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via Federal Express

December 14, 2000
MFG Project No. 020055

Mr. Paul Skyllingstad
Department of Ecology
Industrial Section
PO Box 47706
Olympia, WA 98504

RE: Technical Memorandum, Evaluation of Groundwater Extraction and Re-injection Alternatives, Kaiser Mead Works

Dear Mr. Skyllingstad:

On behalf of Kaiser Aluminum & Chemical Corporation (Kaiser), MFG, Inc. is pleased to submit three (3) copies of the enclosed Technical Memorandum on the evaluation of groundwater extraction and reinjection alternatives. This submittal is in compliance with Agreed Order Number DE 99TCPIS-95. The primary objective of the study was to select the design parameters for a groundwater pump and treat system that would be one component of the remedy to address groundwater contamination from spent potliner. The other components, addressed in the Engineering Design Report (MFG, Inc., November 2000), are characterized as source control measures and include consolidation/capping of waste piles and various measures to eliminate water and sewer line leaks. The major effect of these source control measures will be to substantially reduce or eliminate infiltration of water that could mobilize residual SPL constituents in the soil beneath the piles and some adjacent areas.

A calibrated, numerical groundwater flow and transport model was developed and used to simulate the effects of alternative pump and treat remedies, which included simulations of the effects of other components of the remedy. Additional data were collected and hydrogeologic conditions were re-evaluated in support of the modeling effort. Based on the results of the modeling, we are recommending that the remedial measures be implemented in a phased manner over a two-year period. The implementation of the consolidation/capping and water/sewer line leak repairs, combined with an intensive groundwater monitoring program, should be done on an accelerated basis and the effects of these source (infiltration) controls monitored. If specific criteria are not met within two years of their implementation (50% reduction in contaminant mass transport at the northern plant boundary) then the groundwater extraction, treatment , and re-injection system would be implemented. A system that extracts 25 gallons per minute from the basal portion of the

Zone A sand is the least intrusive (impacts due to re-injection) and most effective (treatment plant performance) configuration.

If you should have any questions, please call Deborah Lambert or Doug Frick at (425) 921-4000. Kaiser and we would be happy to sit down with you and other reviewers and answer any questions that may arise.

Sincerely,
MFG, INC.

for
Deborah P. Lambert, P.E.
Senior Engineer

Douglas R. Frick, C.P.G.
Senior Consulting Hydrogeologist

Attachments
cc: Bud Leber, KACC
David Sprecher, KACC
Mike Sawatzky, KACC

TECHNICAL MEMORANDUM

EVALUATION OF GROUNDWATER EXTRACTION AND RE-INJECTION ALTERNATIVES KAISER MEAD WORKS

December 14, 2000

Prepared for:

Kaiser Aluminum & Chemical Corporation
2111 East Hawthorne Road
Mead, WA 99021

Prepared by:

MFG, Inc.
19203 36th Avenue W, Suite 101
Lynnwood, WA 98036

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1.0 INTRODUCTION

This technical memorandum, prepared by MFG, Inc. on behalf of Kaiser Aluminum & Chemical Corporation (Kaiser), describes the results of a groundwater modeling project for the Mead Works facility north of Spokane, Washington and presents recommendations for the design of a groundwater remediation system. Kaiser operates an aluminum smelting plant at the facility, which was constructed in 1942 and taken over by Kaiser in 1947. Historic handling practices for spent potlining material (SPL) resulted in contaminant releases to soil and groundwater. The contamination was first discovered in 1978 and attention has been focused on cyanide and fluoride. Since 1978, various remedial actions have been taken by Kaiser to reduce contaminant releases. In addition, various investigations have been conducted, including periodic groundwater monitoring, at the facility and in off-site areas. The contaminant plume, generally defined by the 100 ppb total cyanide level, extends northward 2.5 miles to the Little Spokane River (Figure 1).

The Feasibility Study (ReTec, 1993) identified remedial actions to address soil and groundwater contamination associated with releases of SPL constituents from the facility. The selected remedy included: 1) consolidation/capping of waste piles; 2) repair of plant water lines; and 3) extraction and treatment of groundwater, with re-injection of treated water. The "pump and treat" aspect of the remedy was to be implemented after 10 years if monitoring data indicated that the cleanup objectives had not been achieved. Department of Ecology (Ecology) Agreed Order No. DE 99TCPIS-95, effective January 10, 2000, required Kaiser to prepare and submit an Engineering Design Report (EDR) with construction plans and specifications for the cleanup project. The EDR for the consolidation and capping of the SPL Pile, the Rubble Pile, and the Butt Tailings Pile was submitted to Ecology in August 2000. The pump and treat portion of the remedy will be addressed in a separate EDR.

This report is organized as follows:

Section 1.2 presents a brief discussion of previous investigations. The cleanup objectives for the selected cleanup action are presented in Section 1.3. Section 1.4 describes the evaluation of disposal options for treated groundwater. Section 2 includes descriptions of the regional and local hydrogeologic settings, including the conceptual hydrogeologic model. The construction and calibration of the numerical groundwater flow model are described in Section 3. The fate and transport modeling of extraction/re-injection alternatives is presented in Section 4. Section 5 presents the recommended design parameters for the groundwater remediation system. Recommendations for effectiveness and compliance monitoring are presented in Section 6.

