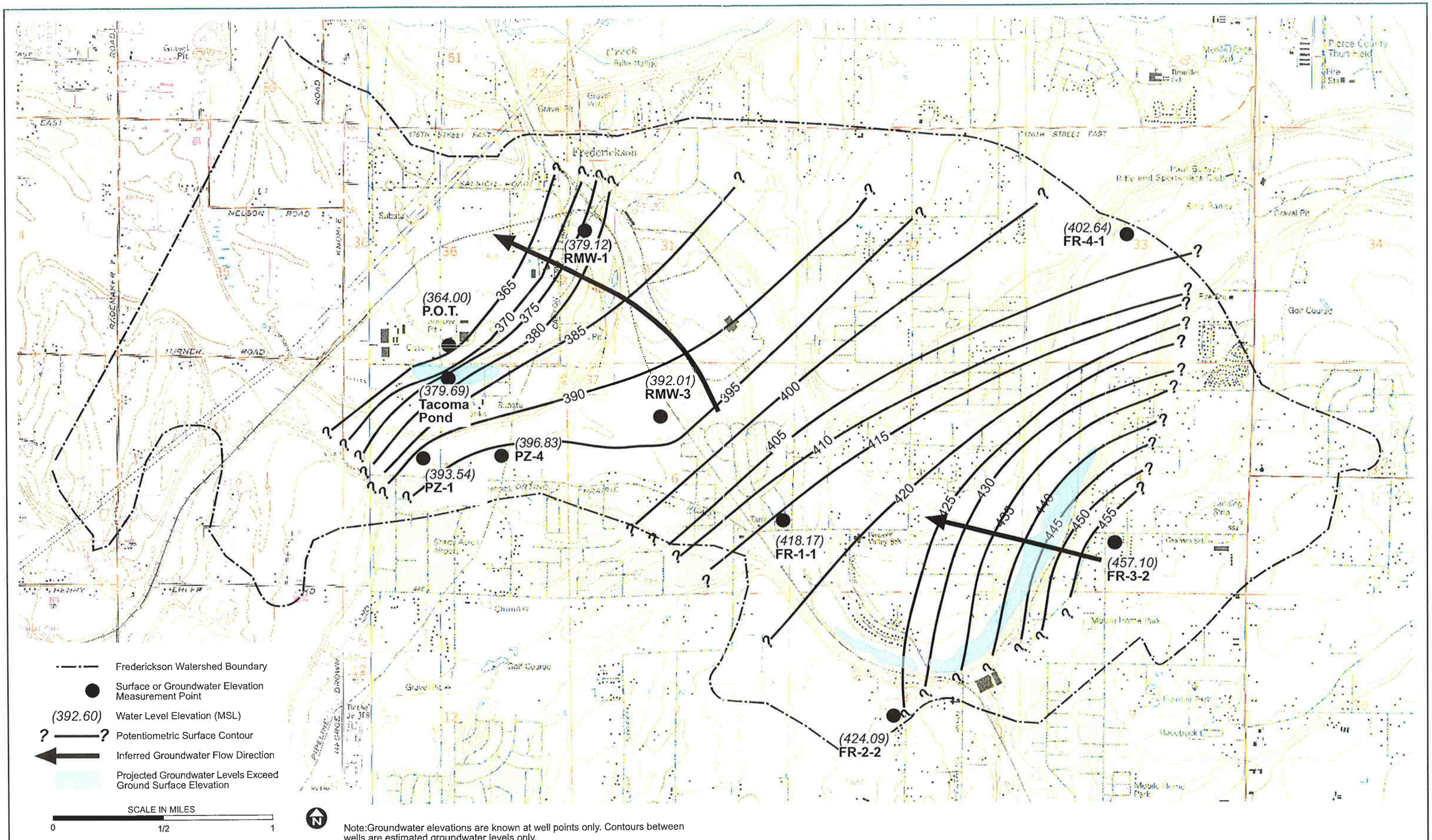
Figure 6

98/Frederickson 7/00



Fredrickson Flooding Assessment	Project No. 54984009NA.04	Water Level Gauging Program Results	Figure 7
URS			

98/Frederickson 7/00



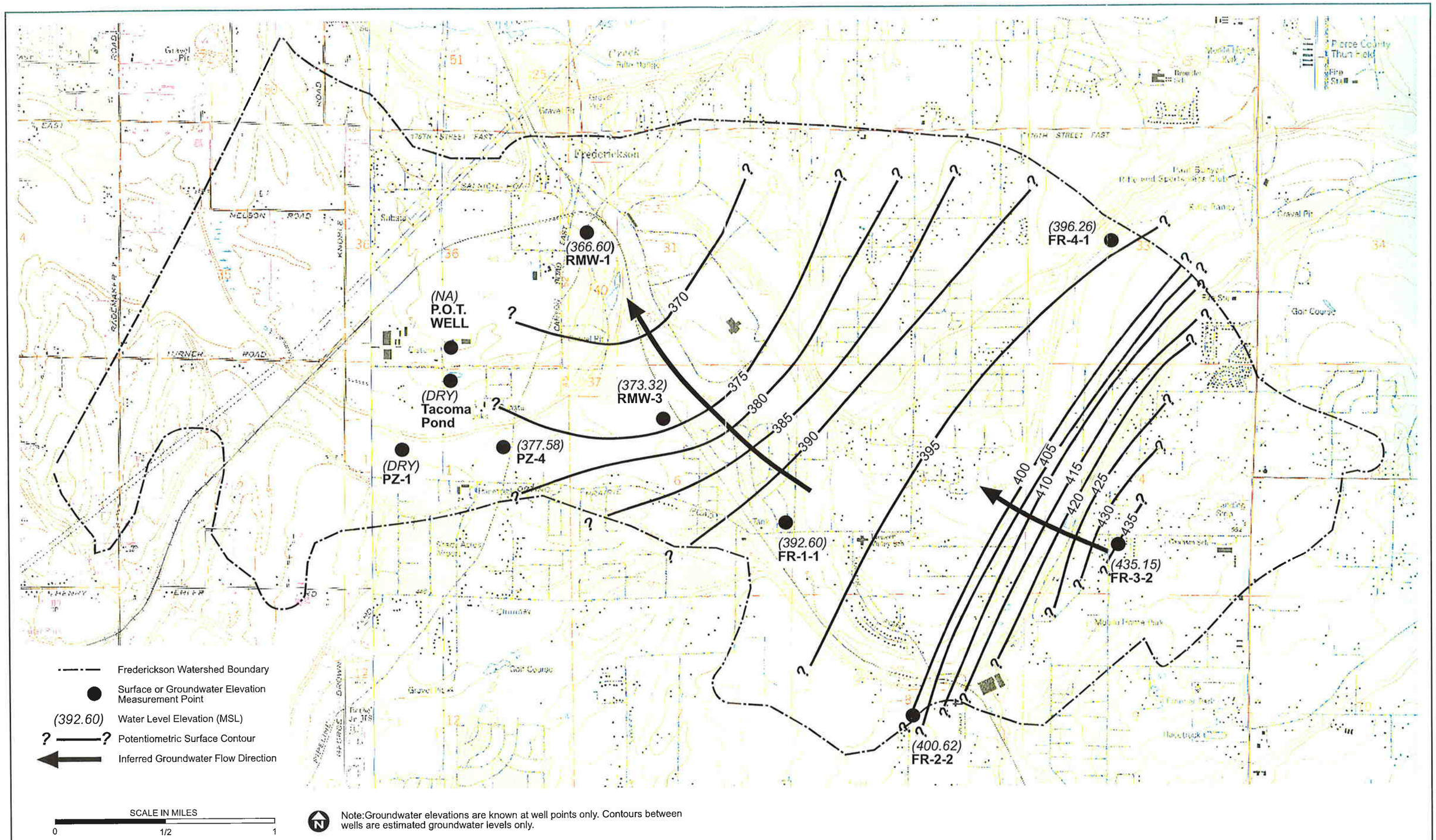
Note:Groundwater elevations are known at well points only. Contours between wells are estimated groundwater levels only.

Fredrickson Flooding Assessment	Project No. 54984009NA.04
URS	

Shallow Aquifer Potentiometric Surface Contour Map - March 19, 1999

Figure 8

98/Frederickson 7/00

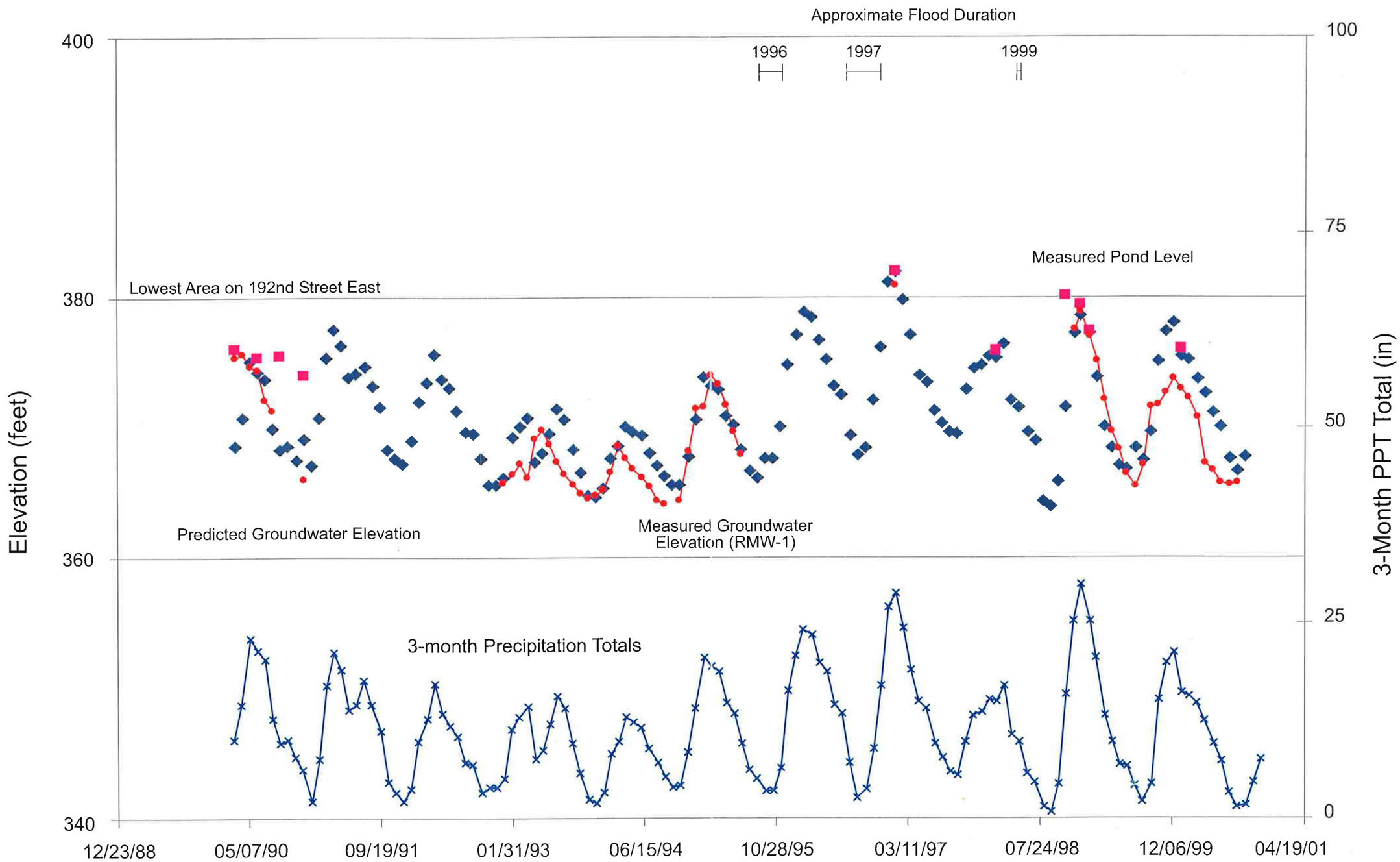


Fredrickson Flooding Assessment	Project No. 54984009NA.04
URS	

Shallow Aquifer Potentiometric Surface Contour Map - November 3, 1999

Figure 9

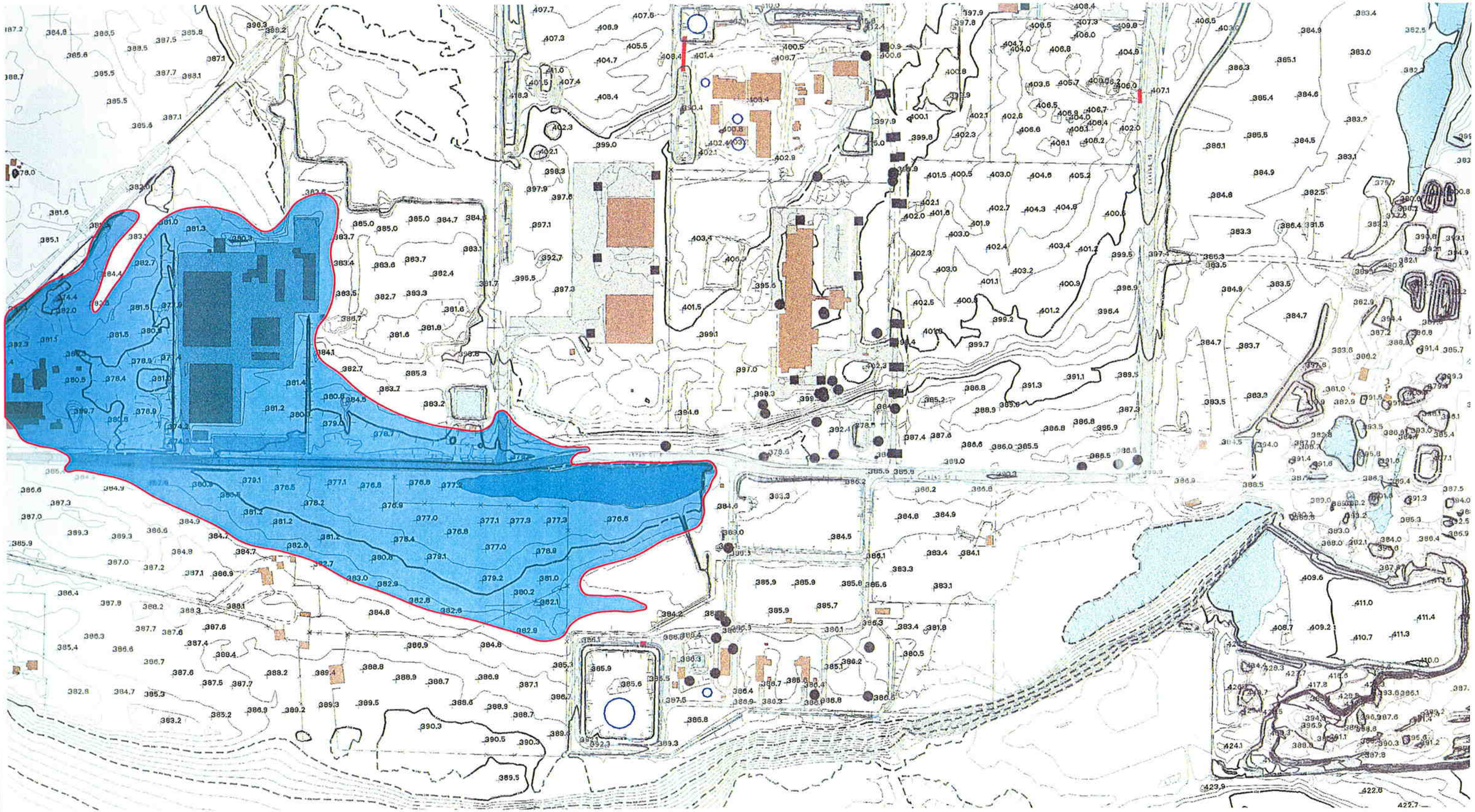
98/Frederickson 7/00



Fredrickson Flooding Assessment	Project No. 54984009NA.04	Predicted and Measured Groundwater Levels	Figure 10

URS

98/Frederickson 7/00



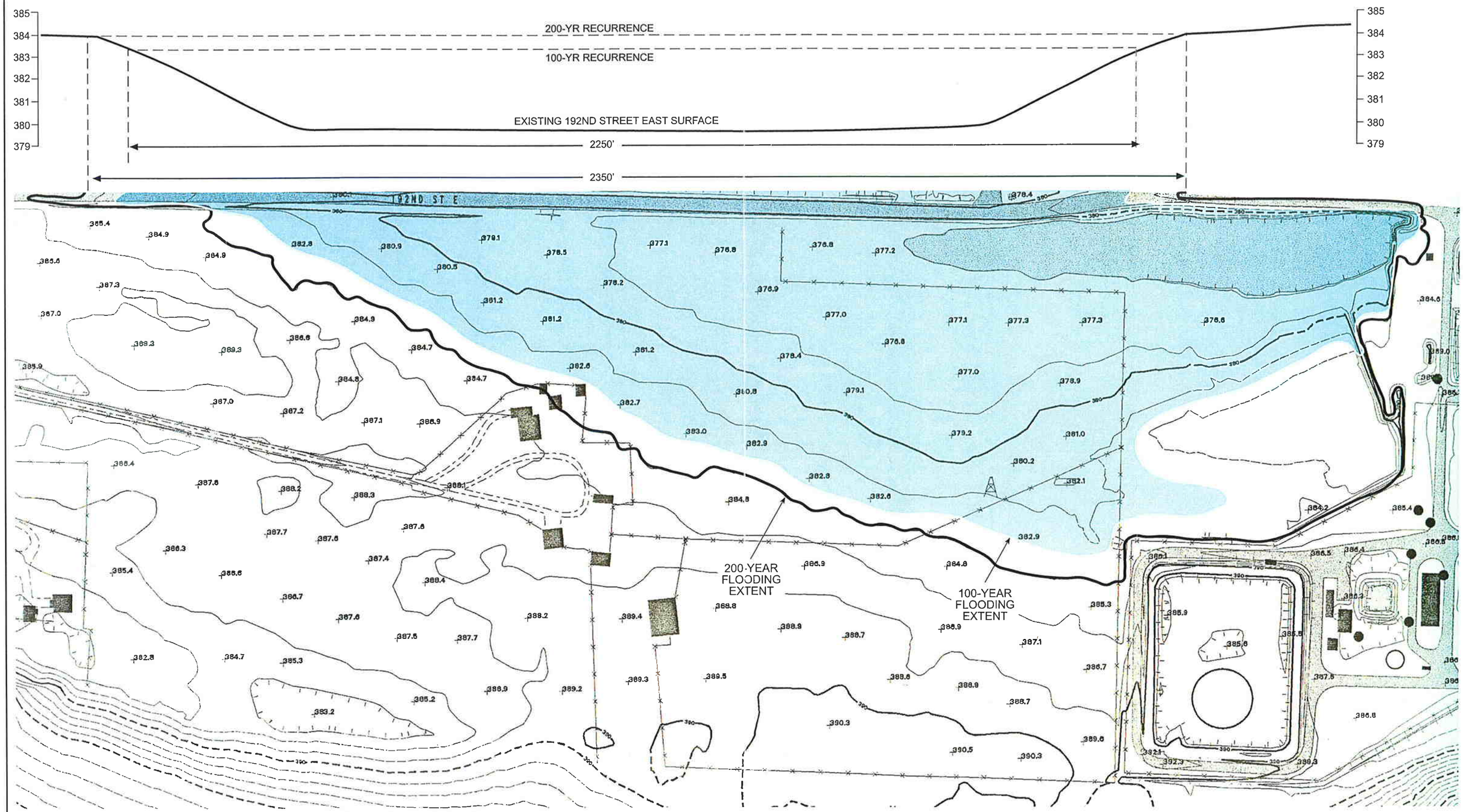
SCALE IN FEET
0 400

Note: Recurrence interval for 3-month cumulative precipitation following average water year

Fredrickson Flooding Assessment	Project No. 54984009NA.04	Extent of Groundwater-induced Flooding Predicted for 100-Year Recurrence Interval	Figure 11

URS

98/Frederickson 2/01



SCALE IN FEET
0 200

Note: Recurrence interval for 3-month cumulative precipitation following average water year.
Groundwater elevation predictions were made using available water level data that is incomplete. These groundwater elevation predictions were developed solely for use by Pierce County in evaluating potential solutions to periodic groundwater flooding. No other use by any other party of these equations or predicted groundwater elevations is intended.