1.1 Purpose and Objectives

The necessity for this project arose during the initial design phase for the groundwater treatment system. Treatability studies confirmed that potential cyanide and fluoride treatment technologies could achieve significant levels of cyanide and fluoride removal; however, capital and operational costs associated with the treatment technologies could be extremely large depending on the groundwater extraction rate, the influent concentrations of cyanide, fluoride and other constituents, and the degree of removal required for each constituent prior to discharge. In addition, equipment, chemical handling, waste management and other system requirements for treatment of groundwater impacted by SPL constituents begin to exceed the limits of engineering feasibility at higher groundwater extraction rates, due to the inherent difficulties associated with removing these constituents from groundwater. Thus, Kaiser was at the point in the design process for the groundwater treatment system where it was essential to optimize the extraction system parameters.

Various extraction rates were estimated during previous feasibility analyses (ReTec, 1993 and 1996), ranging from 200 to 600 gpm for plume capture based on free cyanide and fluoride cleanup standards, respectively. Given the high potential costs and feasibility limitations associated with groundwater treatment at the Site, it was considered essential at this early stage in the treatment design process to define clear objectives for the extraction system and refine the previous estimates of pumping rates and treatment requirements. The crucial need was to optimize the extraction system to recover the contaminant mass consistent with meeting the cleanup objectives. This optimization would consider the effects on contaminant concentrations of both the source reduction and pump and treat components of the remedy at the points of compliance (POCs). For clarification, source reduction means remedial measures that reduce the transport of residual SPL constituents in the subsurface soils beneath portions of the piles and surrounding areas to the water table. These source reduction measures can be characterized as infiltration controls.

In order to proceed with the design of the treatment system and complete the extraction system design, additional data collection and analysis were necessary to define the optimum configuration of the extraction and re-injection systems, the total extraction rate, and the expected contaminant concentrations (total cyanide, fluoride and other constituents) in the treatment plant influent. To facilitate the evaluation of system alternatives for extraction/re-injection and to support the subsequent detailed design of the extraction/re-injection and treatment systems, the following tasks were recommended:

1) installation of extraction test and observation wells in Zone A;

2) pumping and re-injection tests to provide data for refinement of aquifer hydraulic properties and estimation of extraction and re-injection well efficiency;

3) development of a calibrated, numerical groundwater flow model for simulation of various extraction and re-injection well arrays and modeling of contaminant transport;

4) fate and transport modeling for prediction of the effects on water quality of selected alternatives; and

5) submission to Ecology, for review and approval, of a technical memorandum with supporting documentation that describes the results of this work and presents recommended design parameters.

Detailed design of the groundwater remediation system would proceed after Ecology approval of the system design parameters. The latter include the points of compliance and cleanup objectives, the contaminant removal efficiency, the location and rates of groundwater extraction, the location and rates of treated groundwater re-injection, and criteria for terminating system operation.

1.2 Previous Investigations

Following the 1978 discovery of groundwater contamination at the Mead Works, Kaiser conducted a number of investigations to evaluate the nature and extent of contamination, the source of contaminants at the plant and the transport mechanisms to and within the groundwater system. In addition, a series of independent remedial actions were taken to reduce the release of contaminants to soil and groundwater. The results of these studies and the effects of the remedial actions were reported and analyzed in the Remedial Investigation report prepared in 1988 (Site Characterization Analysis, Hart Crowser, Inc., December 1988), and in periodic monitoring reports over the period of 1981 to the present.

The general transport mechanisms of cyanide and fluoride to groundwater were described in the RI (Hart Crowser, 1988) and subsequent monitoring reports (Hart Crowser, 1982 to 1997). The primary assumptions for this transport theory were as follows:

- Historic SPL handling practices (prior to 1980) resulted in the transport of cyanide and fluoride into soils around and beneath the waste piles, temporary storage areas and other areas.
- Infiltration of natural precipitation was not believed to have mobilized cyanide and fluoride in the soils or waste piles in sufficient quantities to have resulted in the observed concentrations in the Zone A sands.
- Up until its closure in 1981, leakage of an estimated 60 gpm from the unlined settling basin, referred to as Tharp Lake, was believed to move laterally along the shallow aquitard surface and remobilize cyanide in the soil beneath the potlining handling area.

- Infiltration of ponded water and leakage from water and sewer lines are believed to have contributed, and continue to contribute, to downward migration of SPL constituents in soils to groundwater in a similar manner to the Tharp Lake seepage.

1.3 Cleanup Objectives

The Feasibility Study (ReTec, 1993) identified proposed cleanup standards for soil and groundwater. The proposed cleanup levels for groundwater were 0.32 mg/L free cyanide and 4 mg/L fluoride. A conditional point of compliance (POC) for groundwater was identified as the plant property boundary.

The Department of Ecology clarified its position on groundwater cleanup levels and points of compliance in a letter to Mr. Mike Sawatzky (Paul Skyllingstad, December 8, 1999). Two points of compliance were identified: one conditional POC at the plant's northern property boundary; and a second conditional POC at a series of springs, which are located at and around 13607 North Minihdoka Trail. The latter POC was characterized as the point where groundwater becomes surface water. The cleanup standards proposed for these two conditional POCs are as follows:

<u>Northern Plant Property Boundary</u>
200 µg/L free cyanide (drinking water MCL)
4 mg/L fluoride (drinking water MCL)

<u>Downgradient POC at Springs</u>
5.2 µg/L free (WAD) cyanide (chronic fresh water criteria)
0.96 mg/L fluoride (MTCA Method B)

1.4 Evaluation of Disposal Options for Treated Groundwater

Kaiser has evaluated four options for disposal of treated groundwater: direct discharge to the Little Spokane River; discharge to the Spokane wastewater treatment facility; discharge to Kaiser's wastewater system under the existing National Pollutant Discharge Elimination System (NPDES) permit, and re-circulation/re-injection to groundwater.