Fredrickson Flooding Assessment	Project No. 54984009NA.04	Options for Raising the Surface Elevation of 192nd Street East	Figure 12
URS			

98/Frederickson 2/01

Appendix A

Precipitation Data for The Study Area

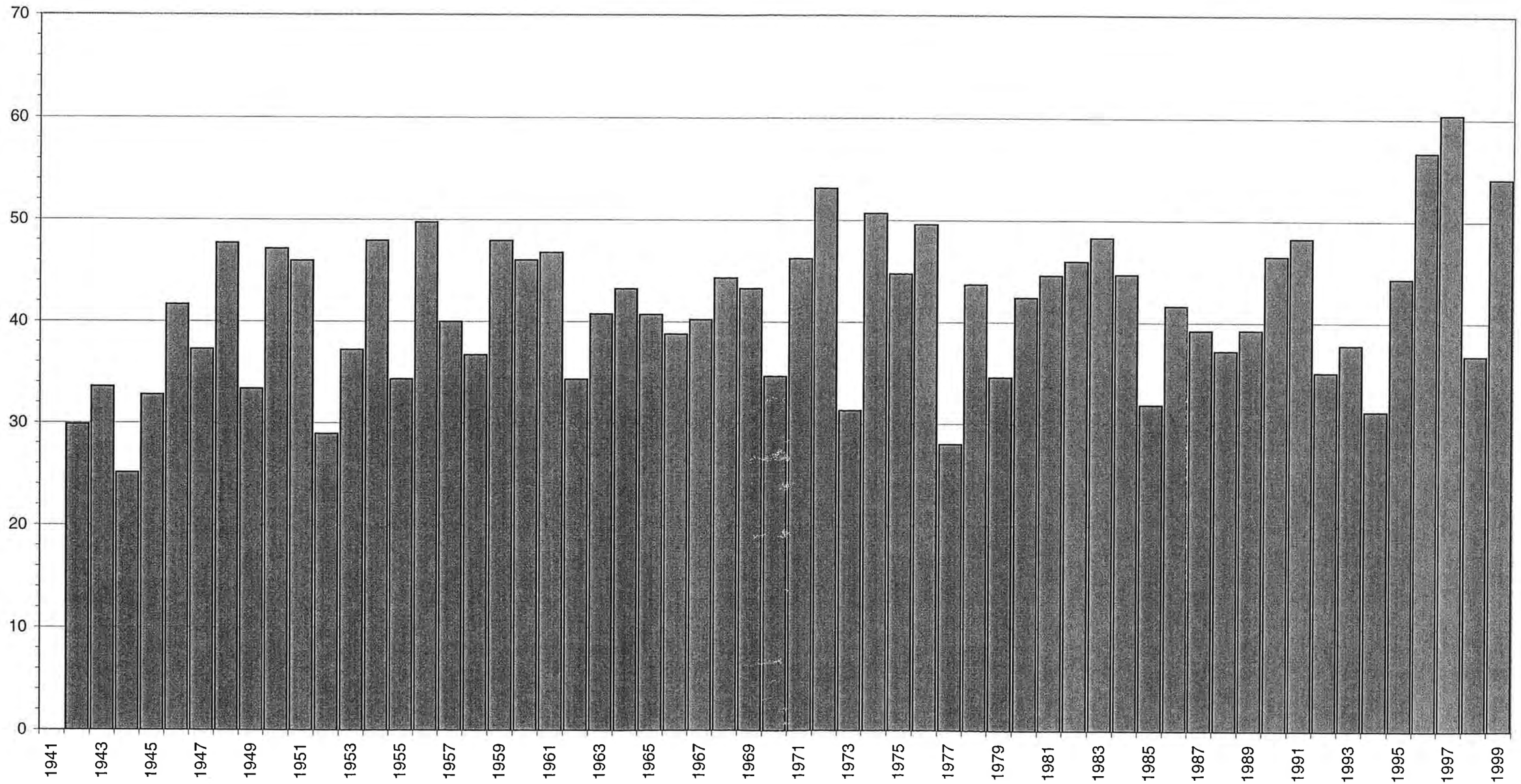
Monthly Precipitation for McMillin Reservoir, Pierce County, Washington (Meteorological Station No. 455224)

Calendar Year	Precipitation (hundredths of an inch)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1941	?	?	179	207	387	145	0	245	288	267	404	719	?
1942	268	229	186	157	292	304	136	21	3	263	864	406	3129
1943	185	218	398	388	176	215	27	109	108	424	208	265	2721
1944	386	319	129	240	188	85	10	29	228	138	375	135	2262
1945	459	491	380	367	414	14	37	76	391	298	543	524	3994
1946	568	530	441	150	66	512	230	9	297	367	587	705	4462
1947	504	298	309	301	29	391	124	26	86	837	377	439	3721
1948	430	515	367	374	380	222	265	187	378	289	610	638	4655
1949	89	651	310	218	161	87	50	73	161	395	720	618	3533
1950	718	582	708	317	116	167	79	122	173	709	767	772	5230
1951	581	848	378	44	174	10	5	68	242	524	430	377	3681
1952	309	332	304	273	161	101	42	29	11	103	124	418	2207
1953	1297	311	295	291	326	241	32	147	136	416	694	711	4897
1954	859	413	243	345	189	324	132	241	227	275	524	442	4214
1955	228	323	392	469	159	140	250	15	216	702	816	1037	4747
1956	758	269	575	61	110	317	52	108	170	594	281	608	3903
1957	232	532	629	186	214	244	100	194	185	338	335	599	3788
1958	690	550	151	439	170	169	2	42	188	374	939	666	4380
1959	755	269	320	320	235	316	53	73	475	394	788	514	4512
1960	513	444	402	395	476	133	0	434	111	413	1149	311	4781
1961	605	949	386	304	301	108	51	54	47	349	400	530	4084
1962	238	238	407	313	310	98	33	272	244	328	897	527	3905
1963	176	519	405	432	161	165	184	203	79	482	761	443	4010
1964	1023	180	325	208	164	352	155	130	100	243	791	768	4439
1965	669	400	59	451	176	44	132	283	56	345	452	610	3677
1966	522	248	525	262	161	320	179	26	229	339	536	705	4052
1967	951	291	471	297	84	231	10	0	108	710	285	289	3727
1968	510	617	477	134	234	393	60	521	202	514	554	677	4893
1969	681	227	235	393	276	194	35	46	496	230	309	615	3737
1970	891	292	225	389	181	41	50	24	218	319	439	780	3849
1971	734	339	621	275	206	313	106	43	448	315	553	600	4553
1972	823	799	658	461	104	281	151	139	432	86	347	818	5099
1973	365	223	263	177	230	335	7	27	252	416	851	824	3970
1974	708	474	554	452	318	214	214	11	34	175	782	738	4674
1975	834	606	336	178	192	117	51	465	1	701	559	918	4958
1976	575	464	326	307	238	135	142	429	167	135	150	274	3342
1977	135	160	445	132	407	165	18	382	397	291	568	732	3832
1978	516	272	271	409	265	119	163	209	556	48	621	304	3753
1979	262	668	232	305	166	67	188	205	391	422	222	881	4009
1980	566	590	373	428	140	257	59	98	207	96	812	885	4511
1981	263	654	284	391	224	398	97	46	311	522	459	711	4360
1982	591	877	353	363	81	149	181	96	216	437	455	636	4435
1983	750	440	561	144	194	333	386	248	246	212	883	479	4876
1984	568	419	494	299	477	477	1	41	120	315	832	542	4585
1985	47	223	320	206	167	235	3	122	178	685	437	160	2783
1986	850	472	340	232	340	103	203	32	308	289	985	318	4472
1987	462	395	555	362	333	54	54	44	71	35	316	686	3367
1988	408	149	598	467	435	240	118	60	209	298	917	351	4250
1989	374	330	695	357	281	140	69	82	29	215	752	451	3775
1990	1065	601	342	304	290	404	70	152	4	588	1074	426	5320
1991	361	575	486	666	271	155	28	138	59	187	717	357	4000
1992	609	352	210	468	22	194	103	92	198	222	691	363	3524
1993	357	33	477	660	400	323	220	31	0	174	163	475	3313
1994	335	459	409	284	186	232	119	42	247	536	604	880	4333
1995	421	535	492	288	156	173	176	0	172	471	951	617	4452
1996	816	873	257	723	457	134	108	30	234	607	826	1223	6288
1997	782	383	706	380	291	282	196	113	251	613	427	310	4734
1998	760	405	501	153	308	118	29	5	46	398	1116	969	4808
1999	863	653	506	128	326	228	97	88	44	310	1133	514	4890
2000	433	630	467	345									

Notes:

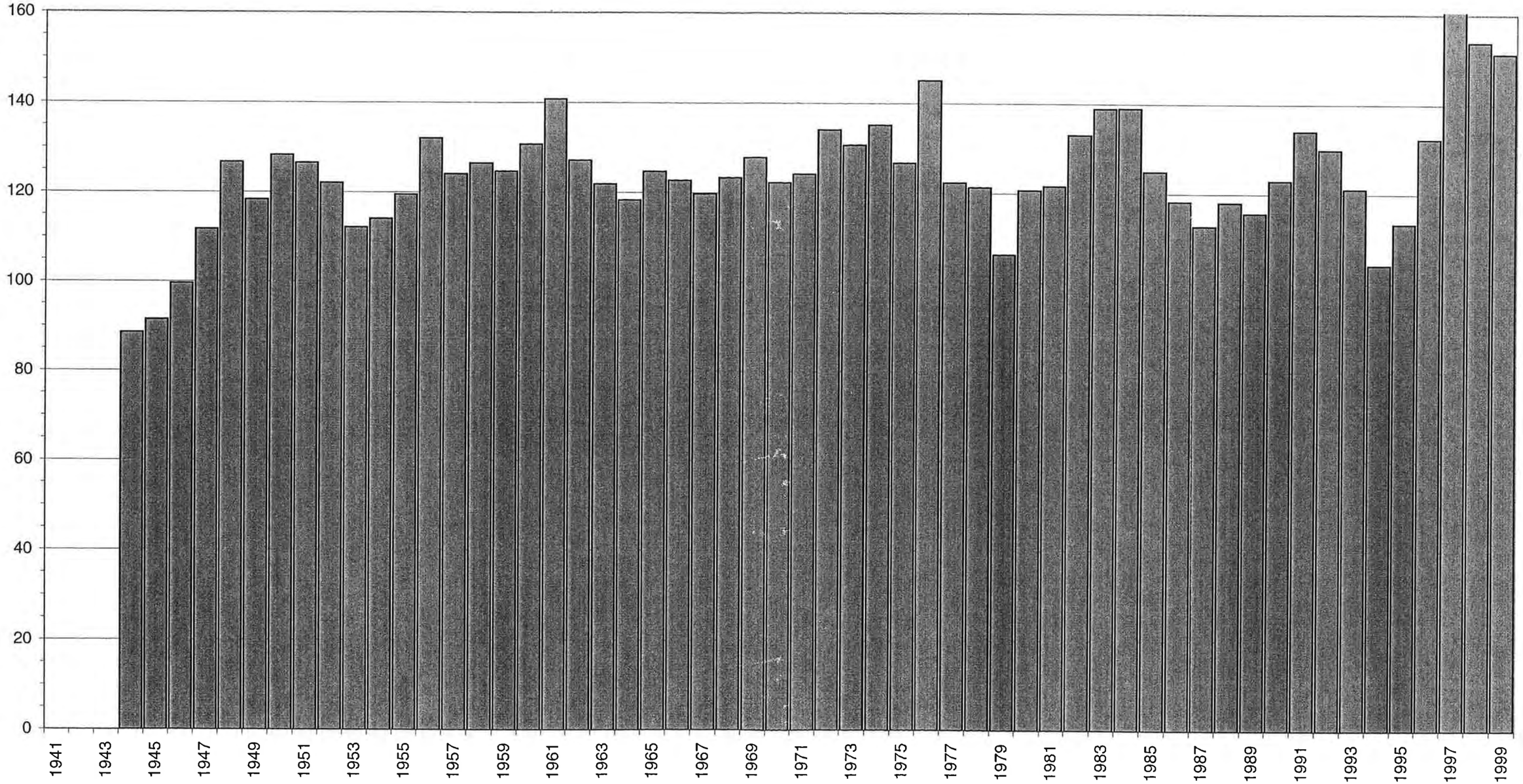
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Water Year Total (1 Oct - 30 Sept)	2-yr Sum	3-yr Sum	J	F	M	A	M	J	J	A	S	O	N	D	No. of (3-mo precip>24")	Max 3-mo precip per water year	Max monthly precip per water year
	Precipitation (inch)															3-mo Sum														
1941	0.00	0.00	1.79	2.07	3.87	1.45	0.00	2.45	2.88	2.67	4.04	7.19								7.73	7.39	5.32	3.90	5.33	8.00	9.59	13.90	0		
1942	2.68	2.29	1.86	1.57	2.92	3.04	1.36	0.21	0.03	2.63	8.64	4.06	29.86			13.91	12.16	6.83	5.72	6.35	7.53	7.32	4.61	1.60	2.87	11.30	15.33	0	13.91	7.19
1943	1.85	2.18	3.98	3.88	1.76	2.15	0.27	1.09	1.08	4.24	2.08	2.65	33.57	63.43		14.55	8.09	8.01	10.04	9.62	7.79	4.18	3.51	2.44	6.41	7.40	8.97	0	15.33	8.64
1944	3.86	3.19	1.29	2.40	1.88	0.85	0.10	0.29	2.28	1.38	3.75	1.35	25.11	58.68	88.54	8.59	9.70	8.34	6.88	5.57	5.13	2.83	1.24	2.67	3.95	7.41	6.48	0	9.70	4.24
1945	4.59	4.91	3.80	3.67	4.14	0.14	0.37	0.76	3.91	2.98	5.43	5.24	32.77	57.88	91.45	9.69	10.85	13.30	12.38	11.61	7.95	4.65	1.27	5.04	7.65	12.32	13.65	0	13.30	4.91
1946	5.68	5.30	4.41	1.50	0.66	5.12	2.30	0.09	2.97	3.67	5.87	7.05	41.68	74.45	99.56	16.35	16.22	15.39	11.21	6.57	7.28	8.08	7.51	5.36	6.73	12.51	16.59	0	16.35	5.68
1947	5.04	2.98	3.09	3.01	0.29	3.91	1.24	0.26	0.86	8.37	3.77	4.39	37.27	78.95	111.72	17.96	15.07	11.11	9.08	6.39	7.21	5.44	5.41	2.36	9.49	13.00	16.53	0	17.96	7.05
1948	4.30	5.15	3.67	3.74	3.80	2.22	2.65	1.87	3.78	2.89	6.10	6.38	47.71	84.98	126.66	12.46	13.84	13.12	12.56	11.21	9.76	8.67	6.74	8.30	8.54	12.77	15.37	0	16.53	8.37
1949	0.89	6.51	3.10	2.18	1.61	0.87	0.50	0.73	1.61	3.95	7.20	6.18	33.37	81.08	118.35	13.37	13.78	10.50	11.79	6.89	4.66	2.98	2.10	2.84	6.29	12.76	17.33	0	15.37	6.51
1950	7.18	5.82	7.08	3.17	1.16	1.67	0.79	1.22	1.73	7.09	7.67	7.72	47.15	80.52	128.23	20.56	19.18	20.08	16.07	11.41	6.00	3.62	3.68	3.74	10.04	16.49	22.48	0	20.56	7.20
1951	5.81	8.48	3.78	0.44	1.74	0.10	0.05	0.68	2.42	5.24	4.30	3.77	45.98	93.13	126.50	21.20	22.01	18.07	12.70	5.96	2.28	1.89	0.83	3.15	8.34	11.96	13.31	0	22.48	8.48
1952	3.09	3.32	3.04	2.73	1.61	1.01	0.42	0.29	0.11	1.03	1.24	4.18	28.93	74.91	122.06	11.16	10.18	9.45	9.09	7.38	5.35	3.04	1.72	0.82	1.43	2.38	6.45	0	13.31	5.24
1953	12.97	3.11	2.95	2.91	3.26	2.41	0.32	1.47	1.36	4.16	6.94	7.11	37.21	66.14	112.12	18.39	20.26	19.03	8.97	9.12	8.58	5.99	4.20	3.15	6.99	12.46	18.21	0	20.26	12.97
1954	8.59	4.13	2.43	3.45	1.89	3.24	1.32	2.41	2.27	2.75	5.24	4.42	47.94	85.15	114.08	22.64	19.83	15.15	10.01	7.77	8.58	6.45	6.97	6.00	7.43	10.26	12.41	0	22.64	8.59
1955	2.28	3.23	3.92	4.69	1.59	1.40	2.50	0.15	2.16	7.02	8.16	10.37	34.33	82.27	119.48	11.94	9.93	9.43	11.84	10.20	7.68	5.49	4.05	4.81	9.33	17.34	25.55	1	12.41	5.24
1956	7.58	2.69	5.75	0.61	1.10	3.17	0.52	1.08	1.70	5.94	2.81	6.08	49.75	84.08	132.02	26.11	20.64	16.02	9.05	7.46	4.88	4.79	4.77	3.30	8.72	10.45	14.83	1	26.11	10.37
1957	2.32	5.32	6.29	1.86	2.14	2.44	1.00	1.94	1.85	3.38	3.35	5.99	39.99	89.74	124.07	11.21	13.72	13.93	13.47	10.29	6.44	5.58	5.38	4.79	7.17	8.58	12.72	0	14.83	6.29
1958	6.90	5.50	1.51	4.39	1.70	1.69	0.02	0.42	1.88	3.74	9.39	6.66	36.73	76.72	126.47	16.24	18.39	13.91	11.40	7.60	7.78	3.41	2.13	2.32	6.04	15.01	19.79	0	18.39	6.90
1959	7.55	2.69	3.20	3.20	2.35	3.16	0.53	0.73	4.75	3.94	7.88	5.14	47.95	84.68	124.67	23.60	16.90	13.44	9.09	8.75	8.71	6.04	4.42	6.01	9.42	16.57	16.96	0	23.60	9.39
1960	5.13	4.44	4.02	3.95	4.76	1.33	0.00	4.34	1.11	4.13	11.49	3.11	46.04	93.99	130.72	18.15	14.71	13.59	12.41	12.73	10.04	6.09	5.67	5.45	9.58	16.73	18.73	0	18.15	7.88
1961	6.05	9.49	3.86	3.04	3.01	1.08	0.51	0.54	0.47	3.49	4.00	5.30	46.78	92.82	140.77	20.65	18.65	19.40	16.39	9.91	7.13	4.60	2.13	1.52	4.50	7.96	12.79	0	20.65	11.49
1962	2.38	2.38	4.07	3.13	3.10	0.98	0.33	2.72	2.44	3.28	8.97	5.27	34.32	81.10	127.14	11.68	10.06	8.83	9.58	10.30	7.21	4.41	4.03	5.49	8.44	14.69	17.52	0	12.79	5.30
1963	1.76	5.19	4.05	4.32	1.61	1.65	1.84	2.03	0.79	4.82	7.61	4.43	40.76	75.08	121.86	16.00	12.22	11.00	13.56	9.98	7.58	5.10	5.52	4.66	7.64	13.22	16.86	0	17.52	8.97
1964	10.23	1.80	3.25	2.08	1.64	3.52	1.55	1.30	1.00	2.43	7.91	7.68	43.23	83.99	118.31	22.27	16.46	15.28	7.13	6.97	7.24	6.71	6.37	3.85	4.73	11.34	18.02	0	22.27	10.23
1965	6.69	4.00	0.59	4.51	1.76	0.44	1.32	2.83	0.56	3.45	4.52	6.10	40.72	83.95	124.71	22.28	18.37	11.28	9.10	6.86	6.71	3.52	4.59	4.71	6.84	8.53	14.07	0	22.28	7.91
1966	5.22	2.48	5.25	2.62	1.61	3.20	1.79	0.26	2.29	3.39	5.36	7.05	38.79	79.51	122.74	15.84	13.80	12.95	10.35	9.48	7.43	6.60	5.25	4.34	5.94	11.04	15.80	0	15.84	6.10
1967	9.51	2.91	4.71	2.97	0.84	2.31	0.10	0.00	1.08	7.10	2.85	2.89	40.23	79.02	119.74	21.92	19.47	17.13	10.59	8.52	6.12	3.25	2.41	1.18	8.18	11.03	12.84	0	21.92	9.51
1968	5.10	6.17	4.77	1.34	2.34	3.93	0.60	5.21	2.02	5.14	5.54	6.77	44.32	84.55	123.34	10.84	14.16	16.04	12.28	8.45	7.61	6.87	9.74	7.83	12.37	12.70	17.45	0	16.04	7.10
1969	6.81	2.27	2.35	3.93	2.76	1.94	0.35	0.46	4.96	2.30	3.09	6.15	43.28	87.60	127.83	19.12	15.85	11.43	8.55	9.04	8.63	5.05	2.75	5.77	7.72	10.35	11.54	0	19.12	6.81
1970	8.91	2.92	2.25	3.89	1.81	0.41	0.50	0.24	2.18	3.19	4.39	7.80	34.65	77.93	122.25	18.15	17.98	14.08	9.06	7.95	6.11	2.72	1.15	2.92	5.61	9.76	15.38	0	18.15	8.91
1971	7.34	3.39	6.21	2.75	2.06	3.13	1.06	0.43	4.48	3.15	5.53	6.00	46.23	80.88	124.16	19.53	18.53	16.94	12.35	11.02	7.94	6.25	4.62	5.97	8.06	13.16	14.68	0	19.53	7.80
1972	8.23	7.99	6.58	4.61	1.04	2.81	1.51	1.39	4.32	0.86	3.47	8.18	53.16	99.39	134.04	19.76	22.22	22.80	19.18	12.23	8.46	5.36	5.71	7.22	6.57	8.65	12.51	0	22.80	8.23
1973	3.65	2.23	2.63	1.77	2.30	3.35	0.07	0.27	2.52	4.16	8.51	8.24	31.3	84.46	130.69	15.30	14.06	8.51	6.63	6.70	7.42	5.72	3.69	2.86	6.95	15.19	20.91	0	15.30	8.18
1974	7.08	4.74	5.54	4.52	3.18	2.14	2.14	0.11	0.34	1.75	7.82	7.38	50.7	82.00	135.16	23.83	20.06	17.36	14.80	13.24	9.84	7.46	4.39	2.59	2.20	9.91	16.95	0	23.83	8.51
1975	8.34	6.06	3.36	1.78	1.92	1.17	0.51	4.65	0.01	7.01	5.59	9.18	44.75	95.45	126.75	23.54	21.78	17.76	11.20	7.06	4.87	3.60	6.33	5.17	11.67	12.61	21.78	0	23.54	8.34
1976	5.75	4.64	3.26	3.07	2.38	1.35	1.42	4.29	1.67	1.35	1.50	2.74	49.61	94.36	145.06	20.52	19.57	13.65	10.97	8.71	6.80	5.15	7.06	7.38	7.31	4.52	5.59	0	21.78	9.18
1977	1.35	1.60	4.45	1.32	4.07	1.65	0.18	3.82	3.97	2.91	5.68	7.32	28	77.61	122.36	5.59	5.69	7.40	7.37	9.84	7.04	5.90	5.65	7.97	10.70	12.56	15.91	0	9.84	4.45
1978	5.16	2.72	2.71	4.09	2.65	1.19	1.63	2.09	5.56	0.48	6.21	3.04	43.71	71.71	121.32	18.16	15.20	10.59	9.52	9.45	7.93	5.47	4.91	9.28	8.13	12.25	9.73	0	18.16	7.32
1979	2.62	6.68	2.32	3.05	1.66	0.67	1.88	2.05	3.91	4.22	2.22	8.81	34.57	78.28	106.28	11.87	12.34	11.62	12.05	7.03	5.38	4.21	4.60	7.84	10.18	10.35	15.25	0	12.34	6.68
1980	5.66	5.90	3.73	4.28	1.40	2.57	0.59	0.98	2.07	0.96	8.12	8.85	42.43	77.00	120.71	16.69	20.37	15.29	13.91	9.41	8.25	4.56	4.14	3.64	4.01	11.15	17.93	0	20.37	8.81
1981	2.63	6.54	2.84	3.91	2.24	3.98	0.97	0.46	3.11	5.22	4.59	7.11	44.61	87.04	121.61	19.60	18.02	12.01	13.29	8.99	10.13	7.19	5.41	4.54	8.79	12.92	16.92	0	19.60	8.85
1982	5.91	8.77	3.53	3.63	0.81	1.49	1.81	0.96	2.16	4.37	4.55	6.36	45.99	90.60	133.03	17.61	21.79	18.21	15.93	7.97	5.93	4.11	4.26	4.93	7.49	11.08	15.28	0	21.79	8.77
1983	7.50	4.40	5.61	1.44	1.94	3.33	3.86	2.48	2.46	2.12	8.83	4.79	48.3	94.29	138.90	18.41	18.26	17.51	11.45	8.99	6.71	9.13	9.67	8.80	7.06	13.41	15.74	0	18.41	7.50
1984	5.68	4.19	4.94	2.99	4.77	4.77	0.01	0.41	1.20	3.15	8.32	5.42	44.7	93.00	138.99	19.30	14.66	14.81	12.12	12.70	12.53	9.55	5.19	1.62	4.76	12.67	16.89	0	19.30	8.83
1985	0.47	2.23	3.20	2.06	1.67	2.35	0.03	1.22	1.78	6.85	4.37	1.60	31.9	76.60	124.90	14.21	8.12	5.90	7.49	6.93	6.08	4.05	3.60	3.03	9.85	13.00	12.82	0	16.89	8.32
1986	8.50	4.72	3.40	2.32	3.40	1.03	2.03	0.32	3.08	2.89	9.85	3.18	41.62	73.52	118.22	14.47	14.82	16.62	10.44	9.12	6.75	6.46	3.38	5.43	6.29	15.82	15.92	0	16.62	8.50
1987	4.62	3.95	5.55	3.62	3.33	0.54	0.54	0.44	0.71	0.35	3.16	6.86	39.22	80.84	112.74	17.65	11.75	14.12	13.12	12.50	7.49	4.41	1.52	1.69	1.50	4.22	10.37	0	17.65	9.85
1988	4.08	1.49	5.98	4.67	4.35	2.40	1.18	0.60	2.09	2.98	9.17	3.51	37.21	76.43	118.05	14.10	12.43	11.55	12.14	15.00	11.42	7.93	4.18	3.87	5.67	14.24	15.66	0	15.00	6.86
1989	3.74	3.30	6.95	3.57	2.81	1.40	0.69	0.82	0.29	2.15	7.52	4.51	39.23	76.44	115.66	16.42	10.55	13.99	13.82	13.33	7.78	4.90	2.91	1.80	3.26	9.96	14.18	0	16.42	9.17
1990	10.65	6.01	3.42	3.04	2.90	4.04	0.70	1.52	0.04	5.88	10.74	4.26	46.5	85.73	122.94	22.68	21.17	20.08	12.47	9.36	9.98	7.64	6.26	2.26	7.44	16.66	20.88	0	22.68	10.65
1991	3.61	5.75	4.86	6.66	2.71	1.55	0.28	1.38	0.59	1.87	7.17	3.57	48.27	94.77	134.00	18.61	13.62	14.22	17.27	14.23	10.92	4.54	3.21	2.25	3.84	9.63	12.61	0	20.88	10.74
1992	6.09	3.52	2.10	4.68	0.22	1.94	1.03	0.92	1.98	2.22	6.91	3.63	35.09	83.36	129.86	16.83	13.18	11.71	10.30	7.00	6.84	3.19	3.89	3.93	5.12	11.11	12.76	0	16.83	7.17
1993	3.57	0.33	4.77	6.60	4.00	3.23	2.20	0.31	0.00	1.74	1.63	4.75	37.77	72.86	121.13	14.11	7.53	8.67	11.70	15.37	13.83	9.43	5.74	2.51	2.05	3.37	8.12	0	15.37	6.91
1994	3.35	4.59	4.09	2.84	1.86	2.32	1.19	0.42	2.47	5.36	6.04	8.80	31.25	69.02	104.11	9.73	12.69	12.03	11.52	8.79	7.02	5.37	3.93	4.08	8.25	13.87	20.20	0	12.69	4.75
1995	4.21	5.35	4.92	2.88	1.56	1.73	1.76	0.00	1.72	4.71	9.51	6.17	44.33	75.58	113.35	19.05	18.36	14.48	13.15	9.36	6.17	5.05	3.49	3.48	6.43	15.94	20.39	0	20.20	8.80
1996	8.16	8.73	2.57	7.23	4.57	1.34	1.08	0.30	2.34	6.07	8.26	12.23	56.71	101.04	132.29	23.84	23.06	19.46	18.53	14.37	13.14	6.99	2.72	3.72	8.71	16.67	26.56	1	23.84	9.51
1997	7.82	3.83	7.06	3.80	2.91	2.82	1.96	1.13	2.51	6.13	4.27	3.10	60.4	117.11	161.44	28.31	23.88	18.71	14.69	13.77	9.53	7.69	5.91	5.60	9.77	12.91	13.50	1	28.31	12.23
1998	7.60	4.05	5.01	1.53	3.08	1.18	0.29	0.05	0.46	3.98	11.16	9.69	36.75	97.15	153.86	14.97	14.75	16.66	10.59	9.62	5.79	4.55	1.52	0.80	4.49	15.60	24.83	0	16.66	7.60
1999	8.63	6.53	5.06	1.28	3.26	2.28	0.97	0.88	0.44	3.10	11.33	5.14	54.16	90.91	151.31	29.48	24.85	20.22	12.87	9.60	6.82	6.51	4.13	2.29	4.42	14.87	19.57	2	29.48	11.16
													4	2	23															

Water Year Precipitation (inches)



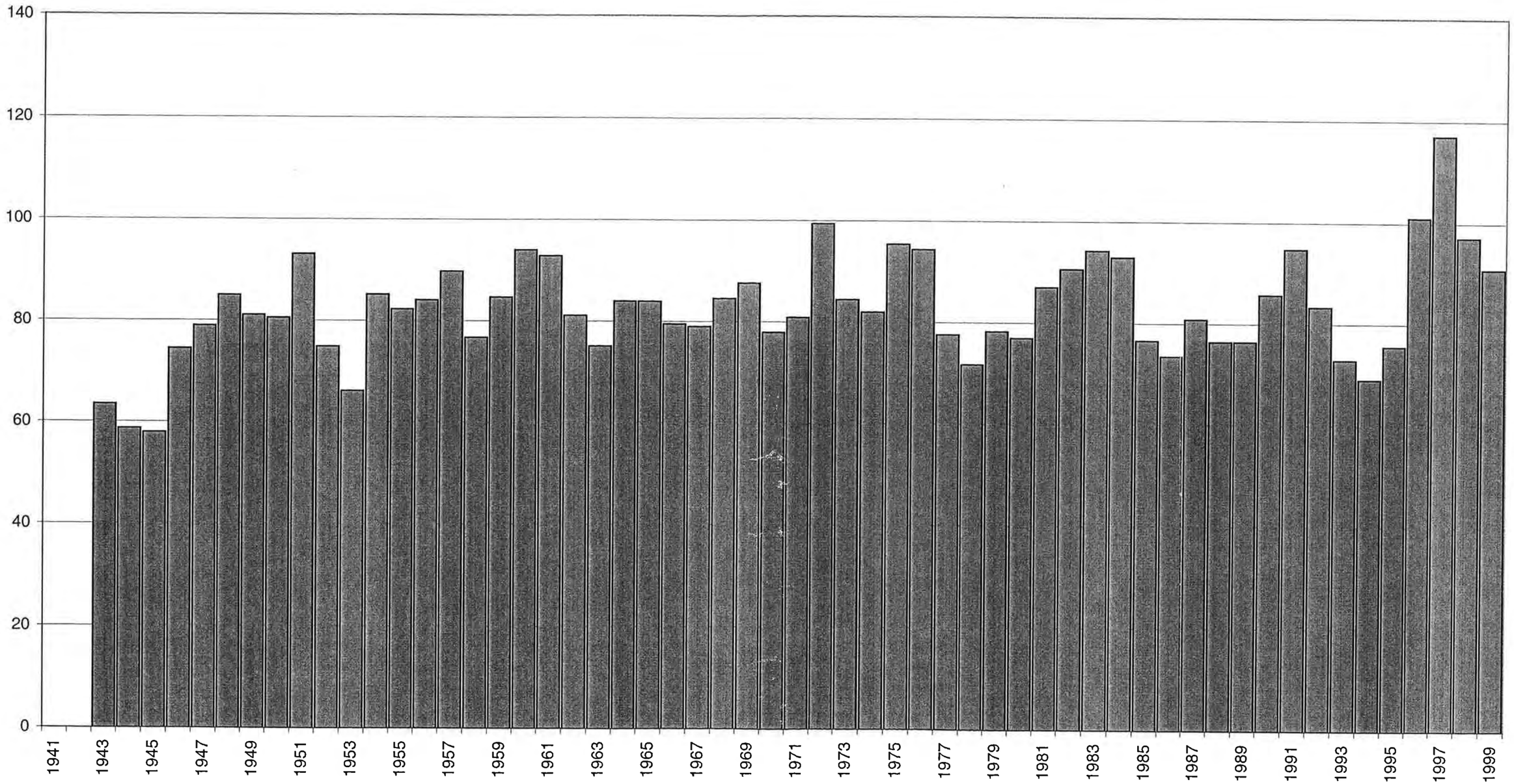
mcmillin-res/annual

3-Consecutive Year Sum Precipitation (inch)



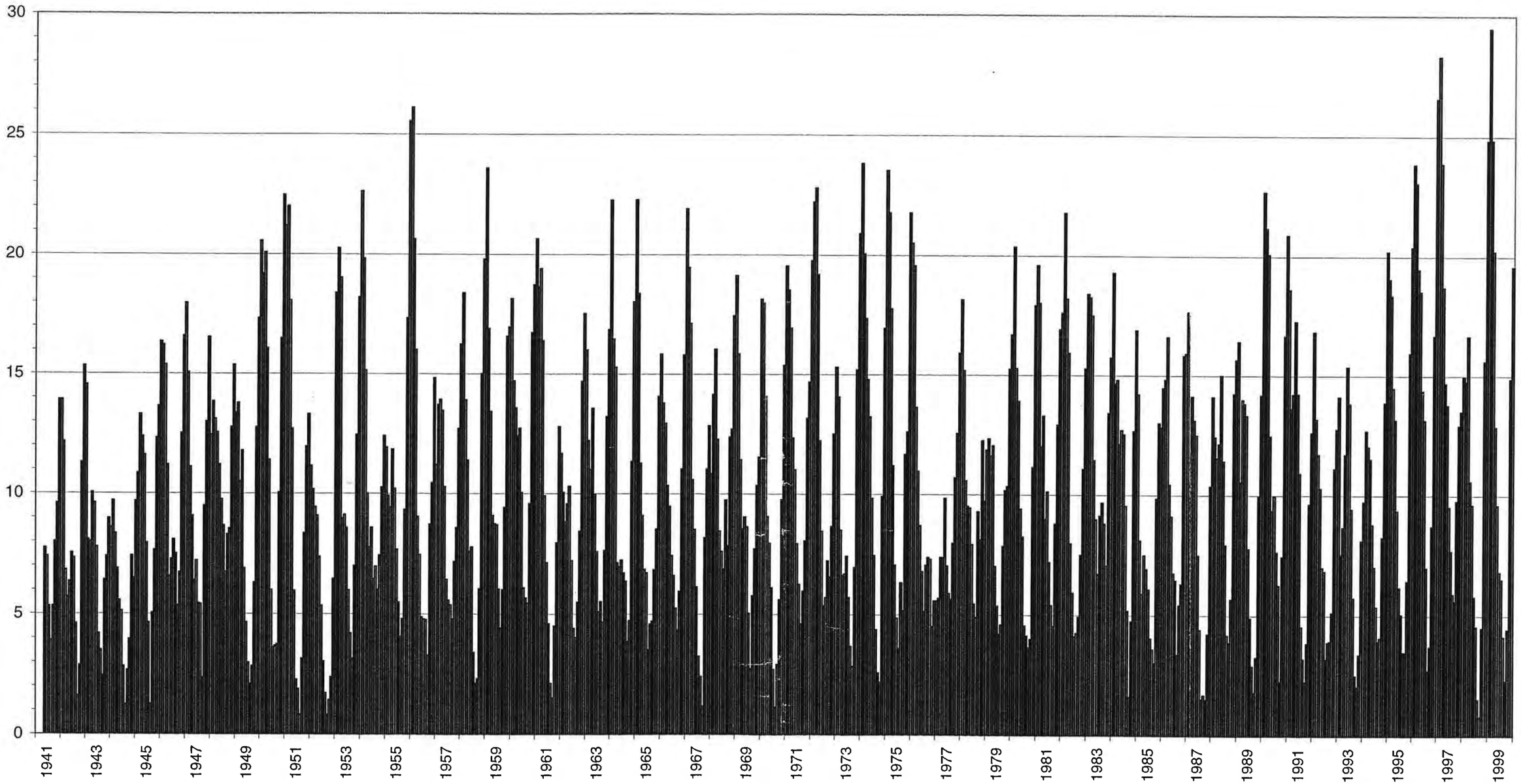
mcmillin-res/3yr-sum

2-Consecutive Year Sum Precipitation (inch)



mcmillin-res/2yr-sum

3-Consecutive Month Sum Precipitation (inch)



mcmillin-res/3mo-sum

U.S.G.S. FREQUENCY ANALYSIS
MAXIMUM 3-MONTH CUMULATIVE
PRECIPITATION DATA

1

U. S. GEOLOGICAL SURVEY
ANNUAL PEAK FLOW FREQUENCY ANALYSIS
Following Bulletin 17-B Guidelines
Program peakfq
(Version 2.4, Apr, 1998)

--- PROCESSING DATE/TIME ---

1900 AUG 2 16:06:55

--- PROCESSING OPTIONS ---

```
Plot option          = None
Basin char output    = None
Print option         = Yes
Debug print          = No
Input peaks listing  = Long
Input peaks format   = WATSTORE peak file
```

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U. S. GEOLOGICAL SURVEY
ANNUAL PEAK FLOW FREQUENCY ANALYSIS
Following Bulletin 17-B Guidelines
Program peakfq
(Version 2.4, Apr, 1998)

Station - 455224 FREDRICKSON - MCMILLIN RESERVOIR
1900 AUG 2 16:06:55

I N P U T D A T A S U M M A R Y

```
Number of peaks in record              =       58
Peaks not used in analysis             =        0
Systematic peaks in analysis           =       58
Historic peaks in analysis             =        0
Years of historic record               =        0
Generalized skew                       = ********
Standard error of generalized skew     =    0.550
Skew option                            = STATION SKEW
Gage base discharge                    =      0.0
User supplied high outlier threshold   =   --
User supplied low outlier criterion    =   --
Plotting position parameter            =     0.00
```

```
*********  NOTICE  --  Preliminary machine computations.        *********
*********  User responsible for assessment and interpretation.  *********

 *WCF107I-ACCEPTED GEN SKEW OUTSIDE MAP LIMITS.********  -0.400   0.800
  WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.                   0.0
  WCF198I-LOW OUTLIERS BELOW FLOOD BASE WERE DROPPED.          1    991.2
  WCF163I-NO HIGH OUTLIERS OR HISTORIC PEAKS EXCEEDED HHBASE.      3367.2
 *WCF151I-WRC WEIGHTED SKEW REPLACED BY USER OPTION.**********     0.067  -1
```

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Station - 455224 FREDRICKSON - MCMILLIN RESERVOIR
1900 AUG 2 16:06:55

ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	3.2620	0.0941	-0.258
BULL.17B ESTIMATE	991.2	0.9828	3.2648	0.0882	0.067

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	'EXPECTED PROBABILITY' ESTIMATE	95-PCT CONFIDENCE LIMITS FOR BULL. 17B ESTIMATES LOWER	UPPER
0.9950	--	992.7	--	--	--
0.9900	--	1060.0	--	--	--
0.9500	1322.0	1261.0	1311.0	1225.0	1405.0
0.9000	1420.0	1377.0	1413.0	1329.0	1499.0
0.8000	1550.0	1528.0	1546.0	1465.0	1626.0
0.5000	1836.0	1845.0	1836.0	1756.0	1919.0
0.2000	2181.0	2199.0	2187.0	2080.0	2307.0
0.1000	2390.0	2397.0	2404.0	2264.0	2556.0
0.0400	2638.0	2619.0	2665.0	2476.0	2860.0
0.0200	2813.0	2767.0	2853.0	2622.0	3080.0
0.0100	2981.0	2904.0	3038.0	2762.0	3294.0
0.0050	3145.0	3032.0	3222.0	2896.0	3506.0
0.0020	3357.0	3189.0	3466.0	3067.0	3782.0

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Station - 455224 FREDRICKSON - MCMILLIN RESERVOIR
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I N P U T D A T A L I S T I N G

WATER YEAR	DISCHARGE	CODES	WATER YEAR	DISCHARGE	CODES
1942	1391.0		1971	1953.0	
1943	1533.0		1972	2280.0	
1944	970.0		1973	1530.0	
1945	1330.0		1974	2383.0	
1946	1635.0		1975	2354.0	
1947	1796.0		1976	2178.0	
1948	1653.0		1977	1256.0	
1949	1537.0		1978	1816.0	
1950	2056.0		1979	1234.0	
1951	2248.0		1980	2037.0	

1952	1331.0	1981	1960.0
1953	2026.0	1982	2179.0
1954	2264.0	1983	1841.0
1955	1734.0	1984	1930.0
1956	2611.0	1985	1689.0
1957	1483.0	1986	1662.0
1958	1839.0	1987	1765.0
1959	2360.0	1988	1500.0
1960	1815.0	1989	1642.0
1961	2065.0	1990	2268.0
1962	1469.0	1991	2088.0
1963	1752.0	1992	1683.0
1964	2227.0	1993	1537.0
1965	2228.0	1994	1387.0
1966	1584.0	1995	2020.0
1967	2192.0	1996	2384.0
1968	1604.0	1997	2831.0
1969	1912.0	1998	1666.0
1970	1815.0	1999	2948.0

Explanation of peak discharge qualification codes

PEAKFQ CODE	WATSTORE CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

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Station - 455224 FREDRICKSON - MCMILLIN RESERVOIR
1900 AUG 2 16:06:55

EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	BULL.17B ESTIMATE
1999	2948.0	0.0169	0.0169
1997	2831.0	0.0339	0.0339
1956	2611.0	0.0508	0.0508
1996	2384.0	0.0678	0.0678
1974	2383.0	0.0847	0.0847
1959	2360.0	0.1017	0.1017
1975	2354.0	0.1186	0.1186
1972	2280.0	0.1356	0.1356
1990	2268.0	0.1525	0.1525
1954	2264.0	0.1695	0.1695
1951	2248.0	0.1864	0.1864
1965	2228.0	0.2034	0.2034
1964	2227.0	0.2203	0.2203

1967	2192.0	0.2373	0.2373
1982	2179.0	0.2542	0.2542
1976	2178.0	0.2712	0.2712
1991	2088.0	0.2881	0.2881
1961	2065.0	0.3051	0.3051
1950	2056.0	0.3220	0.3220
1980	2037.0	0.3390	0.3390
1953	2026.0	0.3559	0.3559
1995	2020.0	0.3729	0.3729
1981	1960.0	0.3898	0.3898
1971	1953.0	0.4068	0.4068
1984	1930.0	0.4237	0.4237
1969	1912.0	0.4407	0.4407
1983	1841.0	0.4576	0.4576
1958	1839.0	0.4746	0.4746
1978	1816.0	0.4915	0.4915
1960	1815.0	0.5085	0.5085
1970	1815.0	0.5254	0.5254
1947	1796.0	0.5424	0.5424
1987	1765.0	0.5593	0.5593
1963	1752.0	0.5763	0.5763
1955	1734.0	0.5932	0.5932
1985	1689.0	0.6102	0.6102
1992	1683.0	0.6271	0.6271
1998	1666.0	0.6441	0.6441
1986	1662.0	0.6610	0.6610
1948	1653.0	0.6780	0.6780
1989	1642.0	0.6949	0.6949
1946	1635.0	0.7119	0.7119
1968	1604.0	0.7288	0.7288
1966	1584.0	0.7458	0.7458
1949	1537.0	0.7627	0.7627
1993	1537.0	0.7797	0.7797
1943	1533.0	0.7966	0.7966
1973	1530.0	0.8136	0.8136
1988	1500.0	0.8305	0.8305
1957	1483.0	0.8475	0.8475
1962	1469.0	0.8644	0.8644
1942	1391.0	0.8814	0.8814
1994	1387.0	0.8983	0.8983
1952	1331.0	0.9153	0.9153
1945	1330.0	0.9322	0.9322
1977	1256.0	0.9492	0.9492
1979	1234.0	0.9661	0.9661
1944	970.0	0.9831	0.9831

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U. S. GEOLOGICAL SURVEY
ANNUAL PEAK FLOW FREQUENCY ANALYSIS
Following Bulletin 17-B Guidelines
Program peakfq
(Version 2.4, Apr, 1998)