Direct discharge to the Little Spokane River would involve constructing a pipeline from the plant to the river and would require that the treated water meet fresh water aquatic standards. Treatment technologies that have been evaluated during this investigation will not produce treated groundwater that meets those standards. Direct discharge to the Little Spokane River is likely not feasible.

The Mead plant is located outside the Spokane city limits and outside the sewer service boundaries. Discharge to the City of Spokane's wastewater treatment facility would involve construction of a pipeline from the plant to a sewer line with adequate capacity, obtaining an agreement between the City and the County to reserve future treatment facility capacity, and possible annexation of Kaiser's property to the City. Concerns regarding current treatment facility capacity and biosolids quality would likely preclude discharge of treated groundwater until the next phase of treatment facility capacity is constructed in approximately five years. Discharge to the City of Spokane's wastewater treatment facility, therefore, is likely not feasible.

Kaiser holds an NPDES permit that allows treated wastewater discharge to Deadman Creek. Review of historic water quality and flow data indicates that there is capacity within the current NPDES permit to discharge limited quantities (10 to 25 gpm) of treated groundwater to Kaiser's wastewater system. During storm events discharge of treated groundwater may be further limited. Additional evaluation of wastewater and groundwater quality, such as whole effluent toxicity, is required to confirm the feasibility of this discharge option.

On-site re-circulation/re-injection of treated groundwater would require installation of injection wells and approval of Ecology. Concerns regarding potential bio-fouling would also need to be addressed. Re-circulation/re-injection of treated groundwater appears to be technically feasible.

2.0 HYDROGEOLOGIC SETTING

The Remedial Investigation for the Site presented the characterization of the site hydrogeology, contaminant sources and contaminant migration (Site Characterization Analysis, 1988, Hart Crowser). Subsequent to the RI, additional studies were conducted in 1989-90 to further characterize the distribution of a shallow aquitard believed to create perched water conditions and to have a significant effect on contaminant transport to the water table (Hart Crowser, 1989 and 1990). Other sources of information included published reports, logs for area water wells, and periodic groundwater monitoring reports for the Site. The above sources were used in conjunction with field data collected during the current study to update and revise the site characterization.

2.1 Regional Hydrogeology

The Spokane Aquifer extends from the Idaho border, where it is contiguous with the Rathdrum Prairie Aquifer, westward to along the Spokane River to Nine Mile Falls, northwest of Spokane. North of Spokane, a mesa composed of consolidated rocks separates the aquifer into the Hillyard Trough to the east and the Lower Spokane River Valley to the west. The unconsolidated sediments that comprise the Spokane Aquifer are bounded laterally and below by consolidated rocks, except in the Hillyard Trough, where low permeability fluviolacustrine deposits underlie the aquifer. The Mead Works lies over the Hillyard Trough segment of the Spokane Aquifer. The general hydrogeologic conditions are illustrated in a regional cross section extending from the Mead Works to the Little Spokane River (Figure 2).

The aquifer is composed primarily of poorly sorted, reworked sands and gravels of glaciofluvial origin deposited in a bedrock valley. Cobbles and boulders occur frequently in the lower portion of the aquifer. Lenses and beds of finer-grained sediments (silty clay, sandy silt, clay) are also present. The aquifer in the area of the Hillyard Trough is generally finer and more stratified than the eastern part of the aquifer. The aquifer is bounded below by the regional aquitard, also of glaciofluvial origin but composed predominantly of clays and silts with occasional sand and gravel zones.

The depth below ground to the base of the aquifer ranges from about 285 feet at the plant to less than 50 feet near the Little Spokane River. The change in depth is primarily a function of lowering topography northward toward the river rather than change in bottom elevation. The regional water table is encountered at a depth of about 150 feet at the plant, decreasing northward to the surface where groundwater discharges from springs above the Little Spokane River. The water table elevation decreases from about 1,780 feet MSL at the plant to less than 1,700 feet MSL near the Little Spokane River. Groundwater flow is unconfined, although semi-unconfined conditions may exist locally where silt and clay lenses are extensive. Flow from the plant area is strongly toward the northwest to the discharge areas associated with the springs and the river (Figure 1). The approximate average gradient is 0.007 ft/ft (35 feet per mile). The aquifer water budget for the regional groundwater flow model, prepared by CH2MHILL for the Spokane Aquifer Joint Board (CH, 1997) to support the wellhead protection program, predicted a discharge rate from the Spokane Aquifer of 182 cfs to the Little Spokane River Valley at the north end of the Halyard Trough.

Recently, studies by several water districts have identified the presence of a deeper confined aquifer below the regional aquitard in the northern portion of the Hillyard Trough and the Little Spokane River Valley. Available data on the thickness and continuity of aquitard and differences in water levels suggest minimal hydrologic connection between the Spokane Aquifer and this deeper confined zone.

2.2 Plant Area Hydrogeologic Units

Approximately 285 feet of sands and gravels with some silts, clays and cobbles underlie the Site and are bounded below by the regional aquitard. The lower 140 to 150 feet of these unconsolidated sediments are saturated and comprise the Spokane Aquifer. Beneath the Site, the stratigraphy of the saturated zone consists of alternating beds of permeable sand and gravel and less permeable silt and clay that separate the three identified water-bearing zones (Zones A, B, and C from top to bottom) observed in monitor well borings and some plant production well borings on site. The site stratigraphy and hydrogeologic characteristics are illustrated in cross sections A-A’ and B-B’ (Figures 4 and 5, respectively). The cross section locations are shown on Figure 3. Zone C is generally much thicker and coarser-grained than the upper zones. The plant production wells are completed in Zone C, which is approximately 90 to 100 feet thick. The Zone A and B sands occur in the upper part of the Spokane Aquifer. A silty clay unit separates the Zone A sand from the Zone B sand. The confining bed between the Zone B sand and the underlying Zone C sand was characterized generally as silty clay.