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End PEAKFQ analysis.
  Stations processed :       1
  Number of errors   :       0
  Stations skipped   :       0
  Station years      :      58
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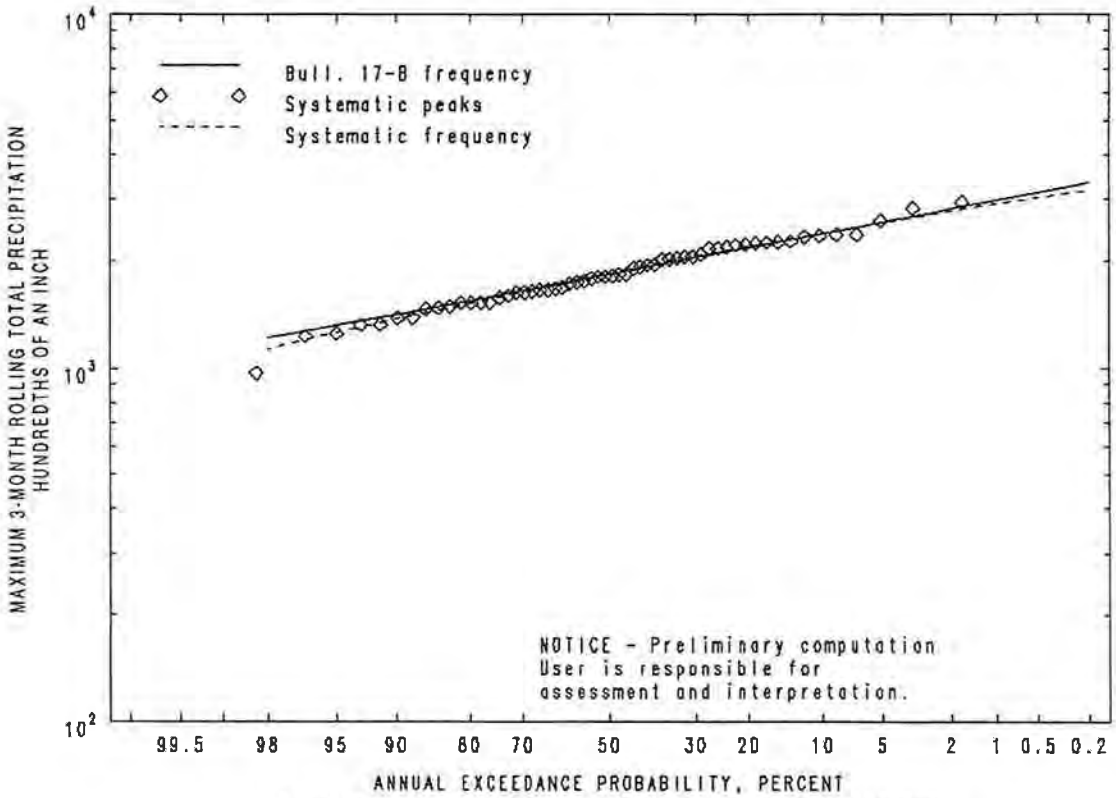

Station - 455224 FREDRICKSON - MCMILLIN RESERVOIR
1900 AUG 4 13:54:17

U.S.G.S. FREQUENCY ANALYSIS
WATER YEAR PRECIPITATION DATA

1

U. S. GEOLOGICAL SURVEY
ANNUAL PEAK FLOW FREQUENCY ANALYSIS
Following Bulletin 17-B Guidelines
Program peakfq
(Version 2.4, Apr, 1998)

--- PROCESSING DATE/TIME ---

1900 AUG 1 13:44:40

--- PROCESSING OPTIONS ---

```
Plot option          = Graphics device
Basin char output    = None
Print option         = Yes
Debug print          = No
Input peaks listing  = Long
Input peaks format   = WATSTORE peak file
```

1

U. S. GEOLOGICAL SURVEY
ANNUAL PEAK FLOW FREQUENCY ANALYSIS
Following Bulletin 17-B Guidelines
Program peakfq
(Version 2.4, Apr, 1998)

Station - 455224 FREDRICKSON - MCMILLIN RESERVOIR
1900 AUG 1 13:44:40

I N P U T D A T A S U M M A R Y

```
Number of peaks in record              =       58
Peaks not used in analysis             =        0
Systematic peaks in analysis           =       58
Historic peaks in analysis             =        0
Years of historic record               =        0
Generalized skew                       = ********
Standard error of generalized skew     =    0.550
Skew option                            = STATION SKEW
Gage base discharge                    =      0.0
User supplied high outlier threshold   =   --
User supplied low outlier criterion    =   --
Plotting position parameter            =     0.00
```

```
*********  NOTICE  --  Preliminary machine computations.        *********
*********  User responsible for assessment and interpretation.  *********

 *WCF107I-ACCEPTED GEN SKEW OUTSIDE MAP LIMITS.********  -0.400   0.800
  WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.                   0.0
  WCF195I-NO LOW OUTLIERS WERE DETECTED BELOW CRITERION.            2411.3
  WCF163I-NO HIGH OUTLIERS OR HISTORIC PEAKS EXCEEDED HHBASE.       6864.3
 *WCF151I-WRC WEIGHTED SKEW REPLACED BY USER OPTION.**********    -0.357  -1
```

1

Station - 455224 FREDRICKSON - MCMILLIN RESERVOIR
1900 AUG 1 13:44:40

ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	3.6094	0.0804	-0.357
BULL.17B ESTIMATE	0.0	1.0000	3.6094	0.0804	-0.357

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	'EXPECTED PROBABILITY' ESTIMATE	95-PCT CONFIDENCE LIMITS FOR BULL. 17B ESTIMATES LOWER	UPPER
0.9950	2374.0	2374.0	2308.0	2132.0	2574.0
0.9900	2521.0	2521.0	2467.0	2287.0	2714.0
0.9500	2948.0	2948.0	2920.0	2740.0	3121.0
0.9000	3190.0	3190.0	3171.0	2999.0	3353.0
0.8000	3495.0	3495.0	3486.0	3322.0	3650.0
0.5000	4113.0	4113.0	4113.0	3951.0	4285.0
0.2000	4766.0	4766.0	4776.0	4562.0	5017.0
0.1000	5116.0	5116.0	5137.0	4873.0	5432.0
0.0400	5494.0	5494.0	5533.0	5200.0	5891.0
0.0200	5740.0	5740.0	5793.0	5409.0	6194.0
0.0100	5960.0	5960.0	6031.0	5595.0	6469.0
0.0050	6162.0	6162.0	6251.0	5763.0	6723.0
0.0020	6405.0	6405.0	6523.0	5965.0	7032.0

1

Station - 455224 FREDRICKSON - MCMILLIN RESERVOIR
1900 AUG 1 13:44:40

I N P U T D A T A L I S T I N G

WATER YEAR	DISCHARGE	CODES	WATER YEAR	DISCHARGE	CODES
1942	2986.0		1971	4623.0	
1943	3357.0		1972	5316.0	
1944	2511.0		1973	3130.0	
1945	3277.0		1974	5070.0	
1946	4168.0		1975	4475.0	
1947	3727.0		1976	4961.0	
1948	4771.0		1977	2800.0	
1949	3337.0		1978	4371.0	
1950	4715.0		1979	3457.0	
1951	4598.0		1980	4243.0	

1952	2893.0	1981	4461.0
1953	3721.0	1982	4599.0
1954	4794.0	1983	4830.0
1955	3433.0	1984	4470.0
1956	4975.0	1985	3190.0
1957	3999.0	1986	4162.0
1958	3673.0	1987	3922.0
1959	4795.0	1988	3721.0
1960	4604.0	1989	3923.0
1961	4678.0	1990	4650.0
1962	3432.0	1991	4827.0
1963	4076.0	1992	3509.0
1964	4323.0	1993	3777.0
1965	4072.0	1994	3125.0
1966	3879.0	1995	4433.0
1967	4023.0	1996	5671.0
1968	4432.0	1997	6040.0
1969	4328.0	1998	3675.0
1970	3465.0	1999	5416.0

Explanation of peak discharge qualification codes

PEAKFQ CODE	WATSTORE CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

1

Station - 455224 FREDRICKSON - MCMILLIN RESERVOIR
1900 AUG 1 13:44:40

EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	BULL.17B ESTIMATE
1997	6040.0	0.0169	0.0169
1996	5671.0	0.0339	0.0339
1999	5416.0	0.0508	0.0508
1972	5316.0	0.0678	0.0678
1974	5070.0	0.0847	0.0847
1956	4975.0	0.1017	0.1017
1976	4961.0	0.1186	0.1186
1983	4830.0	0.1356	0.1356
1991	4827.0	0.1525	0.1525
1959	4795.0	0.1695	0.1695
1954	4794.0	0.1864	0.1864
1948	4771.0	0.2034	0.2034
1950	4715.0	0.2203	0.2203

1961	4678.0	0.2373	0.2373
1990	4650.0	0.2542	0.2542
1971	4623.0	0.2712	0.2712
1960	4604.0	0.2881	0.2881
1982	4599.0	0.3051	0.3051
1951	4598.0	0.3220	0.3220
1975	4475.0	0.3390	0.3390
1984	4470.0	0.3559	0.3559
1981	4461.0	0.3729	0.3729
1995	4433.0	0.3898	0.3898
1968	4432.0	0.4068	0.4068
1978	4371.0	0.4237	0.4237
1969	4328.0	0.4407	0.4407
1964	4323.0	0.4576	0.4576
1980	4243.0	0.4746	0.4746
1946	4168.0	0.4915	0.4915
1986	4162.0	0.5085	0.5085
1963	4076.0	0.5254	0.5254
1965	4072.0	0.5424	0.5424
1967	4023.0	0.5593	0.5593
1957	3999.0	0.5763	0.5763
1989	3923.0	0.5932	0.5932
1987	3922.0	0.6102	0.6102
1966	3879.0	0.6271	0.6271
1993	3777.0	0.6441	0.6441
1947	3727.0	0.6610	0.6610
1953	3721.0	0.6780	0.6780
1988	3721.0	0.6949	0.6949
1998	3675.0	0.7119	0.7119
1958	3673.0	0.7288	0.7288
1992	3509.0	0.7458	0.7458
1970	3465.0	0.7627	0.7627
1979	3457.0	0.7797	0.7797
1955	3433.0	0.7966	0.7966
1962	3432.0	0.8136	0.8136
1943	3357.0	0.8305	0.8305
1949	3337.0	0.8475	0.8475
1945	3277.0	0.8644	0.8644
1985	3190.0	0.8814	0.8814
1973	3130.0	0.8983	0.8983
1994	3125.0	0.9153	0.9153
1942	2986.0	0.9322	0.9322
1952	2893.0	0.9492	0.9492
1977	2800.0	0.9661	0.9661
1944	2511.0	0.9831	0.9831

1

U. S. GEOLOGICAL SURVEY
ANNUAL PEAK FLOW FREQUENCY ANALYSIS
Following Bulletin 17-B Guidelines
Program peakfq
(Version 2.4, Apr, 1998)

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  Number of errors   :       0
  Stations skipped   :       0
  Station years      :      58
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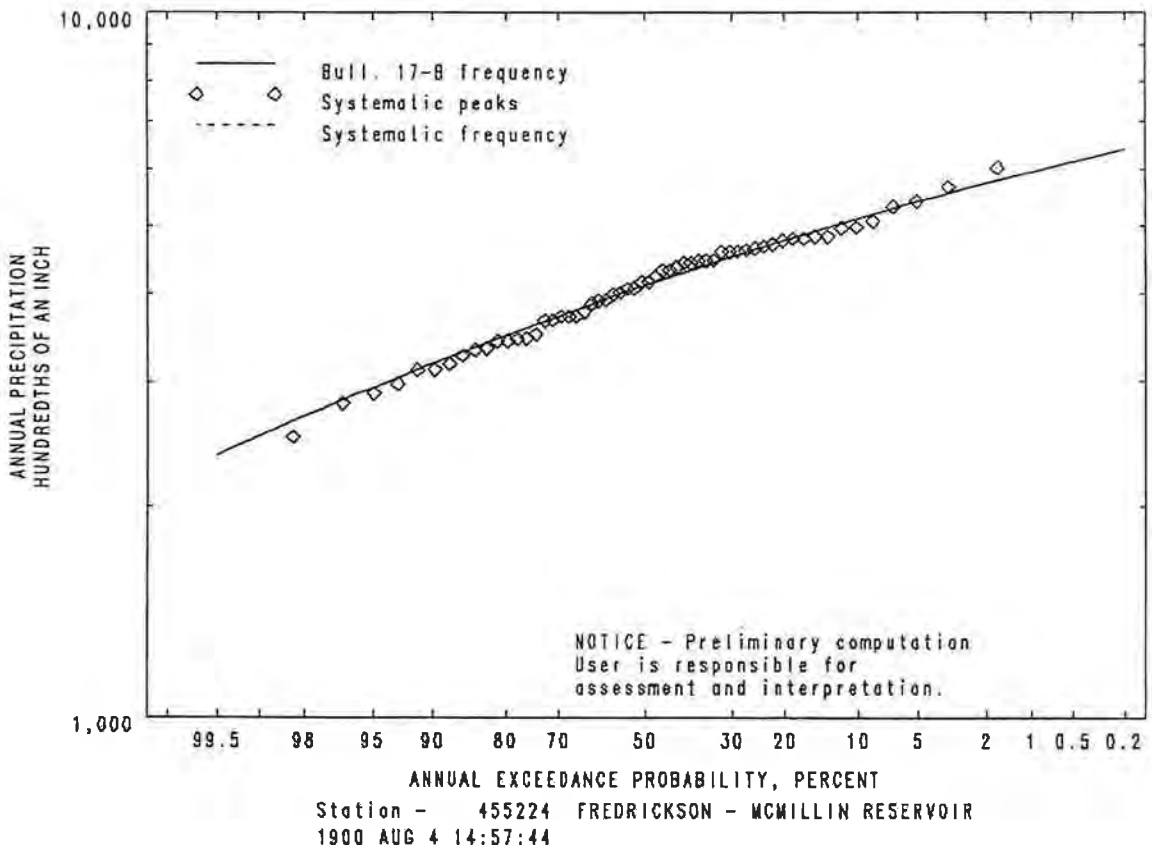
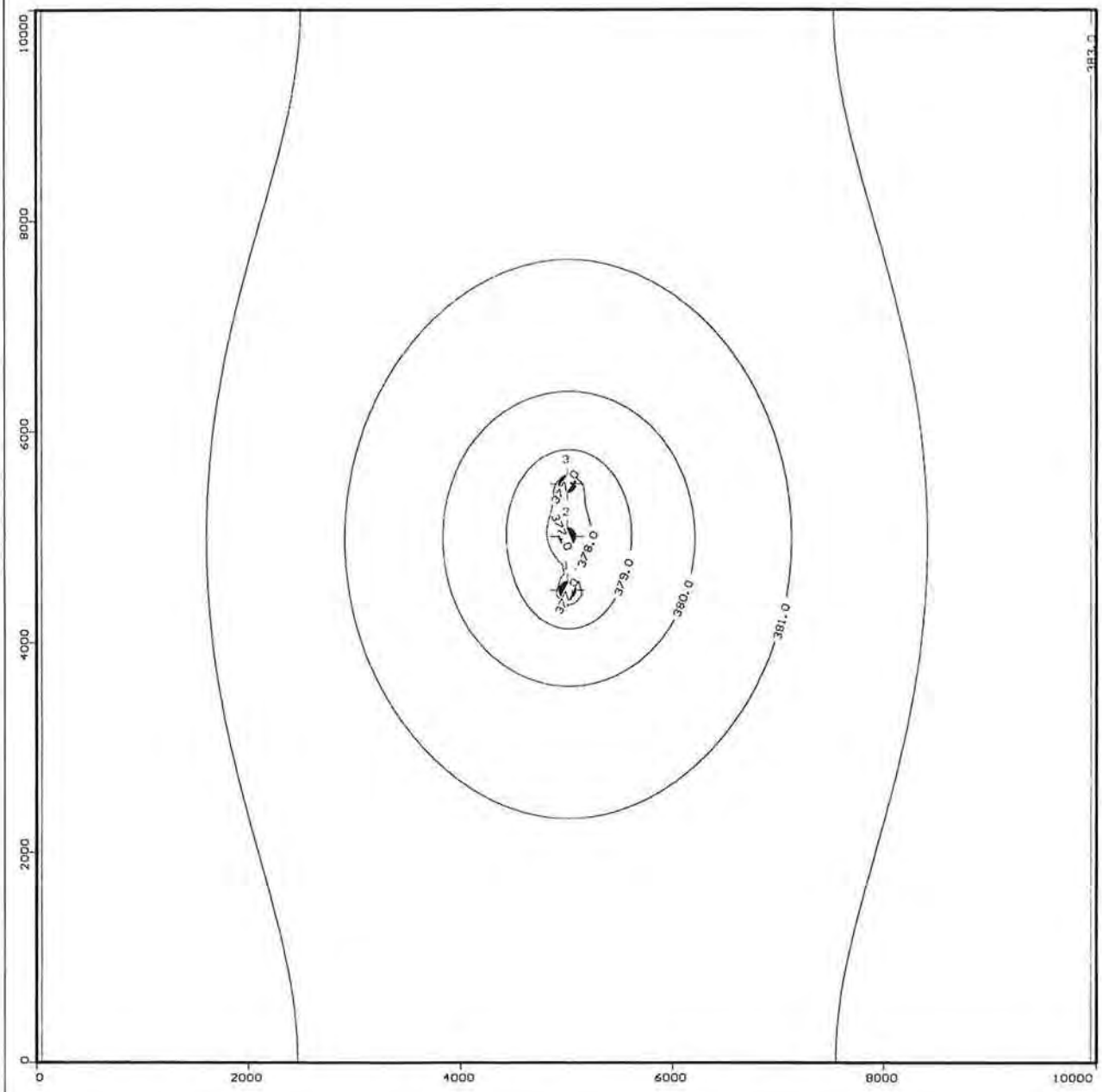

10,000
1,000
Bull. 17-B frequency
Systematic peaks
Systematic frequency
ANNUAL PRECIPITATION
HUNDREDTHS OF AN INCH
NOTICE - Preliminary computation
User is responsible for
assessment and interpretation.
99.5 98 95 90 80 70 50 30 20 10 5 2 1 0.5 0.2
ANNUAL EXCEEDANCE PROBABILITY, PERCENT
Station - 455224 FREDRICKSON - MCMILLIN RESERVOIR
1900 AUG 4 14:57:44



URS Corporation
27 Feb 01

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
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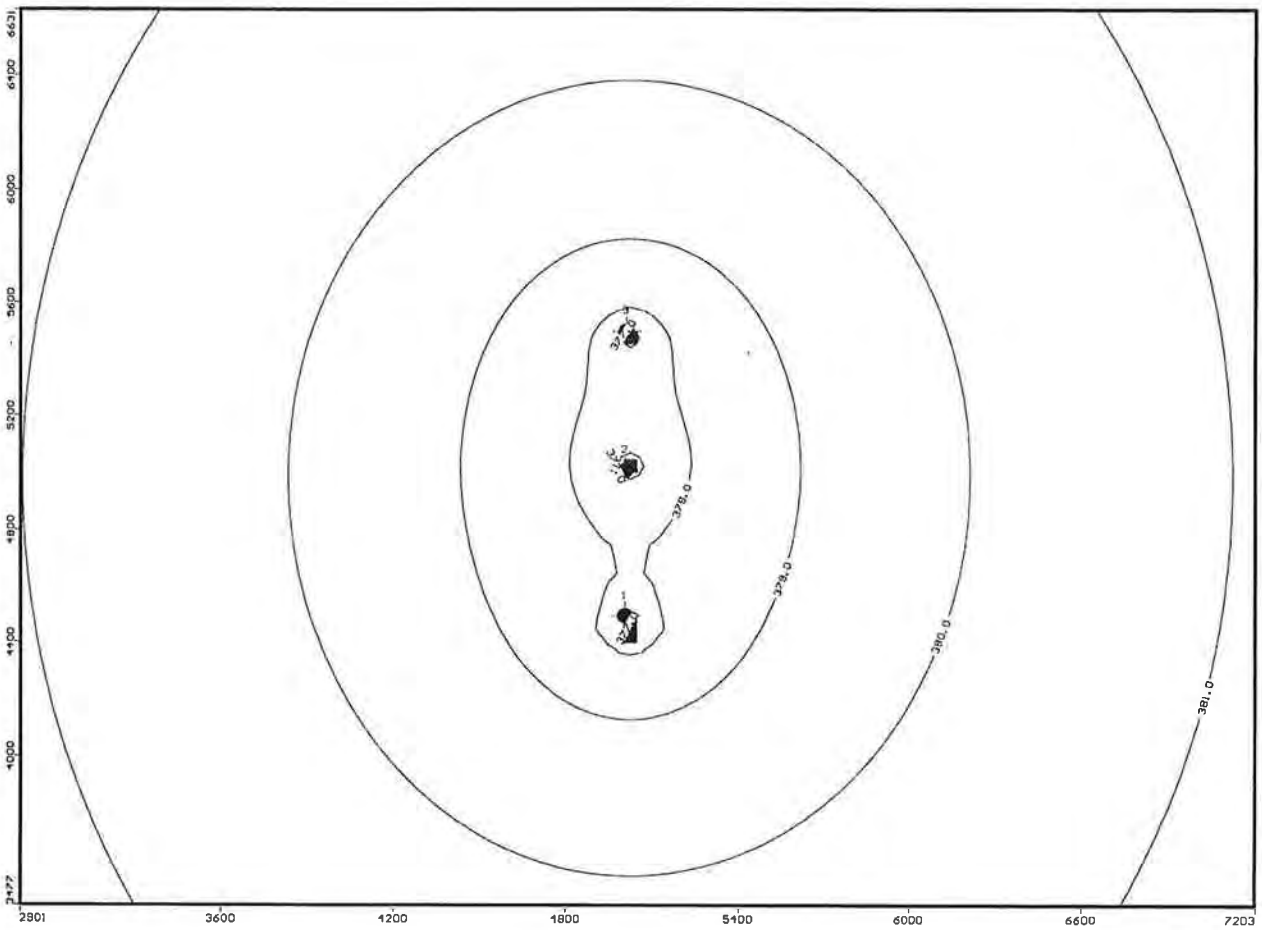
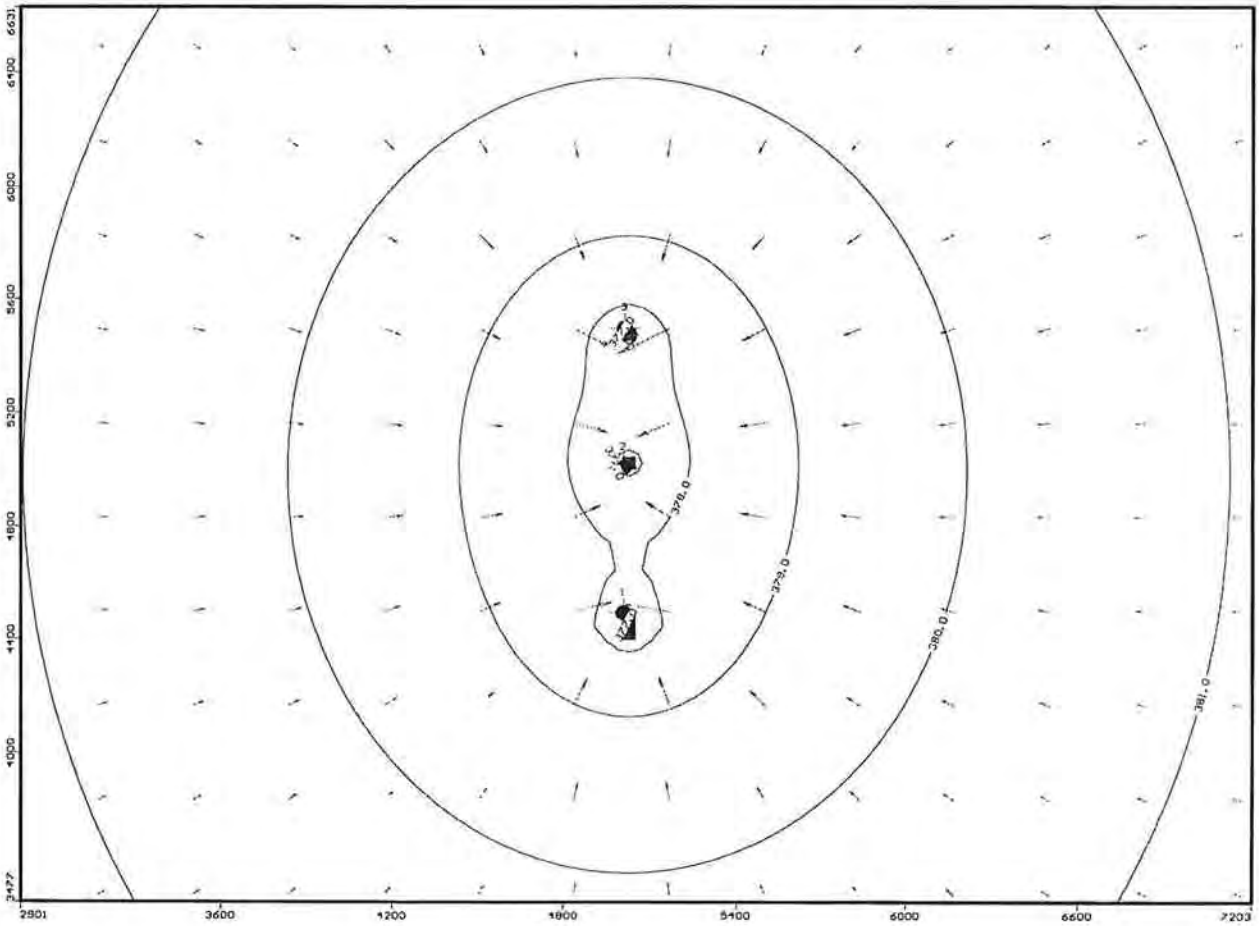


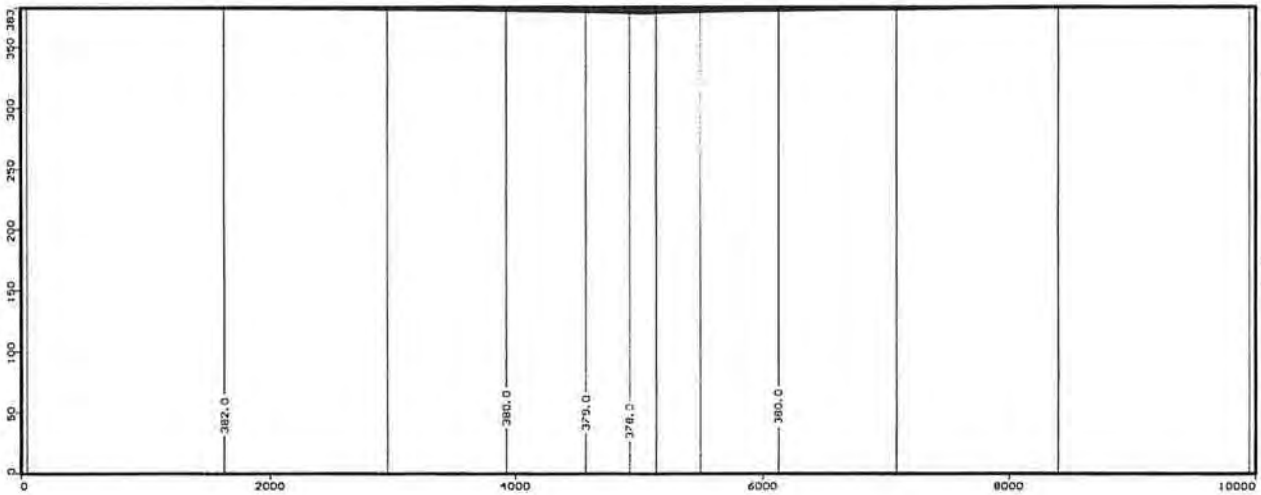
URS Corporation
27 Feb 01

Visual MODFLOW v.2.8.2, (C) 1995-1999
Waterloo Hydrogeologic, Inc.
NC: 119 NR: 112 NL: 1
Current Layer: 1



URS Corporation
27 Feb 01

Visual MODFLOW v.2.8.2, (C) 1995-1999
Waterloo Hydrogeologic, Inc.
NC: 119 NR: 112 NL: 1
Current Layer: 1



URS Corporation
27 Feb 01

Visual MODFLOW v.2.8.2, (C) 1995-1999
Waterloo Hydrogeologic, Inc.
NC: 119 NR: 112 NL: 1
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Appendix B

Photos of Flooding and Non-Flooding Events

Photo 1. *View to east of flooding segment of 192nd Street East during spring 1997 flooding.*

Photo 2. *Same view taken in summer 1998.*

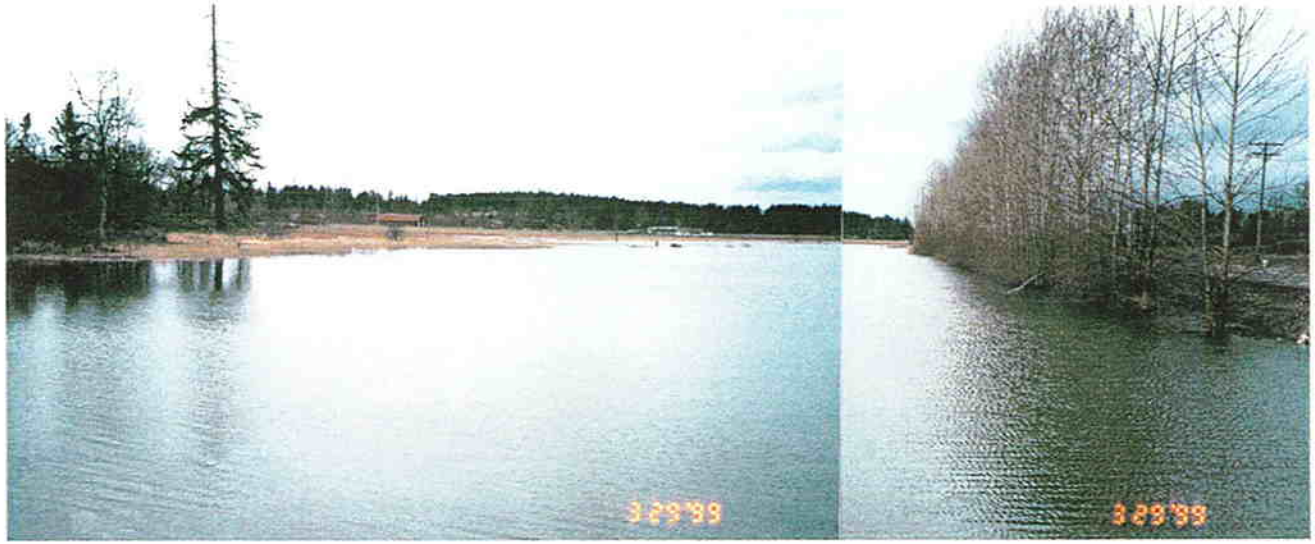


Photo 3. View to the west of pond adjacent to 192nd Street East taken in March 1999.

Photo 4. View to the east of the pond encroaching on 192nd Street East taken the same day.

Photo 5. *View to the west of pond adjacent to 192nd Street East taken in summer 1999. Buildings in photo background are also visible in top photo on previous page.*

Photo 6. *View to the west of the pond showing the staff gauge (on power pole) used to monitor water levels in the pond taken in summer 1999.*

Appendix C

Monitoring Well and Test Pit Lithologic Logs and Construction Diagrams

Project: Frederickson Flooding Assessment
Project Location: Pierce County
Project Number: 54-984009NA

Log of Boring FR-1-1

Sheet 1 of 2

Date(s) Drilled	1/14/99	Logged By	J CROOK	Checked By	J GIBBENS
Drilling Method	AIR HAMMER	Drilling Contractor	LAYNE CHRISTENSEN	Total Depth Drilled (feet bgs)	40.0
Drill Rig Type	AP1000	Sampler Type	SPLIT SPOON, CUTTINGS	Approximate Surface Elevation (feet msl)	
Groundwater Level	36 feet below TOC	Hammer Weight and Drop	140lb/30"	Top of PVC Elevation	
Diameter of Hole (inches)	6 5/8" Diameter of Well (inches) 2"	Type of Well Casing	2" PVC	Screen Perforation	0.020"
Type of Sand Pack	COLORADO SILICA SAND	Type and Depth of Seal(s)	3/8" BENTONITE CHIPS		
Comments	204th Street East and 67th Ave East				

Elevation, feet	Depth, feet	SAMPLES Type	Number	Blows per 6-inch Interval	Percent Recovery	Graphic Log	MATERIAL DESCRIPTION	Well Completion Log	Drilling Rate (Time, 24-hour clock)	REMARKS
	0						Asphalt (road)		1254	
							Dry, brown, sandy GRAVEL (GP) cobbles to 4"			
	5									
	10								1313	
							Dry, brown, sandy, silty GRAVEL (GM)			
	15									
	20									
							Dense, dry, brown, medium to fine, well-graded SAND (SW)			
	25	X		34 55 52/2	100				1350	
							Dry, brown, sandy GRAVEL (GP)			
							Moist, brown to gray, sandy, silty GRAVEL (GM)			
	30									

Report: ENV_23A; Project File: I:\PROJECTS\WCIA\98\984009NA\DATA\WELLLO-1\FRED.GPJ; Data Template:WC_CORP1.GDT Printed: 1/21/99

Project: Frederickson Flooding Assessment
Project Location: Pierce County
Project Number: 54-984009NA

Log of Boring FR-1-1

Elevation, feet	Depth, feet	SAMPLES Type	SAMPLES Number	SAMPLES Blows per 6-inch Interval	SAMPLES Percent Recovery	Graphic Log	MATERIAL DESCRIPTION	Well Completion Log			Drilling Rate (Time, 24-hour clock)	REMARKS
	30											
	35						Water Cobbles to 4"					
	40										1600	
	45											
	50											
	55											
	60											
	65											
	70											

Report: ENV_23A; Project File: I:\PROJECTS\WCIA\9\984009NA\DATA\WELLLO~1\FRED.GPJ; Data Template:WC_CORP1.GDT Printed: 1/21/99

Project: Frederickson Flooding Assessment
Project Location: Pierce County
Project Number: 54-984009NA

Log of Boring FR-2-2

Date(s) Drilled	1/13/99	Logged By	J CROOK	Checked By	J GIBBENS
Drilling Method	AIR HAMMER	Drilling Contractor	LAYNE CHRISTENSEN	Total Depth Drilled (feet bgs)	130.0
Drill Rig Type	AP1000	Sampler Type	SPLIT SPOON, CUTTINGS	Approximate Surface Elevation (feet msl)	
Groundwater Level	105 feet below TOC	Hammer Weight and Drop	140lb/30"	Top of PVC Elevation	
Diameter of Hole (inches)	6 5/8" Diameter of Well (inches) 2"	Type of Well Casing	2" PVC	Screen Perforation	0.020"
Type of Sand Pack	COLORADO SILICA SAND	Type and Depth of Seal(s)	BENTONITE PELLETS		
Comments	End of pavement north of Intersection of 224th Street East and 78th Ave East				

Elevation, feet	Depth, feet	SAMPLES Type	Number	Blows per 6-inch Interval	Percent Recovery	Graphic Log	MATERIAL DESCRIPTION	Well Completion Log	Drilling Rate (Time, 24-hour clock)	REMARKS
	0						Asphalt (road)			
							Dry, brown, sandy GRAVEL (GP) cobbles to 4"			
	5									
	10									
	15						Dry, brown, silty SAND (SM) cobbles to 4"			
	20						Dry, brown, gravelly SAND (SW) with trace clay, cobbles to 2"		1130	
	25			70 R	100		Sand lenses to 4" Cobbles to 6"		1150	
	30									

Report: ENV_23A; Project File: I:\PROJECTS\WCI\A98\984009NA\DATA\WELLLO-1\FRED.GPJ; Data Template:WC_CORP1.GDT Printed: 1/21/99

Project: Frederickson Flooding Assessment
Project Location: Pierce County
Project Number: 54-984009NA

Log of Boring FR-2-2

Elevation, feet	Depth, feet	SAMPLES: Type	SAMPLES: Number	SAMPLES: Blows per 6-inch Interval	SAMPLES: Percent Recovery	Graphic Log	MATERIAL DESCRIPTION	Well Completion Log			Drilling Rate (Time, 24-hour clock)	REMARKS
	30											
	35											
	40											
	45						Moist, brown, sandy GRAVEL (GP) with trace clay, angular to subrounded clasts to 4"				1206	
	50										1220	
	55										1230	
	60											
	65						Smaller cobbles to 2"				1300	
	70											

Report: ENV_23A; Project File: I:\PROJECTS\WCIA\98\984009NA\DATA\WELLLO-1\FRED.GPJ; Data Template:WC_CORP1.GDT Printed: 1/21/99

Project: Frederickson Flooding Assessment
Project Location: Pierce County
Project Number: 54-984009NA

Log of Boring FR-2-2

Elevation, feet	Depth, feet	SAMPLES Type	SAMPLES Number	SAMPLES Blows per 6-inch Interval	SAMPLES Percent Recovery	Graphic Log	MATERIAL DESCRIPTION	Well Completion Log			Drilling Rate (Time, 24-hour clock)	REMARKS
	70											
	75						1' Sand lens					
	80						Moist, brown, sandy GRAVEL (GP) with trace clay, cobbles to 3", sand lenses to 1'					
	85											
	90											
	95						Wet, brown, silty, clayey GRAVEL (GM)					
	100			47 67 90	75						1355	
	105											
	110						Small rounded gravel <1"					

Report: ENV_23A; Project File: I:\PROJECTS\WCIA\98\984009NA\DATA\WELLLO-1\FRED.GPJ; Data Template:WC_CORP1.GDT Printed: 1/21/99

Project: Frederickson Flooding Assessment
Project Location: Pierce County
Project Number: 54-984009NA

Log of Boring FR-2-2

Elevation, feet	Depth, feet	SAMPLES Type	SAMPLES Number	SAMPLES Blows per 6-inch Interval	SAMPLES Percent Recovery	Graphic Log	MATERIAL DESCRIPTION	Well Completion Log			Drilling Rate (Time, 24-hour clock)	REMARKS
											1416	
	115						Wet, brown to gray, sandy GRAVEL (GW) with sand lenses <4"					
	120											
	125			75 50/3	30							
	130											
	135										1500	
	140											
	145											
	150											

Report: ENV_23A; Project File: I:\PROJECTS\WCIA\98984009NA\DATA\WELLLO-1\FRED.GPJ; Data Template:WC_CORP1.GDT Printed: 1/21/99

Project: Frederickson Flooding Assessment
Project Location: Pierce County
Project Number: 54-984009NA

Log of Boring FR-3-1

Sheet 1 of 1

Date(s) Drilled	1/11/99	Logged By	J CROOK	Checked By	J GIBBENS
Drilling Method	AIR HAMMER	Drilling Contractor	LAYNE CHRISTENSEN	Total Depth Drilled (feet bgs)	25.0
Drill Rig Type	AP1000	Sampler Type	CUTTINGS	Approximate Surface Elevation (feet msl)	
Groundwater Level	NA	Hammer Weight and Drop	NA	Top of PVC Elevation	
Diameter of Hole (inches)	6 5/8" Diameter of Well (inches) 2"	Type of Well Casing	2" PVC	Screen Perforation	0.020"
Type of Sand Pack	COLORADO SILICA SAND	Type and Depth of Seal(s)	3/8" BENTONITE CHIPS		
Comments	204th Street E and 92nd Ave East				

Elevation, feet	Depth, feet	SAMPLES Type	Number	Blows per 6-inch Interval	Percent Recovery	Graphic Log	MATERIAL DESCRIPTION	Well Completion Log			Drilling Rate (Time, 24-hour clock)	REMARKS
	0						Dry, brown, sandy, silty GRAVEL (GM), rounded to angular clasts to 3", small brown clay lenses				0940	
	5											
							Sand lenses					
	10											
	15											
	20											
							Cuttings become sandier					
	25										1130	No water encountered during drilling
	30											

Report: ENV_23A; Project File: I:\PROJECTS\WC\A\9\9\984009NA\DATA\WELLLO-1\FRED.GPJ; Data Template:WC_CORP1.GDT Printed: 1/21/99

Project: Frederickson Flooding Assessment
Project Location: Pierce County
Project Number: 54-984009NA

Log of Boring FR-3-2

Date(s) Drilled	1/11/99 - 1/12/99	Logged By	J CROOK	Checked By	J GIBBENS
Drilling Method	AIR HAMMER	Drilling Contractor	LAYNE CHRISTENSEN	Total Depth Drilled (feet bgs)	150.0
Drill Rig Type	AP1000	Sampler Type	SPLIT SPOON, CUTTINGS	Approximate Surface Elevation (feet msl)	
Groundwater Level	59 feet below TOC	Hammer Weight and Drop	140lb/30"	Top of PVC Elevation	
Diameter of Hole (inches)	6 5/8" Diameter of Well (inches) 2"	Type of Well Casing	2" PVC	Screen Perforation	0.020"
Type of Sand Pack	COLORADO SILICA SAND	Type and Depth of Seal(s)	3/8" BENTONITE CHIPS		
Comments	204th Street E and 92nd Ave East				

Elevation, feet	Depth, feet	SAMPLES Type	Number	Blows per 6-inch Interval	Percent Recovery	Graphic Log	MATERIAL DESCRIPTION	Well Completion Log			Drilling Rate (Time, 24-hour clock)	REMARKS
	0						Hard. moist/dry, brown, silty, sandy, cobbly GRAVEL (GM)				1145	
	5						Occasional softer sandier lenses					
	10											
	15						Moist, gray, coarser GRAVEL, occasional cobble to 4"					
	20						Finer, soft, cuttings more sand					
	25	X		50/R	0							Sampler on rock or cobble
	30											

Report: ENV_23A; Project File: I:\PROJECTS\WCIA\98\984009NA\DATA\WELLLO-1\FRED.GPJ; Data Template:WC_CORP1.GDT Printed: 1/21/99

Project: Frederickson Flooding Assessment
Project Location: Pierce County
Project Number: 54-984009NA

Log of Boring FR-3-2

Elevation, feet	Depth, feet	SAMPLES Type	SAMPLES Number	SAMPLES Blows per 6-inch Interval	SAMPLES Percent Recovery	Graphic Log	MATERIAL DESCRIPTION	Well Completion Log			Drilling Rate (Time, 24-hour clock)	REMARKS
	30											
	35						Cobbles to 4", more sand, minimal silt					
	40											
	45						More sand, smaller cobbles to 2"					
	50	X		47 50/3"	25		Moist, gray, sandy GRAVEL (GM) with some silt, brown clay lenses to <1", cobbles to 1.5"					
	55											
	60						Some water, gravel, less sand, less silt					
	65											
	70											

Report: ENV_23A; Project File: I:\PROJECTS\WC\A\984009NA\DATA\WELLLO-1\FRED.GPJ; Data Template:WC_CORP1.GDT Printed: 1/21/99

Project: Frederickson Flooding Assessment
Project Location: Pierce County
Project Number: 54-984009NA

Log of Boring FR-3-2

Elevation, feet	Depth, feet	SAMPLES Type	SAMPLES Number	SAMPLES Blows per 6-inch Interval	SAMPLES Percent Recovery	Graphic Log	MATERIAL DESCRIPTION	Well Completion Log			Drilling Rate (Time, 24-hour clock)	REMARKS
	70						More water, gravel, small amount of silt, sand					
	75			34 55 41	40		Cobbles to 4" Gravel, rounded to angular up to 4"				1430	
	80						Dense, moist, brown, well graded sand (SW)					
	85											
	90						Well graded sand with trace gravel					
	95											
	100			12 20 52	5		Small lenses of clay <1"				1542	
	105											
	110											