Monitoring well construction data and recent water level measurements are summarized in Table 1.

2.2.1 Field Investigation

Aquifer testing was conducted at the facility to obtain hydraulic property data for the Zone A sand. This data was necessary to allow estimation of the hydraulic properties of the Zone A sand in the area of the planned groundwater extraction system. Previous aquifer tests of Zone A were of short duration (3 hours or less) and not optimally located for this purpose. The selected aquifer test site was at the location of monitoring wells TH-8 and TH-3A, adjacent to the northern side of the plant boundary near the center of the contaminant plume. One test well (KM-1) was installed in the Zone A sand and one observation well was completed in the Zone B sand. Existing Zone A monitoring wells TH-8 and TH-3A were used as observation wells. The well completions and aquifer testing were accomplished during the period of August 14-26, 2000. The testing program included a step-drawdown test, a 24-hour pumping test, a 3-1/2 hour pumping test, and an injection test. Five water samples were collected from the pumping test discharge during the course of the 24-hour test and analyzed for total cyanide and fluoride. The testing program and results are presented in Appendix A. The test results are summarized in Section 2.2.3.1.

MFG and Kaiser personnel completed a field survey of selected area wells and springs on September 7-8, 2000. A GPS unit was used to verify the approximate locations of data locations used in the numerical flow model. Subsequently in early November, most of the site monitoring wells were surveyed to obtain horizontal coordinates and elevations for the wells. Water level measurements were taken on November 1st and 2nd to facilitate preparation of a current Zone A potentiometric map. At that time, a water sample was collected from well OB-1, which is screened in the Zone B sand, and analyzed for total cyanide, fluoride, total dissolved solids, conductivity and pH.

2.2.2 Unsaturated Zone

The unsaturated zone at the Site extends from the surface to a depth of approximately 145 to 155 feet, where the regional water table is encountered. Fine to coarse sands are dominant, ranging from clean sands to more poorly sorted deposits containing variable amounts of silt and/or gravel. Occasional lenses or beds of silty clay, sandy silt or silty fine sand are present within the unsaturated zone. The water content, as measured in numerous soil samples from borings, of the sandy strata is typically between 2 and 6 percent. Water contents are often much higher (greater than 20 percent) in or above thin zones of fine-grained strata where the downward unsaturated flow of infiltrating water is restricted. Hart Crowser (1983) evaluated the unsaturated flow conditions beneath the facility and concluded from the distribution of water content and the measured unsaturated hydraulic conductivities that groundwater recharge is very small (less than 0.1 inch per year).

An extensive drilling program was carried out in 1989-90 to map the extent of one particular low permeability horizon occurring at depths of around 60 feet. This horizon, called the shallow aquitard, was found to have a perched water zone that was thought to intercept infiltrating water associated with various water line leaks and channel the water under the central portion of the paved SPL pile. These flow conditions were believed to be associated with a trough in the shallow aquitard surface.

The degree of saturation above the shallow aquitard was found to be quite variable both areally and temporally in wells completed in this perched interval. Recent measurements (1997-99) indicate that most of the accessible wells show dry conditions and those wells that do contain water, only have a few inches. Shallower and/or deeper thin zones of saturation have been noted in the boring logs for a number of other wells at the Site.

2.2.3 Saturated Zone

The subsurface conditions at the site are depicted in two cross sections (Figures 4 and 5). These cross sections are based on the November 2000 survey of wells by a licensed surveyor and re-interpretation of stratigraphic correlations.

2.2.3.1 Transmissive Zones

Zone A sand

The Zone A sand is comprised of fine- to coarse-grained sand with some silty sand. The saturated thickness varies from 10 to 20 feet, and is dependent on the elevation of the underlying clay unit relative to the water table surface elevation. The saturated thickness of the Zone A sand thins to the northwest, where it is about five feet at TH-6A. Based on stratigraphic correlation of boring logs for TH-6 and TH-5, the Zone A sand grades from sand to "sand, silt and clay" at TH-5 (Figure 4). The latter interval is correlative with both the Zone A sand and the underlying confining bed at TH-6.

Two short-term (2-3 hours) pumping tests were conducted by Hart Crowser in Zone A sand monitoring wells ES-9 and ES-10 (Hart Crowser, 1988). The estimated hydraulic conductivities from their analysis of the test results were 240 to 374 ft/day at ES-10 and 548 to 642 ft/day at ES-9. Longer-term tests were conducted in August 2000 using a newly-constructed Zone A sand test well, KM-1. Water level measurements were taken throughout the testing program in the test well and in two existing Zone A sand monitoring wells, TH-3A and TH-8, and a new Zone B sand observation well, OB-1. Analysis of the test results, which are summarized in Appendix A, yielded hydraulic conductivity values ranging from about 250 to 650 ft/day, with a representative value of 500 ft/day, and a storage coefficient of 0.10.

Zone B sand

The Zone B sand was encountered in seven borings from early environmental investigations at the Site and in one boring completed for this investigation (OB-1). The Zone B sands are described as fine sand, fine to medium sand, and/or medium to coarse sand, sometimes silty or with silt layers. The thickness reported in boring logs ranged from 6 to 20 feet. With the exception of ES-9 in the eastern part of the plant and ES-10 south of the SPL Pile, the borings that penetrated the Zone B sand are all north of the plant boundary. The smallest sand thickness was found at ES-9 (7 feet) and ES-10 (6 feet).

Zone C sand

The top of the Zone C sand was encountered in five borings drilled as part of the initial environmental investigations in 1978. All five of these borings were located north of the SPL Pile and the Rubble Pile.