Report: ENV_23A; Project File: I:\PROJECTS\WCIA\98\984009NA\DATA\WELLLO~1\FRED.GPJ; Data Template:WC_CORP1.GDT Printed: 1/21/99

Project: Frederickson Flooding Assessment
Project Location: Pierce County
Project Number: 54-984009NA

Log of Boring FR-3-2

Elevation, feet	Depth, feet	SAMPLES Type	SAMPLES Number	SAMPLES Blows per 6-inch Interval	SAMPLES Percent Recovery	Graphic Log	MATERIAL DESCRIPTION	Well Completion Log			Drilling Rate (Time, 24-hour clock)	REMARKS
	115											
	120										0853	1/12/99
	125											
	130						Moist, brown, sandy GRAVEL (GM) to <1" with trace sand and clay				0924	
	135						Cobbles to 3"					
	140											
	145						Gravel					
	150										0945	

Report: ENV_23A; Project File: I:\PROJECTS\WCIA\98\984009NA\DATA\WELLLO-1\FRED.GPJ; Data Template:WC_CORP1.GDT Printed: 1/21/99

Project: Frederickson Flooding Assessment
Project Location: Pierce County
Project Number: 54-984009NA

Log of Boring FR-4-1

Date(s) Drilled	1/15/99	Logged By	J CROOK	Checked By	J GIBBENS
Drilling Method	AIR HAMMER	Drilling Contractor	LAYNE CHRISTENSEN	Total Depth Drilled (feet bgs)	70.0
Drill Rig Type	AP1000	Sampler Type	CUTTINGS	Approximate Surface Elevation (feet msl)	
Groundwater Level	61 below TOC	Hammer Weight and Drop	NA	Top of PVC Elevation	
Diameter of Hole (inches)	6 5/8" Diameter of Well (inches) 2"	Type of Well Casing	2" PVC	Screen Perforation	0.020"
Type of Sand Pack	COLORADO SILICA SAND	Type and Depth of Seal(s)	3/8" BENTONITE CHIPS		
Comments	East side of gravel road, SW 1/4 NE 1/4 SEC 33 T19N R4E				

Elevation, feet	Depth, feet	SAMPLES Type	Number	Blows per 6-inch Interval	Percent Recovery	Graphic Log	MATERIAL DESCRIPTION	Well Completion Log	Drilling Rate (Time, 24-hour clock)	REMARKS
	0						Light brown, dry, gravelly SAND (SW) with trace silt, cobbles to 6"		0915	
	5									Hard drilling
	10								1000	
							Slightly moist			
	15						Dry, brown, sandy GRAVEL (GP), with trace silt, cobbles to 4"			
	20									
	25									
	30									

Report: ENV_23A; Project File: I:\PROJECTS\WCIA\98\984009NA\DATA\WELLLO-1\FRED.GPJ; Data Template:WC_CORP1.GDT Printed: 1/21/99

Project: Frederickson Flooding Assessment
Project Location: Pierce County
Project Number: 54-984009NA

Log of Boring FR-4-1

Elevation, feet	Depth, feet	SAMPLES Type	Number	Blows per 6-inch Interval	Percent Recovery	Graphic Log	MATERIAL DESCRIPTION	Well Completion Log			Drilling Rate (Time, 24-hour clock)	REMARKS
	30										1025	
							SAND, brown, fine, some silt, dry					
	35											
	40										1035	
	45											
	50										1043	
							Dry, gray, silty, fine SAND (SW), with trace clay					
	55											
							Wet, brown SAND					
	60										1100	
	65											
							Wet, gray, fine to medium SAND (SW) with trace silt					
	70										1113	

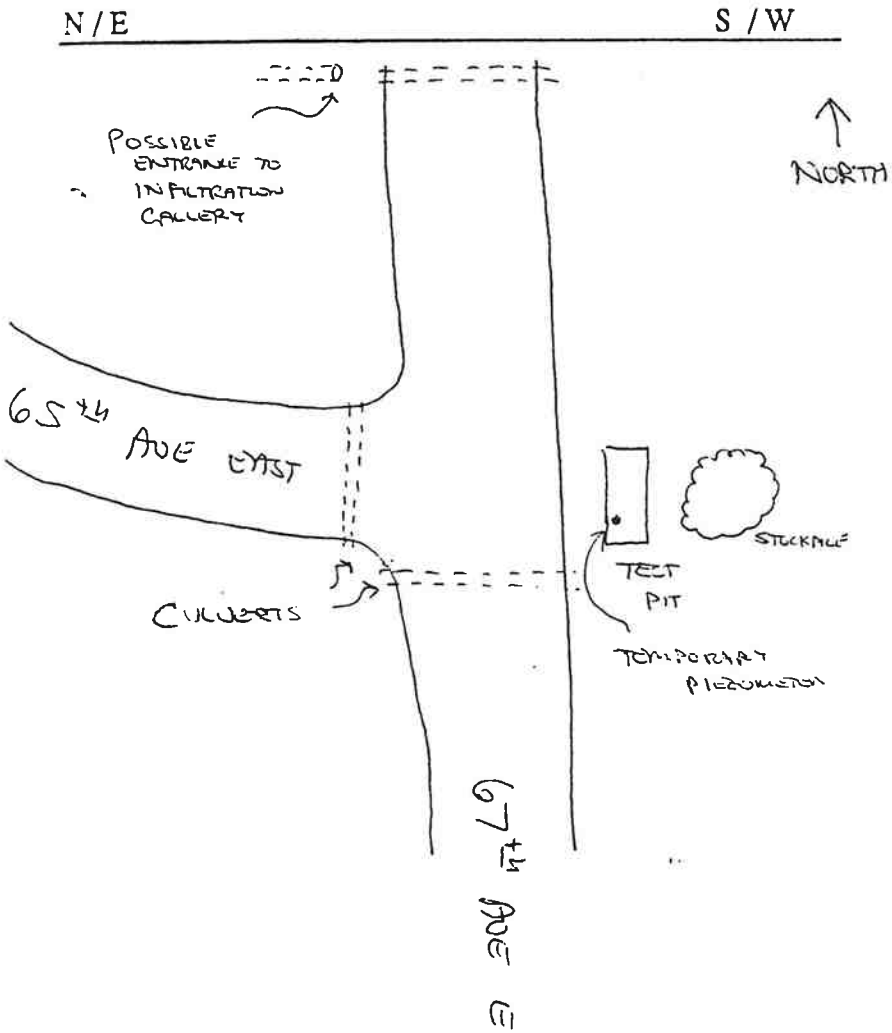
Report: ENV_23A; Project File: I:\PROJECTS\WCIA\98\984009NA\DATA\WELLLO~1\FRED.GPJ; Data Template:WC_CORP1.GDT Printed: 1/21/99

TEST PIT LOG **TEST PIT NUMBER :** TP-FM-1

Project: FREDRICKSON / FIR MEADOWS
Project No.: 54984009 NA.01
Site Location: 67th / 65th AVE EAST
Excavation Co.: COUNTY

Date: 12/21/99
Field Personnel: J GIBBONS / H HUNCOR
Total Depth: 13.5'
Samples Collected:

TP-FM-1



MOIST BLACK VERY SILTY COARSE SAND w/ OCCASIONAL GRAVEL - COARSENING DOWNWARD

MOIST TAN SILTY SANDY COBBLEY GRAVEL WITH OCCASIONAL BOULDER

MOIST YELLOW SLIGHTLY SILTY SANDY VERY COARSE GRAVEL - FEWER COBBLES

MOIST TAN SANDY COARSE GRAVEL

MOIST YELLOW SANDY MEDIUM TO COARSE GRAVEL

WET YELLOW CLAYEY SILTY SANDY MEDIUM GRAVEL CLAY IS INTERSTITIAL

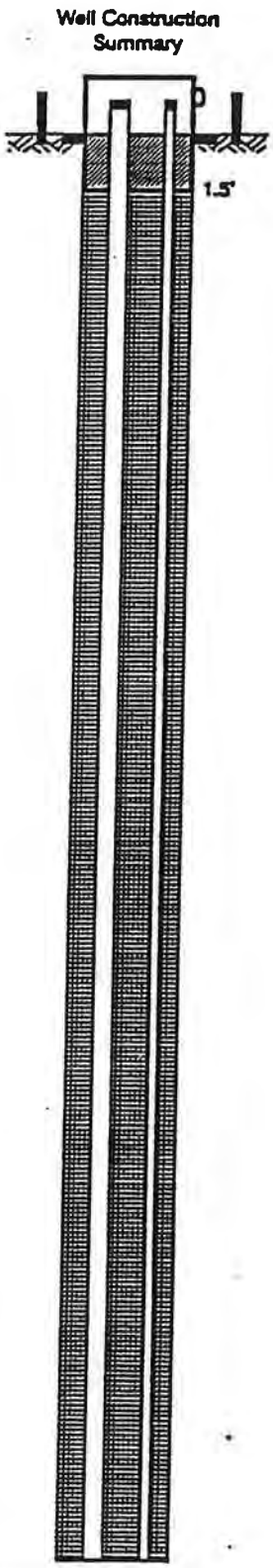
MORE CLAY INTERSTITIAL WITH SANDY GRAVEL

TD = 13.5'

Equipment IR T3W Air Rotary Date 3/3/92

Monument 432.74 feet Coordinates E41156 N45746

Elevation



Sheen	OVM	Blows per Foot	Depth	Sample	
			0		BROWN SILTY GRAVEL (GM) fine to coarse grained, with some sand.
			5		BROWN SILTY SAND (SM) fine to medium grained, with some gravel.
			10		BROWN SILTY GRAVEL (GM) fine to coarse grained, with some sand.
			15		
			20		BROWN SANDY GRAVEL (GW) fine to coarse grained, with some silt.
			25		Grades to a trace of silt.
			30		
			35		
			40		

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Log of BMW 4 (0-40')

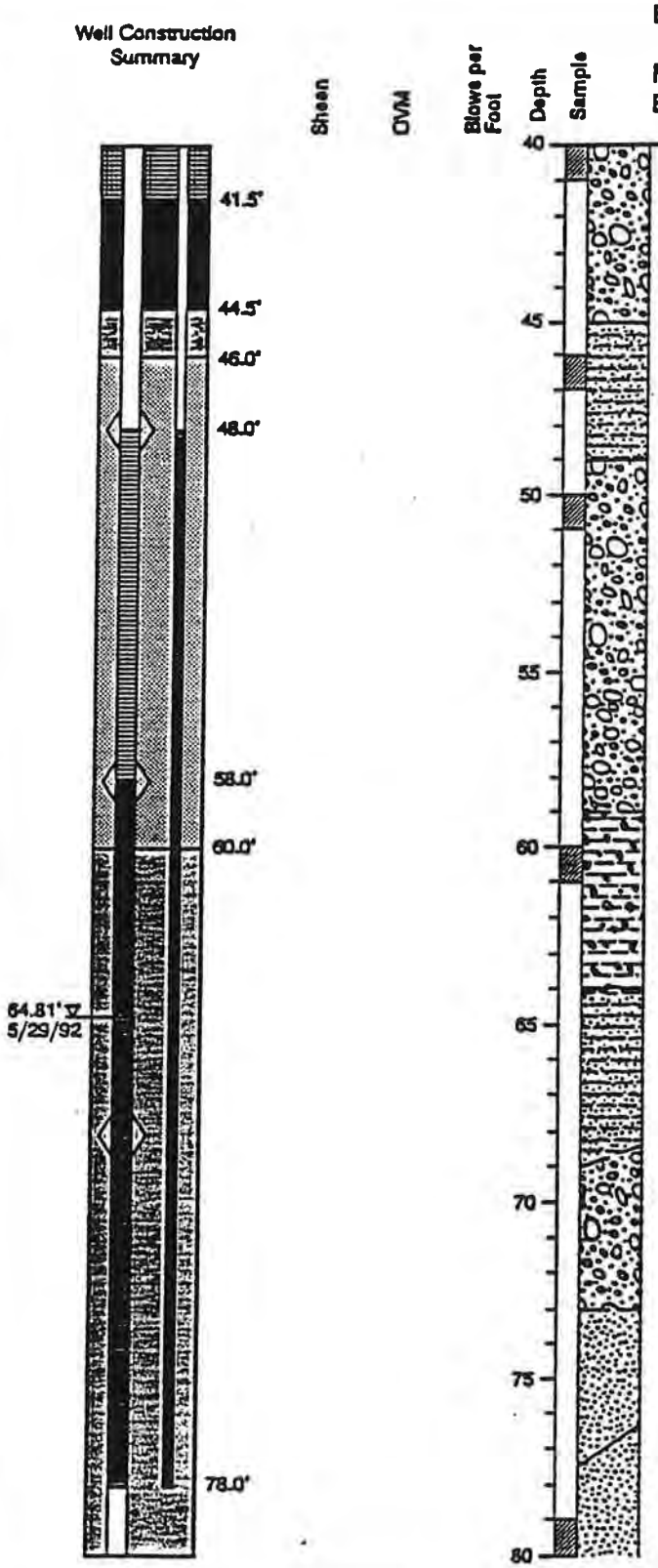
EBASCO/Boeing Frederickson Well Installation
Pierce County, Washington

PLATE 6a

JOB NUMBER	DRAWN	APPROVED	DATE	REVISED	DATE
14,161.007	SES	CMS	2 Sept 92		

Equipment IR T3W Air Rotary Date 3/3/92

Monument Elevation 432.74 feet Coordinates E41156 N45746



DARK BROWN SILTY SAND (SM) medium to coarse grained, with a trace of gravel.

DARK BROWN SANDY GRAVEL (GW) fine to coarse grained, with some silt.

BROWN SILTY GRAVEL (GM) fine to coarse grained, with sand.

BROWN SILTY SAND (SM) medium to coarse grained, with some gravel.

BROWN SANDY GRAVEL (GW) fine to coarse grained, with a trace of silt.

BROWN SAND (SP) medium to coarse grained, with gravel.

BROWN SAND (SP) medium to coarse grained, with a trace of gravel and silt.

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Log of BMW 4 (40'-80')

EBASCO/Boeing Frederickson Well Installation
Pierce County, Washington

PLATE 6h

JOB NUMBER	DRAWN	APPROVED	DATE	REVISED	DATE
14,161.007	SES	CHS	2 Sept 92		

Equipment IR T3W Air Rotary Date 3/3/92

Monument 432.74 feet Coordinates E41156 N45746

Elevation

Well Construction Summary

0.75" piezometer

Sheen	OVM	Blows per Foot	Depth	Sample
			80	
			85	
			90	
			95	
			100	
			105	
			110	
			115	
			120	

BROWN SANDY GRAVEL (GW) fine to coarse grained, with a trace of silt.

Boring terminated on 3/4/92.
Groundwater encountered at 62 feet during drilling.

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Log of BMW 4 (80'-81.5')

EBASCO/Boeing Frederickson Well Installation
Pierce County, Washington

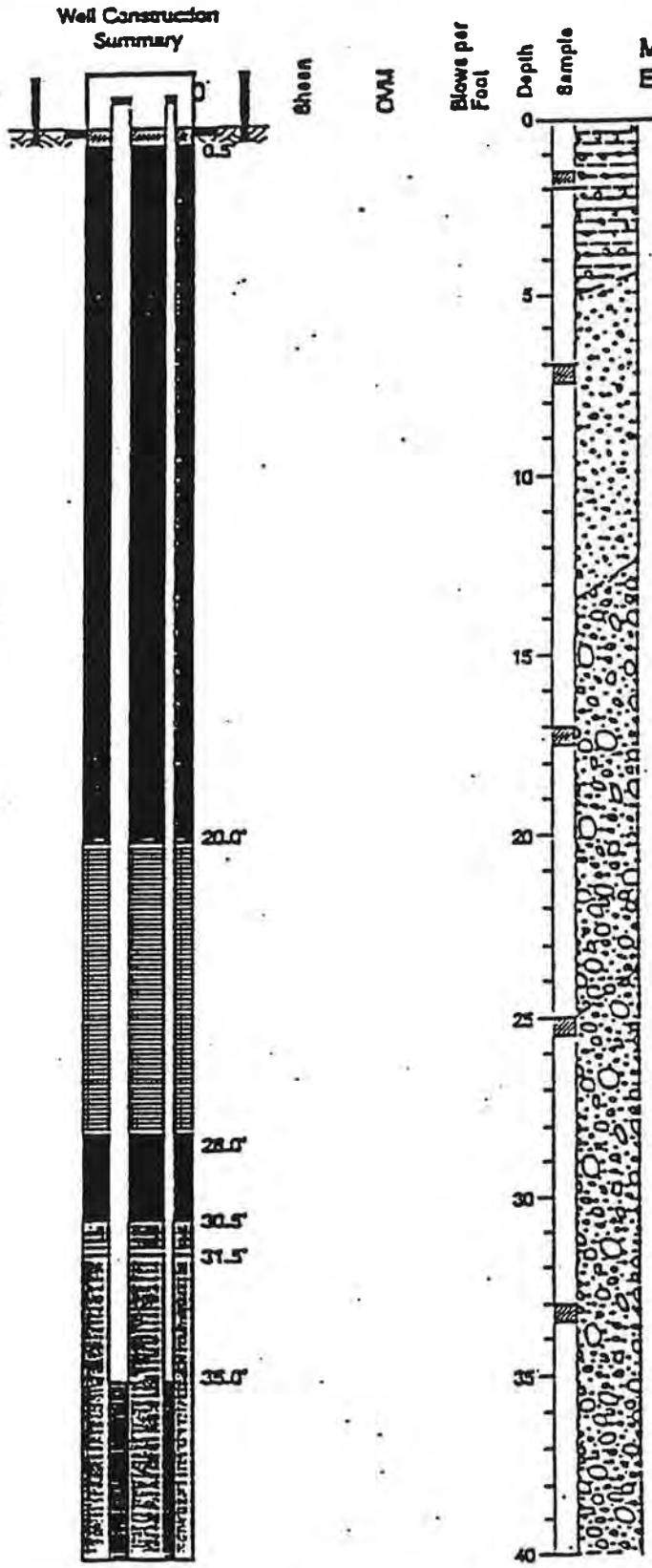
PLATE 6c

JOB NUMBER	DRAWN	APPROVED	DATE	REVISED	DATE
14,161.007	SES	CBS	2 Sept 92		

Equipment IR T3W Air Rotary Date 5/6/92

Monument 426.40 feet Coordinates E41208 N41922

Elevation



DARK BROWN SILTY GRAVEL (GM) fine to coarse grained, with fine to medium sand.

DARK BROWN GRAVELLY SAND (SW) fine to coarse grained, with some silt.

DARK BROWN GRAVEL (GW) fine to coarse grained, with some sand, and a trace of silt.

DARK BROWN SANDY GRAVEL (GW) fine to coarse grained, with some silt.

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Log of BMW 10 (0-40')

EBASCO/Boeing Frederickson Well Installation
Pierce County, Washington

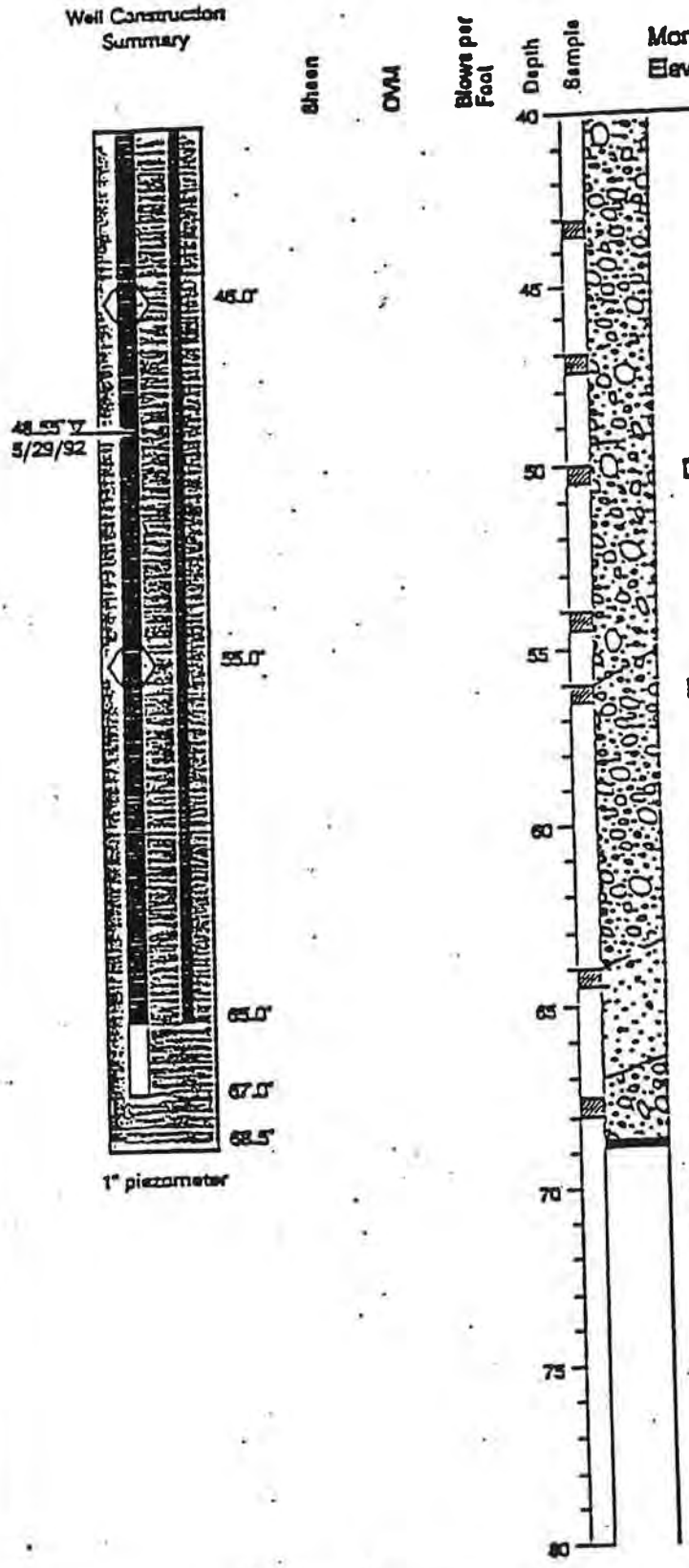
PLATE 12

JOB NUMBER	DRAWN	APPROVED	DATE	REVISED	DATE
14,161.007	SES	CVS	2 Sept 92		

Equipment IR T3W Air Rotary Date 5/6/92

Monument 426.40 feet Coordinates E41206 N41922

Elevation



DARK BROWN GRAVEL (GW) fine to coarse grained, with some coarse sand, and a trace of silt.