The upper Zone C sands were described as fine to medium sands or fine to coarse sands with some gravel. Zone C wells were completed in two of these borings as the lowermost of three nested wells (TH-6C and TH-7C).

The descriptions of Zone C in drillers' logs for four plant water supply wells indicate predominantly medium to coarse sand and fine to coarse gravel with some boulders. Minor clay streaks or beds are noted in two logs. These wells are completed in the lower half of Zone C where the sediments are more productive (cleaner and coarser). Test pumping data for these wells after completion at rates of 1,000 to 5,000 gallons per minute (gpm) indicated specific capacities of 80 to 500 gpm per foot of drawdown. These specific capacity values generally correspond to a transmissivity range of about 20,000 to 100,000 ft^2/day (U.S. Dept. of Interior, 1977), or a hydraulic conductivity range of 250 to 1,250 ft/day.

2.2.3.2 Confining Beds

Zone A clay

The base of the Zone A sand is defined by a fine-grained unit separating the sand from the underlying Zone B sand. This unit is typically a silty clay to clayey silt, although at some locations it is described as a clayey, silty sand, sand and clay, or a fat clay. Eight borings penetrated this unit's full thickness, which ranged from three to 13 feet. This confining bed is not present in the southwest part of the plant (see Figure 5) and also appears to grade from predominantly clay to more permeable strata north of the plant (see Figures 4 and 5).

Zone B clay

The Zone B clay lies between the Zone B sand and the underlying Zone C sands and is described as clay with sand, clay, sandy clay, clayey silt or silty clay. Based on the seven borings which penetrated the full thickness of this unit, it ranges in thickness from 1 to 13 feet, but is typically 3 to 5 feet thick. The lateral extent of this unit is not well defined. It is present in those borings that are deep enough to encounter it, however, and appears to be present over much of the plant area and to the north of the plant.

2.3 Water Levels and Groundwater Flow Conditions

Two Zone A water level elevation maps were presented in the RI (Hart Crowser, 1988) for the periods September 1981 and August 1988. The 1988 map, which is reproduced in this report as Figure 6, is generally consistent with the 1981 map. The 1988 water level elevation contours indicate that the horizontal component of groundwater flow in the Zone A sand is generally westward in the eastern part of the Mead Works and northwest to west-northwest in the western part of the facility and north of the plant boundary. Apparent horizontal gradients range from about 0.0032 (16 feet per mile) in the eastern part of the plant to 0.006 (31 feet per mile) in the vicinity of the SPL Pile.

Static water levels were measured in many of the Site monitoring wells on November 1 and 2, 2000. In addition, the located monitoring wells were surveyed for horizontal coordinates (0.01 accuracy) and elevation (0.01 foot accuracy). The surveyed well locations are shown on Figure 3. The depth to water and static water level elevations are listed in Table 1. The water level elevations are plotted on Figure 7, which also depicts the potentiometric contours for the Zone A sand.

Groundwater flow in the Zone A sand is variable across the Site. In the eastern half of the plant, the November, 2000 water level data indicate a flow direction slightly to the north of due west at a gradient of 0.0030 (17 feet per mile). Further west in the vicinity of the SPL Pile, flow is to the west-northwest at a gradient of 0.0032 (16 feet per mile). The flow direction changes to the northwest at a steeper gradient (0.0072 or 38 feet per mile) to the north of the Rubble Pile. Using these gradients, a hydraulic conductivity of 500 feet/day and an effective porosity of 10-20%, the average linear groundwater flow velocity ranges from about 8-16 feet per day in the plant area to 18-36 feet per day north of the Rubble Pile.

Water level data for the few monitoring wells screened in Zones B and/or C indicate a generally northwest flow direction at a gradient of about 0.0020 (11 feet per mile).

Downward vertical gradients are evident at three locations where monitoring wells are completed in both the Zone A sand and the Zone B sand. At the test well location just north of the Rubble Pile, the vertical gradient between the Zone A sand and the Zone B sand is 2.43 feet/foot. The difference in water level elevation is over 14 feet, with a confining bed thickness of six feet. Approximately 1,050 feet further downgradient at the TH-6 and TH-7 well clusters, the vertical gradients are from 2 to 3.4 feet/foot, respectively. The difference in water level elevation is about 10 feet, with a confining bed thickness of 3 to 5 feet. The confining bed is described in the boring logs as medium-grained silty sand at TH-6 and clay at TH-7.

The steepening of the Zone A gradient northwest of the Rubble Pile reflects the apparent facies change in the Zone A sand and underlying confining bed between TH-6 and TH-5, described in Section 2.2.3.1 (see Figure 4), and increased downward flow from Zone A to Zone B between TH-6 and TH-5. At the latter well, which is screened across Zones B and C and extends several feet up into the Zone A interval, it is probable that the Zone A interval is unsaturated.

An upward gradient exists between the Zone C sand and the Zone B sand at the TH-6 location. The Zone C water level elevation is approximately 1.7 feet higher than in the Zone B, with a gradient of 0.85 feet/foot. Boring logs indicate the two zones are separated by two feet of clay at TH-6.

2.4 Groundwater Quality

The specific conductance (SC) of groundwater in the Spokane Aquifer averages about 300 micromhos/cm, which indicates an average total dissolved solids (TDS) of about 150 mg/L, based on a relationship between SC and TDS for the Spokane Aquifer (Vaccaro & Bolke, 1983). As reported in the RI, the measured SC in three wells downgradient of the Site was around 240 micromhos/cm, correlating to a TDS of about 110 mg/L (Hart Crowser, 1988). The chloride concentration in these three wells ranged from 5 to 10 mg/L, which is consistent with the regional average of 4 mg/L.