DARK BROWN SANDY GRAVEL (GW) fine to coarse grained, with some silt.

GRAY BLACK GRAVELLY SAND (SW) fine to coarse grained, with a trace of silt.

GRAY BLACK SANDY GRAVEL (GW) fine to coarse grained, with a trace of silt.

Boring terminated on 5/7/92.
Groundwater encountered at 50 feet during drilling.

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Log of BMW 10 (40'-68.5')

EBASCO/Boeing Frederickson Well Installation
Pierce County, Washington

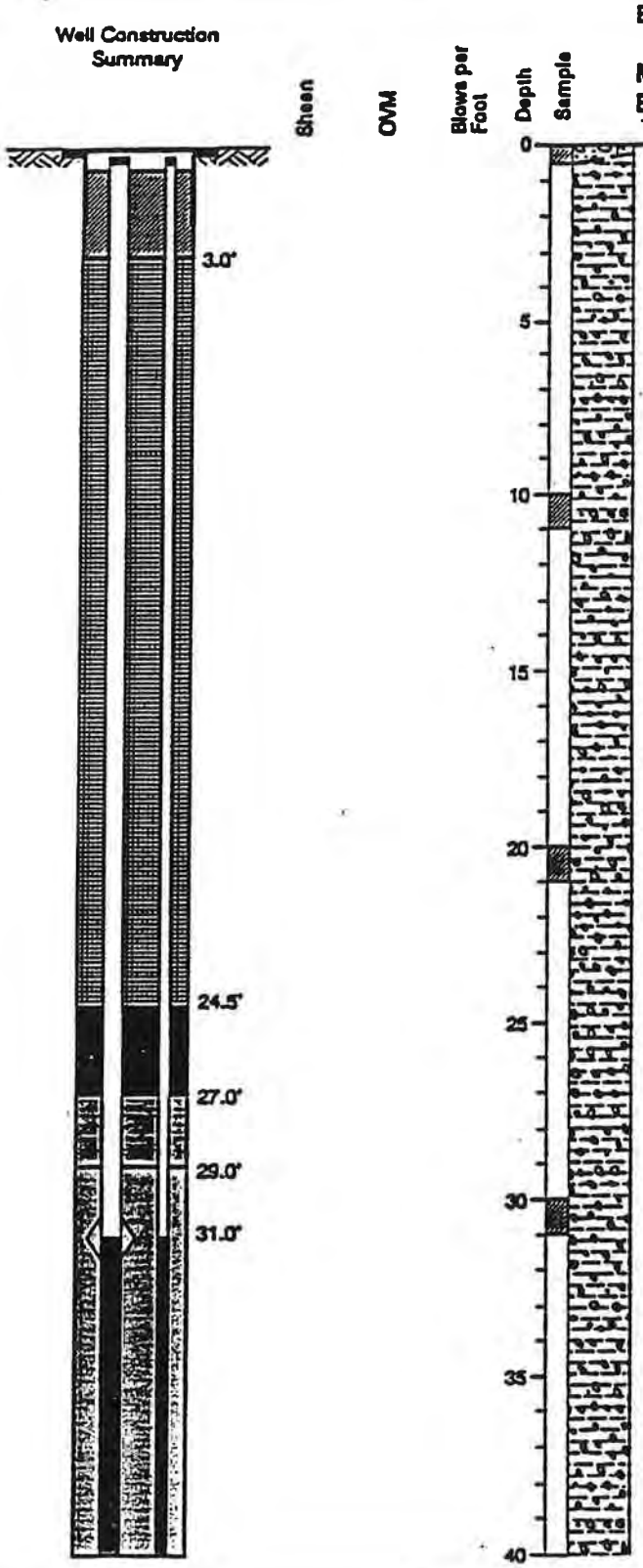
PLATE 12

JOB NUMBER	DRAWN	APPROVED	DATE	REVISED	DATE
14,161.007	SES		2 Sept 92		

Equipment IR T3W Air Rotary Date 2/18/92

Monument 416.50 feet Coordinates E40544 N44032

Elevation



GRAY GRAVEL (GW) fine to coarse grained, with some medium to coarse sand (Fill).

GRAY SILTY GRAVEL (GM) fine to coarse grained, with a trace of fine to medium sand.

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Log of BMW 14 (0-40')

EBASCO/Boeing Frederickson Well Installation
Pierce County, Washington

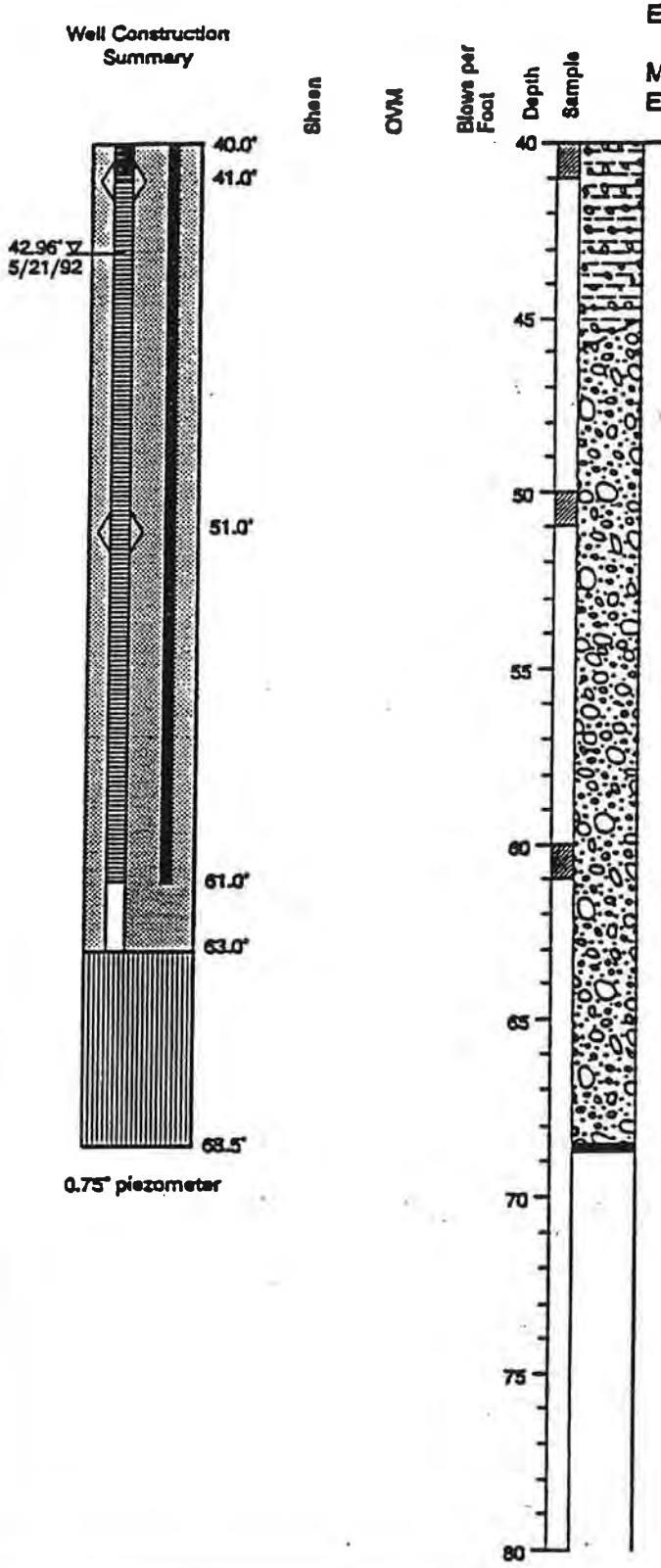
PLATE 15a

JOB NUMBER	DRAWN	APPROVED	DATE	REVISED	DATE
14.161.007	SES	CHS	2 Sept 92		

Equipment IR T3W Air Rotary Date 2/18/92

Monument 416.50 feet Coordinates E40544 N44032

Elevation



GRAY SANDY GRAVEL (GW) fine to coarse grained, with a trace of silt.

Boring terminated on 2/18/92.
Groundwater encountered at 49 feet during drilling.

Applied Geotechnology Inc.
Geotechnical Engineering
Geology & Hydrogeology

Log of BMW 14 (40'-68.5')
EBASCO/Boeing Frederickson Well Installation
Pierce County, Washington

PLATE **15b**

JOB NUMBER	DRAWN	APPROVED	DATE	REVISED	DATE
14,161.007	SES	CHB	2 Sept 92		

Appendix D

Predicted And Measured Groundwater Elevation Data

Depth to Groundwater and Water Level Elevation
Frederickson Watershed

Well	FR-1-1		FR2-2		FR-3-1		FR-3-2		FR-4-1	
Date	DTW (Ft BGS)	Elevation (Ft MSL)	DTW (Ft BGS)	Elevation (Ft MSL)	DTW (Ft BGS)	Elevation (Ft MSL)	DTW (Ft BGS)	Elevation (Ft MSL)	DTW (Ft BGS)	Elevation (Ft MSL)
1/15/99	36 00	388 13	98 40	420 56	25 00		59 2	452 35	42 8	
2/19/99	5 86	418 27	94 43	424 53	25 00	486 15	51 40	460.15	45 82	399 37
2/20/99	5 65	418 48	94 59	424 37	25 00		53 51	458 04	44 66	
2/26/99	5 91	418 22	94 77	424 19	25 00	486 15	54 41	457 14	44 46	400 73
3/4/99	5 45	418 68	94 45	424 51	25 00	486 15	52 56	458 99	43 91	401 28
3/10/99										
3/11/99	5 78	418 35	94 63	424 33	25 00	486 15	53 61	457 94	43 19	402 00
3/12/99										
3/16/99										
3/17/99										
3/18/99										
3/19/99	5 96	418 17	94 87	424 09	25	486 15	54 45	457 10	42 55	402 64
3/23/99										
3/24/99										
3/25/99										
3/26/99	6 23	417 90	95 18	423 78	25	486 15	55 89	455 66	42 29	402 90
3/30/99										
4/1/99	6 40	417 73	95 32	423 64	25	486 15	55 92	455 63		
4/2/99										
4/6/99										
4/7/99	6 98	417 15	95 51	423 45	25	486 15	56 59	454 96	41 68	403 51
4/8/99										
4/9/99										
4/13/99										
4/14/99										
4/15/99	8 18	415 95	95 79	423 17	25	486 15	58 39	453 16	41 67	403 52
4/21/99	9 50	414 63	96	422 96	25	486 15	59 65	451 90	41 66	403 53
4/29/99	10 06	414 07	96 33	422 63	25	486 15	61 11	450 44	41 94	403 25
5/24/99	12 82	411 31	97 08	421 88	25	486 15	62 70	448 85	42 44	402 75
6/8/99									43 2	401 99
6/11/99	15 14	408 99	98 83	420 13	Dry	Dry	65 20	446 35		
6/23/99	16 79	407 34	100 4	418 56	Dry	Dry	66 37	445 18	43 55	401 64
7/8/99	18 54	405 59	102 19	416 77	Dry	Dry	67 54	444 01	44 23	400 96
7/21/99	20 39	403 74	104 19	414 77	Dry	Dry	68 94	442 61	44 83	400 36
8/10/99	23 08	401 05	107 43	411 53	Dry	Dry	70 75	440 80	45 53	399 66
9/7/99	26 4	397 73	111 93	407 03	Dry	Dry	73 28	438 27	46 77	398 42
10/15/99	30 1	394 03	116 54	402 42	Dry	Dry	75 76	435 79	48 41	396 78
10/18/99										
11/3/99	31 53	392 60	118 34	400 62	Dry	Dry	76 4	435 15	48 93	396 26
11/17/99	30 79	393 34	118 17	400 79	Dry	Dry	73 47	438 08	49 59	395 60
12/10/99	27 68	396 45	112 17	406 79	Dry	Dry	63 31	448 24		
12/13/99	27 23	396 90	110 92	408 04	Dry	Dry	63 25	448 30	49 59	395 60
12/14/99										
12/22/99	25 22	398 91	107 25	411 71	Dry	Dry	59 83	451 72	49 15	396 04
12/30/99	25 1	399 03	105 18	413 78	Dry	Dry	61 31	450 24	48 8	396 39
1/5/00	24 46	399 67	103 83	415 13	Dry	Dry	62 41	449 14	48 85	396 34
1/6/00							62 41	449 14		
1/18/00										
1/20/00	21 34	402 79	100 85	418 11	Dry	Dry	61 03	450 52	48 1	397 09
2/4/00	19 57	404 56	98 75	420 21	Dry	Dry	61 4	450 15	47 5	397 69
2/10/00	18	406 13	97 51	421 45	Dry	Dry	59 97	451 58	47 16	398 03
2/18/00	16 79	407 34	96 81	422 15	Dry	Dry	58 78	452 77	47 01	398 18
2/25/00	15 54	408 59	96 58	422 38	Dry	Dry	59 45	452 10	46 43	398 76
3/3/00					Dry	Dry	58 12	453 43		
3/8/00	11 4	412 73	96 03	422 93						
3/9/00			96 03	422 93	Dry	Dry	55 69	455 86		
3/15/00	10 76	413 37	95 91	423 05	Dry	Dry	56 89	454 66	45 26	399 93
3/23/00	9 97	414 16	95 89	423 07	Dry	Dry	57 25	454 30	45 03	400 16
4/3/00	10 18	413 95	96 3	422 66	Dry	Dry	58 68	452 87	44 31	400 88
4/19/00	10 97	413 18	96 43	422 53	Dry	Dry	59 81	451 74	44 27	400 92
5/8/00	12 53	411 60	96 76	422 20	Dry	Dry	61 35	450 20	43 98	401 21
Minimum	5 45	388 13	94 43	400 62	25 00	486 15	51 40	435 15	41 66	395 60
Maximum	36 00	418 68	118 34	424 53	25 00	486 15	76 40	460 15	49 59	403 53
Fluctuation	30 55	30 55	23 91	23 91	0.00	0.00	25 00	25 00	7 93	7 93

Depth to Groundwater and Water Level Elevation
Frederickson Watershed

Well	POND SG		RMW-1		RMW-3		PZ-1		PZ-4		P.O.T. Well	
Date	DTW (Ft BGS)	Elevation (Ft MSL)	DTW (Ft BGS)	Elevation (Ft MSL)	DTW (Ft BGS)	Elevation (Ft MSL)	DTW (Ft BGS)	Elevation (Ft MSL)	DTW (Ft BGS)	Elevation (Ft MSL)	DTW (Ft BGS)	Elevation (Ft MSL)
1/15/99												
2/19/99	2.11	378.18	14.56	377.64	45.85	389.95						
2/20/99												
2/26/99			14.38	377.82	44.95	390.85	35.28	392.52	25.52	395.98		
3/4/99	3.48	379.55	13.15	379.05	43.68	392.12	33.77	394.03	23.94	397.56	21.61	362.74
3/10/99	3.72	379.79										
3/11/99	3.70	379.77	13.19	379.01	43.68	392.12	DRY		24.38	397.12	20.92	363.43
3/12/88	3.68	379.75										
3/16/99	3.86	379.93										
3/17/99	3.74	379.81										
3/18/99	3.70	379.77										
3/19/99	3.62	379.69	13.08	379.12	43.79	392.01	34.26	393.54	24.67	396.83	20.35	364.00
3/23/99	3.42	379.49										
3/24/99	3.36	379.43										
3/25/99	3.40	379.47										
3/26/99	3.40	379.47	13.27	378.93	44.58	391.22	34.77	393.03	25.2	396.30	20.1	364.25
3/30/99	3.40	379.47										
4/1/99	3.34	379.41	13.21	378.99	44.24	391.56	35.18	392.62	25.24	396.26	20.3	364.05
4/2/99	3.26	379.33										
4/6/99	3.04	379.11										
4/7/99	2.98	379.05	13.41	378.79	44.58	391.22	35.63	392.17	25.37	396.13	19.76	364.59
4/8/99	2.92	378.99										
4/9/99	2.86	378.93										
4/13/99	2.58	378.65										
4/14/99	2.52	378.59										
4/15/99			13.97	378.23	45.32	390.48	36.58	391.22	26.57	394.93	19.85	364.50
4/21/99	2.02	378.09	14.41	377.79	45.36	390.44	37.2	390.60	26.55	394.95	20.11	364.24
4/29/99	1.42	377.49	15.14	377.06	46	389.80	38.1	389.70	27.24	394.26		
5/24/99			17.04	375.16	48.33	387.47	40.35	387.45	29.05	392.45		
6/8/99			18.79	373.41	49.73	386.07						
6/11/99							Dry		Dry		Locked	
6/23/99	0.00		19.95	372.25	52.46	383.34	Dry		31.45	390.05	Locked	
7/8/99	0.00		21.14	371.06	52.59	383.21	Dry		32.59	388.91	Locked	
7/21/99	Dry		22.21	369.99	53.86	381.94	Dry		33.69	387.81	Locked	Locked
8/10/99	Dry		23.68	368.52	55.63	380.17	Dry		35.86	385.84	Discontinued	Discontinued
9/7/99	Dry		25.38	366.82	58.38	377.42	Dry		39.1	382.40	Discontinued	Discontinued
10/15/99									39.1	382.40		
10/18/99			26.4	365.80	61.48	374.32	Dry		42.79	378.71	Discontinued	Discontinued
11/3/99	Dry		25.6	366.60	62.48	373.32	DRY		43.92	377.58	Discontinued	Discontinued
11/17/99	Dry		24.81	367.39	60.38	375.42	DRY		39.66	381.84	Discontinued	Discontinued
12/10/99	Dry		21.97	370.23	58.37	377.43	DRY		32.08	389.42	Discontinued	Discontinued
12/13/99	Dry						DRY				Discontinued	Discontinued
12/14/99			21.72	370.48	58.1	377.70	DRY		32.08	389.42	Discontinued	Discontinued
12/22/99	Dry		20.16	372.04	56.59	379.21	DRY		30.36	391.14	Discontinued	Discontinued
12/30/99	Dry		20.39	371.81	56.63	379.17	DRY		31.17	390.33	Discontinued	Discontinued
1/5/00	Dry											
1/6/00			20.7	371.50	56.48	379.32	DRY		31.96	389.54		
1/18/00			20.27	371.93	55.43	380.37	DRY		31.31	390.19		
1/20/00	Dry											
2/4/00	Dry		20.24	371.96	54.65	381.15	DRY		31.44	390.06		
2/10/00	Dry		19.8	372.40	53.92	381.88	41.73	386.07	30.86	390.64		
2/16/00	Dry		19.5	372.70	53.37	382.43	41.29	386.51	30.22	391.28		
2/25/00	Dry				52.95	382.85	41.4	386.40	30.46	391.04		
3/3/00			19.19	373.01								
3/6/00	0.22	376.29	18.28	373.92								
3/9/00					50.89	384.91	39.47	388.33	28.49	393.01		
3/15/00	0.2	376.27	18.27	373.93	50.55	385.25	39.65	388.15	28.73	392.77		
3/23/00	0.25	376.32	18.28	373.92	49.88	385.92	39.6	388.20	28.99	392.51		
4/3/00	0.01	376.08	18.48	373.72	49.57	386.23	39.73	388.07	28.87	392.63		
4/19/00	Dry		19.05	373.15	49.52	386.28	40.49	387.31	29.56	391.94		
5/8/00	Dry		19.66	372.54	49.99	385.81	41.08	386.72	30.21	391.29		
Minimum	0.00	376.08	13.08	365.80	43.68	373.32	33.77	386.07	23.94	377.58	19.76	362.74
Maximum	3.86	379.93	26.40	379.12	62.48	392.12	41.73	394.03	43.92	397.56	21.61	364.59
Fluctuation	3.86	3.85	13.32	13.32	18.80	18.80	7.96	7.96	19.98	19.98	1.85	1.85

Predicted Groundwater Elevations based on Precipitation Using the Modified Speransky Equation

Month	PPT (Inches)	Running 3-Month Total	Water Year (inches)	Predicted Groundwater Elevation	Actual Pond Elevation	Actual RMW-1 Elevation
Nov-89	7.52					
Dec-89	4.51					
Jan-90	10.65	22.68			376.1	375.5
Feb-90	6.01	21.17				375.7
Mar-90	3.42	20.08		375.21392		374.8
Apr-90	3.04	12.47		374.46798	375.5	374.5
May-90	2.9	9.36		373.92952		372.3
Jun-90	4.04	9.98		370.17018		371.5
Jul-90	0.7	7.64		368.63384	375.6	
Aug-90	1.52	6.26		368.94012		
Sep-90	0.04	2.26	46.50	367.78416		
Oct-90	5.88	7.44		369.42744	374.2	366.4
Nov-90	10.74	16.66		367.45144		
Dec-90	4.26	20.88		370.94036		
Jan-91	3.61	18.61		375.49504		
Feb-91	5.75	13.62		377.57972		
Mar-91	4.86	14.22		376.45834		
Apr-91	6.66	17.27		373.99328		
May-91	2.71	14.23		374.28968		
Jun-91	1.55	10.92		374.86638		
Jul-91	0.28	4.54		373.36462		
Aug-91	1.38	3.21		371.72948		
Sep-91	0.59	2.25	48.27	368.57776		
Oct-91	1.87	3.84		368.00924		
Nov-91	7.17	9.63		367.535		
Dec-91	3.57	12.61		369.28586		
Jan-92	6.09	16.83		372.14612		
Feb-92	3.52	13.18		373.61824		
Mar-92	2.1	11.71		375.70292		
Apr-92	4.68	10.30		373.89982		
May-92	0.22	7.00		373.17364		
Jun-92	1.94	6.84		371.5117		
Jul-92	1.03	3.19		369.8815		
Aug-92	0.92	3.89		369.80246		
Sep-92	1.98	3.93	35.09	367.99936		
Oct-92	2.22	5.12		365.93166		
Nov-92	6.91	11.11		365.95142		
Dec-92	3.63	12.76		366.53928		366.09
Jan-93	3.57	14.11		369.49834		366.8
Feb-93	0.33	7.53		370.31344		367.57
Mar-93	4.77	8.67		370.98034		366.52
Apr-93	6.66	11.76		367.72982		369.46
May-93	4	15.43		368.29298		370.05
Jun-93	3.23	13.89		369.81944		369.04
Jul-93	2.2	9.43		371.63242		367.65
Aug-93	0.31	5.74		370.87166		366.83
Sep-93	0	2.51	37.83	368.66842		366
Oct-93	1.74	2.05		366.84556		365.29
Nov-93	1.63	3.37		365.24994		364.98

Predicted Groundwater Elevations based on Precipitation Using the Modified Speransky Equation

Month	PPT (Inches)	Running 3-Month Total	Water Year (inches)	Predicted Groundwater Elevation	Actual Pond Elevation	Actual RMW-1 Elevation
Dec-93	4.75	8.12		365.0227		365.25
Jan-94	3.35	9.73		365.67478		365.62
Feb-94	4.59	12.69		368.02128		366.89
Mar-94	4.09	12.03		368.81662		368.82
Apr-94	2.84	11.52		370.27886		368.02
May-94	1.86	8.79		369.95282		367.17
Jun-94	2.32	7.02		369.70088		366.45
Jul-94	1.19	5.37		368.35226		365.89
Aug-94	0.42	3.93		367.47788		364.83
Sep-94	2.47	4.08	31.25	366.66278		364.59
Oct-94	5.36	8.25		365.95142		
Nov-94	6.04	13.87		366.02552		364.8
Dec-94	8.8	20.20		368.0855		368.42
Jan-95	4.21	19.05		370.86178		371.61
Feb-95	5.35	18.36		373.9888		371.76
Mar-95	4.92	14.48		373.4207		374.19
Apr-95	2.88	13.15		373.07984		373.52
May-95	1.56	9.36		371.16312		371.92
Jun-95	1.73	6.17		371.5061		369.97
Jul-95	1.76	5.05		369.63384		368.26
Aug-95	0	3.49		368.05798		
Sep-95	1.72	3.48	44.33	367.5047		
Oct-95	4.71	6.43		367.95056		
Nov-95	9.51	15.94		367.94562		
Dec-95	6.17	20.39		370.28952		
Jan-96	8.16	**23.84**		374.98746		
Feb-96	8.73	**23.06**		377.18576		
Mar-96	2.57	19.46		378.89006		
Apr-96	7.23	18.53		378.50474		
May-96	4.57	14.37		376.72634		
Jun-96	1.34	13.14		375.38032		
Jul-96	1.08	6.99		373.32528		
Aug-96	0.30	2.72		372.71766		
Sep-96	2.34	3.72	56.71	369.67956		
Oct-96	6.07	8.71		368.18918		
Nov-96	8.26	16.67		368.68318		
Dec-96	12.23	**26.56**		372.28244		
Jan-97	7.82	**28.31**		376.21468		
Feb-97	3.83	23.88		381.10034		
Mar-97	7.06	18.71		381.96484	381.9	380.9
Apr-97	3.80	14.69		379.77642		
May-97	2.91	13.77		377.22244		
Jun-97	2.82	9.53		374.10236		
Jul-97	1.96	7.69		373.64788		
Aug-97	1.13	5.91		371.55332		
Sep-97	2.51	5.60	60.40	370.64436		
Oct-97	6.13	9.77		369.94954		
Nov-97	4.27	12.91		369.7964		
Dec-97	3.10	13.50		373.06438		

Predicted Groundwater Elevations based on Precipitation Using the Modified Speransky Equation

Month	PPT (Inches)	Running 3-Month Total	Water Year (inches)	Predicted Groundwater Elevation	Actual Pond Elevation	Actual RMW-1 Elevation
Jan-98	7.60	14.97		374.61554		
Feb-98	4.05	14.75		374.907		
Mar-98	5.01	16.66		375.63318		
Apr-98	1.53	10.59		375.5245	375.97	
May-98	3.08	9.62		376.46804		
Jun-98	1.18	5.79		372.26146		
Jul-98	0.29	4.55		371.78228		
Aug-98	0.05	1.52		369.89026		
Sep-98	0.46	0.80	36.75	369.2777		
Oct-98	3.98	4.49		365.76088		
Nov-98	11.16	15.60		365.4052		
Dec-98	9.69	**24.83**		367.22806		
Jan-99	8.63	**29.48**		372.7164	380.1	
Feb-99	6.53	**24.85**		377.27602		377.64
Mar-99	5.06	20.22		379.57312	379.47	378.93
Apr-99	1.28	12.87		377.2859	377.49	377.06
May-99	3.26	9.60		374.99868		375.16
Jun-99	2.28	6.82		371.36778		372.25
Jul-99	0.97	6.51		369.7524		369.99
Aug-99	0.88	4.13		368.37908		368.58
Sep-99	0.44	2.29	54.16	368.22594		366.82
Oct-99	3.1	4.42		368.75822		365.8
Nov-99	11.33	14.87		367.84926		367.39
Dec-99	5.14	19.57		369.98468		371.81
Jan-00	3.82	20.29		375.14698		371.93
Feb-00	4.97	13.93		377.46878		372.8
Mar-00	5.76	14.55		377.82446		373.92
Apr-00	2.14	12.87		374.68262	376.08	373.15
May-00						

Historical Groundwater Data for Selected Monitoring Wells in the Study Area

Date	PPT	Water yr	Pond	RMW-1	RMW-3	City Well	BMW-4	BMW-10
10/28/87	0.35							
11/28/87	3.16							
12/28/87	6.86							
1/28/88	4.08							
2/28/88	1.49							
3/28/88	5.98							
4/28/88	4.67							
5/28/88	4.35							
6/28/88	2.4							
7/28/88	1.18							
8/28/88	0.6							
9/28/88	2.09	37.21						
10/28/88	2.98							
11/28/88	9.17							
12/28/88	3.51							
1/28/89	3.74							
2/28/89	3.3							
3/28/89	6.95							
4/28/89	3.57							
5/28/89	2.81							
6/28/89	1.4							
7/28/89	0.69							
8/24/89	0.82							
9/28/89	0.29	39.23						
10/28/89	2.15							
11/28/89	7.52							
12/28/89	4.51							
1/28/90	10.65							
2/8/90			376.1					
2/15/90			376.7	375.5	385.5			
2/20/90			376.7					
2/23/90				375.7	386.3			
2/24/90	6.01		376.6					
3/3/90			376.6					
3/20/90			376.6					
3/24/90			375.4					
3/26/90	3.42			374.8	388.6			
4/7/90			376.3					
4/14/90			376.1					
4/20/90	3.04			373.5	387.8			
5/1/90			376					
5/18/90			375.6					
5/19/90	2.9			372.3	386			
6/2/90	4.04		375.6	371.5	384.5			
7/2/90	0.7			371.7	384.3			
8/2/90								
8/30/90	1.52							
9/15/90	0.04	46.5						
10/9/90			374.2	366.4	376.3			
10/31/90	5.58							
11/30/90	10.74							

Historical Groundwater Data for Selected Monitoring Wells in the Study Area

Date	PPT	Water yr	Pond	RMW-1	RMW-3	City Well	BMW-4	BMW-10
12/30/90	4.26							
1/28/91	3.61				382.1			
2/28/91	5.75							
3/30/91	4.86							
4/30/91	6.66							
5/30/91	2.71							
6/30/91	1.55							
7/30/91	0.28							
8/12/91	1.38				381.1			
9/22/91	0.59	47.97			377			
10/24/91	1.87				375.8			
11/29/91	7.17				375.3			
12/26/91	3.57				374.6			
2/1/92	6.09				376.3			
2/28/92	3.52							
4/4/92	2.1				375.8			
5/2/92	4.68				377.2			
5/29/92	0.22						367.93	377.85
6/30/92	1.94							
7/6/92	1.03				376.6			
8/26/92	0.92				373.23		366.57	371.75
9/18/92	1.98	33.11			371.98		362.25	369.9
10/16/92	2.22				371.26		361.06	368.26
11/17/92	6.91				370.87		360.56	367.57
12/15/92	3.63			366.09	371.59		361.52	368.37
1/22/93	3.57			366.8	372.81		361.72	369.34
2/18/93	0.33			367.57	374.47		362.88	371.18
3/19/93	4.77			366.62	374		363.29	371.23
4/20/93	6.6			369.46	377.78		367.78	375.48
5/24/93	4			370.05	379.34		368.82	378.32
6/21/93	3.23			369.04	379.48		368.75	378.82
7/19/93	2.2			367.65	378.48		367.59	377.87
8/16/93	0.31			366.83	377.31		366.67	376.52
9/17/93	0	37.77		366	375.53		364.93	374.32
10/18/93	1.74			365.29	373.85		363.43	372.22
11/19/93	1.63			364.98	372.89		362.74	370.87
12/17/93	4.75			365.25	372.06		362.54	369.38
1/21/94	3.35			365.62	371.7		361.9	368.56
2/17/94	4.29			366.89	372.97		361.41	368.44
3/25/94	4.09			368.82	375.64		365.36	372.2
4/27/94	2.84			368.02	376.03		364.63	373.84
5/19/94	1.86			367.17	375.71		364.66	373.79
6/16/94	2.32			366.45	374.19		364.34	373.31
7/15/94	1.19			365.89			363.46	372.1
8/22/94	0.42			364.83	371.35		361.64	369.51
9/16/94	2.47	30.95		364.59	371		360.97	368.33
10/19/94	5.36				371.3		359.8	366.89
11/17/94	6.04			364.8	371.29		360.89	367.3
12/21/94	8.8			368.42	374.19		364.12	369.92
1/23/95	4.21			371.61	376.3		368.33	376.82
2/16/95	5.35			371.76	379.85		369.49	379.23

Historical Groundwater Data for Selected Monitoring Wells in the Study Area

Date	PPT	Water yr	Pond	RMW-1	RMW-3	City Well	BMW-4	BMW-10
3/16/95	4.92			374.19	383.88	360	375.04	384.17
4/8/95			376			360.4		
4/14/95	2.88			373.52	385.21	360.7	375.44	385.82
5/17/95	1.56			371.92	384.64	361.6	374.7	385.22
6/16/95	1.73			369.97	382.46	360.5	372.72	383.11
7/17/95	1.76			368.26	380	357	370.78	380.5
8/28/95	0					354		
9/28/95	1.72	44.33				352.5		
10/28/95	4.71					352.2		
11/28/95	9.51					352.7		
12/28/95	6.17					353.5		
1/28/96	8.16					356.5		
2/28/96	8.73					358		
						360.5		
3/28/96	2.57					363		
4/28/96	7.23					364.7		
5/28/96	4.57					365.8		
6/28/96	1.34					363.6		
7/28/96	1.08					360.9		
8/28/96	0.3					358		
9/28/96	2.34	56.71				356.2		
10/28/96	6.07					356.4		
11/28/96	8.26					356.1		
12/28/96	12.23					356.7		
1/28/97	7.82					359.6		
2/28/97	3.83					362.8		
3/28/97	7.06		381.9	380.9	390.94	366	387.1	395.5
4/10/97						366.6	386.37	395.25
4/28/97	3.8					367.2		
5/28/97	2.91					366.7		
6/28/97	2.82					366.6		
7/28/97	1.96					366.8		
8/28/97	1.13					362		
9/28/97	2.51	60.4				358		
10/28/97	6.13					356.6		
11/28/97	4.27					356.9		
12/28/97	3.1					357.8		
1/28/98	7.6					358.6		
2/28/98	4.05					361		
3/28/98	5.01					365.06		
4/2/98			375.97			364.66		
4/28/98	1.53					364.22		
5/28/98	3.08					361.95		
6/28/98	1.18					358.5		
7/28/98	0.29					357.93		
8/28/98	0.05					356.81		
9/28/98	0.46	36.75				356.99		
10/28/98	3.98					357.18		
11/28/98	11.16					357.37		
12/28/98	9.69					358.5		
1/28/99	5.15					358.09		

Historical Groundwater Data for Selected Monitoring Wells in the Study Area

Date	PPT	Water yr	Pond	RMW-1	RMW-3	City Well	BMW-4	BMW-10
2/19/99	4.81		378.18	377.64	389.95	365.45		
3/4/99						368.55		
3/10/99			379.79			367.92		
3/11/99			379.77	379.01	392.12			
3/12/99			379.75					
3/16/99			379.93					
3/17/99			379.81					
3/18/99			379.77					
3/19/99			379.69	379.12	392.01			
3/23/99			379.49					
3/24/99			379.43					
3/25/99			379.47					
3/26/99			379.47	378.93	391.22			
3/30/99	4.10		379.47					
4/1/99			379.41	378.99	391.56			
4/2/99			379.33					
4/6/99			379.11					
4/7/99			379.05	378.79	391.22			
4/8/99			378.99					
4/9/99			378.93					
4/13/99			378.65					
4/14/99			378.59					
4/15/99				378.23	390.48			
4/21/99			378.09	377.79	390.44			
4/29/99	1.28		377.49	377.06	389.80			
5/24/99	3.26			375.16	387.47			
6/8/99				373.41	386.07			
6/11/99								
6/23/99	2.28			372.25	383.34			
7/8/99				371.06	383.21			
7/21/99	0.97			369.99	381.94			
8/10/99	0.88			368.52	380.17			
9/7/99	0.44			366.82	377.42			
10/15/99								
10/18/99	3.10			365.80	374.32			
11/3/99				366.60	373.32			
11/17/99	11.33			367.39	375.42			
12/10/99				370.23	377.43			
12/13/99								
12/14/99				370.48	377.70			
12/22/99				372.04	379.21			
12/30/99	5.14			371.81	379.17			
1/6/00				371.50	379.32			
1/19/00	3.82			371.93	380.37			
2/4/00				371.96	381.15			
2/10/00				372.40	381.88			
2/16/00				372.70	382.43			
2/25/00	4.97				382.85			
3/3/00				373.01				
3/8/00			376.28	373.92				
3/9/00					384.91			

Historical Groundwater Data for Selected Monitoring Wells in the Study Area

Date	PPT	Water yr	Pond	RMW-1	RMW-3	City Well	BMW-4	BMW-10
3/15/00			376.27	373.93	385.21			
3/23/00	5.76		376.32	373.92	385.92			
4/3/00			376.08	373.72	386.23			
4/19/00	2.14			373.15	386.28			
5/8/00				372.54	385.81			

Historical Groundwater Data for Selected Monitoring Wells in the Study Area

Date	PPT	Water yr	BMW-14	11-C	14-A	PZ-1	PZ-4
10/28/87	0.35						
11/28/87	3.16						
12/28/87	6.86						
1/28/88	4.08						
2/28/88	1.49						
3/28/88	5.98						
4/28/88	4.67						
5/28/88	4.35						
6/28/88	2.4						
7/28/88	1.18						
8/28/88	0.6						
9/28/88	2.09	37.21					
10/28/88	2.98						
11/28/88	9.17						
12/28/88	3.51						
1/28/89	3.74						
2/28/89	3.3						
3/28/89	6.95						
4/28/89	3.57						
5/28/89	2.81						
6/28/89	1.4						
7/28/89	0.69						
8/24/89	0.82				372		
9/28/89	0.29	39.23					
10/28/89	2.15						
11/28/89	7.52						
12/28/89	4.51						
1/28/90	10.65						
2/8/90							
2/15/90							
2/20/90							
2/23/90							
2/24/90	6.01						
3/3/90							
3/20/90							
3/24/90							
3/26/90	3.42						
4/7/90							
4/14/90							
4/20/90	3.04						
5/1/90							
5/18/90							
5/19/90	2.9						
6/2/90	4.04						
7/2/90	0.7						
8/2/90					375.03		
8/30/90	1.52						
9/15/90	0.04	46.5					
10/9/90							
10/31/90	5.58				371.03		
11/30/90	10.74						

Historical Groundwater Data for Selected Monitoring Wells in the Study Area

Date	PPT	Water yr	BMW-14	11-C	14-A	PZ-1	PZ-4
12/30/90	4.26						
1/28/91	3.61						
2/28/91	5.75						
3/30/91	4.86						
4/30/91	6.66						
5/30/91	2.71						
6/30/91	1.55						
7/30/91	0.28						
8/12/91	1.38						
9/22/91	0.59	47.97					
10/24/91	1.87						
11/29/91	7.17						
12/26/91	3.57						
2/1/92	6.09						
2/28/92	3.52						
4/4/92	2.1						
5/2/92	4.68						
5/29/92	0.22		373.54	366.88	372.41		
6/30/92	1.94						
7/6/92	1.03						
8/26/92	0.92		367.94	359.68	368.13		
9/18/92	1.98	33.11	366.45	358.61	366.7		
10/16/92	2.22		365.2	357.51	367.12		
11/17/92	6.91		364.97	358.56	368.38		
12/15/92	3.63		366	364.08			
1/22/93	3.57		366.28	364.93			
2/18/93	0.33		367.3	365.68			
3/19/93	4.77		367.48	363.88			
4/20/93	6.6		371.15	368.67			
5/24/93	4		373.51	369.45			
6/21/93	3.23		373.97	368.34			
7/19/93	2.2		373.19	366.21			
8/16/93	0.31		371.99	364.37			
9/17/93	0	37.77	370.01	361.21			
10/18/93	1.74		368.41	359.34			
11/19/93	1.63		367.17	358.61			
12/17/93	4.75		366.46	358.95			
1/21/94	3.35		365.52	359.72			
2/17/94	4.29		365.49	359.8			
3/25/94	4.09		368.79	367.94			
4/27/94	2.84		369.29	366.61			
5/19/94	1.86		369.54	365.19			
6/16/94	2.32		369.21	363.4			
7/15/94	1.19		368.05	359.9			
8/22/94	0.42		365.88	357.71			
9/16/94	2.47	30.95	365.06	356.72			
10/19/94	5.36		363.61	355.16			
11/17/94	6.04		364.54	358.51			
12/21/94	8.8		367.19	368.45			
1/23/95	4.21		372.09	371.35			
2/16/95	5.35		374.11	371.54			

Historical Groundwater Data for Selected Monitoring Wells in the Study Area

Date	PPT	Water yr	BMW-14	11-C	14-A	PZ-1	PZ-4
3/16/95	4.92		379.11	374.22			
4/8/95							
4/14/95	2.88		380.82	373.78			
5/17/95	1.56		380.19	372.12			
6/16/95	1.73		378.42	370			
7/17/95	1.76		376.08	367.78			
8/28/95	0						
9/28/95	1.72	44.33					
10/28/95	4.71						
11/28/95	9.51						
12/28/95	6.17						
1/28/96	8.16						
2/28/96	8.73						
3/28/96	2.57						
4/28/96	7.23						
5/28/96	4.57						
6/28/96	1.34						
7/28/96	1.08						
8/28/96	0.3						
9/28/96	2.34	56.71					
10/28/96	6.07						
11/28/96	8.26						
12/28/96	12.23						
1/28/97	7.82						
2/28/97	3.83						
3/28/97	7.06					394.5	398.5
4/10/97			390.3				
4/28/97	3.8						
5/28/97	2.91						
6/28/97	2.82						
7/28/97	1.96						
8/28/97	1.13						
9/28/97	2.51	60.4					
10/28/97	6.13						
11/28/97	4.27						
12/28/97	3.1						
1/28/98	7.6						
2/28/98	4.05						
3/28/98	5.01						
4/2/98							
4/28/98	1.53						
5/28/98	3.08						
6/28/98	1.18						
7/28/98	0.29						
8/28/98	0.05						
9/28/98	0.46	36.75					
10/28/98	3.98						
11/28/98	11.16						
12/28/98	9.69						
1/28/99	5.15						

Historical Groundwater Data for Selected Monitoring Wells in the Study Area

Date	PPT	Water yr	BMW-14	11-C	14-A	PZ-1	PZ-4
2/19/99	4.81						
3/4/99						394.03	397.56
3/10/99							
3/11/99							397.12
3/12/99							
3/16/99							
3/17/99							
3/18/99							
3/19/99						393.54	396.83
3/23/99							
3/24/99							
3/25/99							
3/26/99						393.03	396.3
3/30/99	4.10						
4/1/99						392.62	396.26
4/2/99							
4/6/99							
4/7/99						392.17	396.13
4/8/99							
4/9/99							
4/13/99							
4/14/99							
4/15/99						391.22	394.93
4/21/99						390.6	394.95
4/29/99	1.28					389.70	394.26
5/24/99	3.26					387.45	392.45
6/8/99							
6/11/99							
6/23/99	2.28						390.05
7/8/99							388.91
7/21/99	0.97						387.81
8/10/99	0.88						385.84
9/7/99	0.44						382.4
10/15/99							382.4
10/18/99	3.10						378.71
11/3/99							377.58
11/17/99	11.33						381.84
12/10/99							389.42
12/13/99							
12/14/99							389.42
12/22/99							391.14
12/30/99	5.14						390.33
1/6/00							389.54
1/19/00	3.82						390.19
2/4/00							390.06
2/10/00						386.07	390.64
2/16/00						386.51	391.28
2/25/00	4.97					386.4	391.04
3/3/00							
3/8/00							
3/9/00						388.33	393.01

Historical Groundwater Data for Selected Monitoring Wells in the Study Area

Date	PPT	Water yr	BMW-14	11-C	14-A	PZ-1	PZ-4
3/15/00						388.15	392.77
3/23/00	5.76					388.2	392.51
4/3/00						388.07	392.63
4/19/00	2.14					387.31	391.94
5/8/00						386.72	391.29