Extensive sampling and analysis of groundwater from site monitoring wells and downgradient wells and springs have been conducted on a periodic basis since the discovery of contamination in 1978. The primary monitoring constituents have been total cyanide, free cyanide and fluoride. The concentrations of total cyanide and fluoride with time at selected wells are shown on Figures B-1, B-2 and B-3 in Appendix B. These graphs are presented in three groups: wells upgradient of the potential source areas; wells within and immediately downgradient of the source areas; and wells further downgradient. In the RI and groundwater monitoring reports, fluctuations in the concentrations of total cyanide and fluoride with time at individual wells have been attributed primarily to the effects of recharge events (from pipe leakage or pond seepage), remedial actions taken to reduce infiltration, and plume shifting as a result of pond closure.

The concentrations of total cyanide and fluoride in groundwater samples collected from monitoring wells at the Site in September 1999, except as noted, are shown on Figure B-4. Most of the wells are completed in the Zone A sand. The contaminant plume is centered on the waste piles, generally between wells HC-8 on the west and well TH-2 on the east. The highest concentrations of total cyanide (62 to 202 mg/L) and fluoride (27.6 to 138 mg/L) are downgradient of the SPL Pile and the eastern half of the Rubble Pile (wells TH-2, HC-9A, HC-12, TH-3A, TH-8 and KM-1).

Total cyanide concentrations are much lower at the western end of the SPL Pile (well ES-10) and east of the Rubble Pile (HC-7 and HC-8). Fluoride concentrations show a similar pattern, except that the fluoride concentrations (2.18 to 12.3 mg/L) are considerably higher than total cyanide (0.02 to 4.9 mg/L) in these three wells. At the Zone A well about 1050 feet downgradient of the piles (TH-6A), the fluoride concentration (10.6 mg/L) exceeds the total cyanide concentration (3.12 mg/L).

Two Zone B wells are located downgradient of the SPL Pile and the Rubble Pile: OB-1 and TH-6B. The concentrations of total cyanide and fluoride are similar at OB-1 (6.02 and 7.05 mg/L, respectively) and somewhat higher downgradient at TH-6B (13.6 and 19.3 mg/L, respectively). Well TH-6C, completed in the Zone C sands adjacent to TH-6A and TH-6B, has very low total cyanide and fluoride concentrations (0.006 and 0.17 mg/L, respectively). Well TH-5, which is completed in the B and Zone Cs approximately 1650 feet northwest of well HC-12, exhibits relatively low concentrations of total cyanide and fluoride

(0.311 and 0.34 mg/L, respectively). The concentrations at TH-5 may not be representative of the contaminant concentrations in the aquifer at that distance downgradient, primarily due to the long screen interval within the Zone B and Zone C sands.

In addition to the variations in water quality between the three zones, substantial chemical stratification is evident within the Zone A sand. A number of Zone A monitoring wells are screened across only part of the full saturated thickness of the Zone A sand. At the aquifer test site, existing well TH-3A is screened through nearly all the full thickness of the Zone A saturated sand (approximately 18 feet), while well TH-8 is screened across a five foot section at the base of the sand. Concentrations of total cyanide and fluoride are significantly lower in TH-3A than in TH-8. Based on data collected during the period of 1983 to 1999, the average concentrations of total cyanide and fluoride are 81% and 56% higher in TH-8 than in well TH-3A: 137,141 versus 75,657 mg/L total cyanide and 128 mg/L versus 82 mg/L fluoride. Fluoride and total cyanide concentrations in water samples collected during the aquifer test from well KM-1, which is screened across the full saturated thickness of the Zone A sand, were consistent with the lower concentrations found historically at TH-3A. This chemical stratification is likely related to density effects associated with the higher dissolved solids content of the contaminated groundwater and stratigraphic conditions that inhibit downgradient flow of the more dense water at the base of the sand. The latter include an apparent increase in elevation of the Zone A basal clay downgradient from TH-3A and the finer-grained character of the basal Zone A sands, which would inhibit flushing of the denser, more contaminated water. Groundwater inflow from upgradient that is relatively low in total dissolved solids may be confined primarily to the upper part of the Zone A saturated sand.

The conditions described above may also be applicable to the observed concentrations of total cyanide and fluoride at wells HC-12 and TH-2, both of which have relatively short screen sections at the base of the Zone A sand and exhibit high concentrations. The actual average concentrations within the Zone A sand are likely significantly lower than indicated by the analytical data for samples collected from these two wells.

Downgradient monitoring of groundwater at wells and spring discharge points indicates much lower concentrations of total cyanide and fluoride. The highest concentrations have historically occurred at sampling location W-195, a spring at 13607 North Minihdoka Trail south of the Little Spokane River. Based on data collected from 1983 to 1999, total cyanide, free cyanide and fluoride concentrations at W-195 have averaged 921 μg/L, 52 μg/L and 0.83 mg/L, respectively. Concentrations at other downgradient locations have been much lower than measured at W-195. The approximate width of the plume, based on a total cyanide concentration of 100 μg/L as measured in 1988, is shown on Figure 1.

The ratio of total cyanide to free cyanide at downgradient locations is generally around 20 to 1. The ratio of total cyanide to free cyanide concentrations in wells in the source areas and immediately downgradient generally range from about 90 in the eastern part of the plume where total cyanide concentrations exceed 50 mg/L to 20 to 30 in the western portion where total cyanide concentrations are typically much lower.

2.5 Conceptual Hydrogeologic Model

The clay intervals that define Zones A, B, and C at the Site are not laterally extensive (i.e., they were not observed in wells situated downgradient from TH-5 nor were they observed in the two southernmost, upgradient Kaiser water supply wells).

Of the three water-bearing zones observed beneath the site, Zone C is comprised of relatively coarse sands and gravels that rest on top of the underlying regional aquitard. These sands and gravels extend as a single hydraulically connected unit to the Little Spokane River where discharge occurs through springs. As the regional water table declines northwestward toward the river, the Zone A sands and then the Zone B sands become unsaturated.

The local groundwater flow system in the Zone A sands beneath the piles is relatively complex. Detailed evaluation of the stratigraphy, water level data, flow directions and water chemistry suggest the possibility that more highly contaminated water is present in the basal portion of the Zone A sand and that this water may be moving downgradient at a slower rate than estimated from the overall flow rate for the Zone A sand.

Regionally, recharge to the Spokane-Rathdrum Prairie Aquifer is primarily from the upgradient portion of the aquifer which extends eastward into Idaho. Infiltration of incident precipitation is believed to be quite small and not significant relative to the upgradient inflow.

The unconfined Spokane Aquifer rests on top of a continuous clay aquitard unit that separates the upper unconfined Spokane Aquifer from a possible deeper confined unit.

3.0 GROUNDWATER FLOW MODEL

3.1 Model Construction

The model was conceptualized as an unconfined aquifer with spring discharge maintaining constant heads adjacent to the Little Spokane River. The model assumes that the Zone A sand is part of a single aquifer comprised of three hydraulically connected water-bearing zones beneath the site. Precipitation infiltration and groundwater flow from upgradient portions of the aquifer provide recharge into the aquifer beneath the site. The underlying regional aquitard is assumed to be a no-flow boundary. Likewise, since groundwater flow is directed strongly toward the river, the sides of the model are assumed to be no-flow boundaries. Five layers were used in the model to accommodate simulation of the two discontinuous clay layers and three water-bearing zones observed beneath the site.

3.1.1 Model Area and Grid

The groundwater flow model area is depicted in Figure 8. Water well driller logs for private and public water wells in the surrounding area were used to supplement stratigraphic data from Kaiser monitor well borings to construct a finite difference grid for the flow model (Figure 8). A five layer, 91 x 81 finite difference grid was designed for the model (Figure 9). The horizontal grid spacing varies from approximately 75 feet at the Kaiser Facility to 600 feet at the edge of the model grid. The model grid was aligned with the direction of groundwater flow to facilitate model construction. Average thicknesses of seven feet and four feet were assigned to the basal Zone A clay and basal Zone B clay, respectively, based on the clay thicknesses observed in monitor well borings. The base of the model was defined as the top of the regional aquitard as observed in the Hillyard Trough.

3.1.2 Boundary Conditions

A constant-head boundary value of 1,795 feet was assigned to grid nodes situated at the upgradient (i.e. southeast) perimeter of the model (Figure 9). Likewise, constant head boundaries were assigned to grid nodes situated at the northwest perimeter of the model, where spring discharge to the Little Spokane River occurs.

Constant-head values were assigned to the northwestern perimeter of the model (adjacent to Little Spokane River) based on topographic elevation of the springs. Thus, the constant-head values for the springs ranged from 1,700 feet (at Wandermere Spring) to 1,640 feet near Dartford (spring W-195) to 1,660 feet near Waikiki Springs. Groundwater discharge was assumed to occur adjacent to the Little Spokane River at an elevation of 1,640 feet between Dart Hill (a bedrock feature located adjacent to and immediately southwest of Wandermere Lake) and Waikiki Springs. Dart Hill was included as an area of no-flow. A constant-head value of 1,795 feet was assigned to grid nodes at the southeastern perimeter of the model based on calibration to water levels observed in Zone A at the Site. Since the direction of groundwater flow is parallel to the sides of the model, the model sides were assumed to be no-flow boundaries. Likewise, the base of the model was assumed to be a no-flow boundary to represent the contact between the base of the Zone C sand and the regional clay aquitard.

3.1.3 Hydraulic Properties

Hydraulic properties used in the model were derived from the results of aquifer testing described in Section 2.2.1 and Appendix B and information used for the regional groundwater flow model, prepared by CH2MHill for the Spokane Aquifer Joint Board (CH2MHill, 1997).

The distribution of hydraulic conductivity in the model is depicted in cross sectional view in Figure 10. A conductivity value of 500 ft/day was selected to represent the Zone A Sand (Layer 1, beneath the site). Aquifer testing of deeper sands (Zone C equivalent) performed by CH2MHill revealed hydraulic conductivity ranging from 500 ft/day to 3,500 ft/day at a location situated approximately three miles southeast (upgradient) from the site (CH2MHill, 1997). Consequently, for their regional flow model, CH2MHill used 2,000 ft/day as hydraulic conductivity for the northern part of the unconfined Spokane Aquifer (CH2MHill, 1997). Based on the information described above, a value of 1,500 ft/day was assigned to layer 5 for Zone C in the model. A value of 750 ft/day was assigned to layer 3 grid nodes beneath the site to represent the Zone B sand. The remaining intermediate hydraulic conductivity values shown in Figure 10 were derived indirectly through calibration of the flow model with observed water levels in the simulation area. Storage and effective porosity is 10% for the Zone A sands and 20% for the other sands.

The hydraulic conductivity of the clays in the model range from 0.01 ft/day to 5 ft/day. A value of 0.1 ft/day was assigned to the basal clay of the Zone B sand. Hydraulic conductivity of the basal Zone A clay varies from 0.01 ft/day to 1 ft/day to facilitate the simulation of vertical gradients that are observed between the Zone A and Zone B. Furthermore, the hydraulic conductivity of the Zone A basal clay was increased to 5 ft/day in the model where the Zone A sand becomes unsaturated between TH-6 and TH-5. The clays were assigned a value of 5% for effective porosity and storage. In general, a vertical to horizontal conductivity ratio of 1:10 was used in the model.

3.1.4 Recharge Parameters

A regional recharge value of 1 inch per year was used in the model based on the results of sensitivity analysis (described in Section 3.2) that showed that the flow model is not sensitive to precipitation recharge. However, a value of 0.1 inch per year applied over the Kaiser Facility location based on results of the unsaturated zone study performed by Hart-Crowser in 1983. Recharge was held constant throughout the simulation.

3.2 Model Calibration and Sensitivity Analyses

The flow model was calibrated with five water level data points. Three calibration data points represent contemporaneous water levels measured in April 1996. These data were obtained from the water level database that was developed for regional flow model developed by CH2MHill (CH2MHill, 1997). These data points include one well completed in the Zone C sand (Well No. 17J1) situated approximately 2,000 feet southwest from the site, a second well completed by Kaiser (TH-5) within the Zone B and Zone C sand and situated approximately 1,000 feet northwest (downgradient) from the site, and a third well (7G2) completed in the shallow unconfined aquifer approximately 10,000 feet northwest from the site.

An additional downgradient calibration point was included based on a static water level observed during completion of the Spokane County Water District's Helena Well #1 (HW#1) during February of 1998 Likewise, an additional on-site calibration point (KM-1) was included to represent water levels in the Zone A Sand. Data collected during the September 2000 aquifer test at KM-1 were used for model calibration.

The results of model calibration are summarized in Table 2. Figures 11, 12, and 13 depict the calibrated potentiometric surfaces for the Zone A, Zone B, and Zone C intervals, respectively. The model was calibrated by adjusting model inputs for hydraulic conductivity and recharge within a range of reasonable values and comparing simulated water levels with water levels observed at the calibration points described above. The MODFLOW calibration package was used to perform linear regression of observed head vs. simulated heads. A normalized root-mean square (RMS) value of less than 10% was considered a reasonable calibration target. The final calibrated flow model reflects a mean error of 3.3 feet and an RMS value of 7.3%. Simulated heads were within four feet of observed values at four of the five calibrations points. The simulated head at HW#1 was thirteen feet below the observed static water level at HW#1. However, uncertainty in ground surface elevation and depth to water measurement at HW#1 likely accounts for much of this discrepancy.

The results of sensitivity analysis are summarized in Table 3. Sensitivity analysis was performed by systematically increasing and decreasing values of hydraulic conductivity, recharge, and storage by 50% and recording the simulated heads and mass-balance information. The model sensitivity to storage was evaluated using transient simulations during which 1,450 gallons per minute (gpm) were pumped from the Kaiser supply well (Kaiser Well No. 2). Analysis of head differences during the sensitivity analysis reveal that simulated heads are most sensitive to estimates of hydraulic conductivity in Zone C, whereas the model is least sensitive to hydraulic conductivity of Zone B and estimates of precipitation recharge.

Overall, downgradient calibration point 7G2 revealed the greatest change in head corresponding to variability in Zone C hydraulic conductivity.

Model mass-balance was also recorded during sensitivity analysis. The simulated fluxes into and out of the model varied in a predictable manner such that increases in conductivity and recharge resulted in corresponding increases in flux out of the model through constant-head nodes. Additionally, the mass-balance output show that the percent discrepancy tends to increase when transient pumping is simulated.

3.3 Capture Zone Analysis

MODPATH was used to evaluate complete capture of the plume (> 4 mg/L fluoride). The capture zone analysis was premised on the results of the Substantial and Disproportionate Cost Analysis performed by MFG in which four "flow-tubes" containing elevated concentrations of fluoride and cyanide in Zone A were evaluated for capture and treatment. The calibrated MODFLOW groundwater flow model and MODPATH (particle tracking model) were used to simulate complete capture of flow within all four of the flow-tubes in Zone A. Additionally, complete capture of flow within two of the flow-tubes shown to contain most of the estimated contaminant mass in Zone A was simulated. The locations of simulated cutoff wells and pathlines are shown in Figures 14 and 15. The results indicate that eight cutoff wells pumping a total of 336 gpm are needed to provide complete capture of the plume within the Zone A sand. Likewise, five wells pumping a total of 250 gpm are needed to capture the plume within flow-tubes 3 and 4 in Zone A.

4.0 FATE AND TRANSPORT MODELING

MT3D99 was used to simulate chemical fate and transport for the purpose of evaluating the effects of source reduction as well as the various components of the pump and treat remedy discussed in Section 1.1. MT3D99 is a fully three-dimensional fate and transport code that simulates the effects of advection, dispersion, adsorption and chemical reaction on the fate of chemicals transported in groundwater. For this study, MT3D99 was used to simulate the growth of the plume to its current extent in order to estimate the current loading of cyanide and fluoride into the aquifer. Following the simulation of current conditions, the model was used to evaluate a variety of source reduction and groundwater pump and treat scenarios.

4.1 Input Parameters

MT3D99 requires inputs to describe the source of chemicals in the aquifer (e.g. constant concentration, infiltration, point sources) as well as chemical sinks (e.g. springs or wells that remove contaminated groundwater and chemical mass from the system), physical aquifer parameters (e.g. dispersion), and chemical properties (e.g. partition coefficients, decay constants).

Historical data indicate that concentrations of total cyanide and fluoride have generally fluctuated between about 40 and 100 mg/L in groundwater samples taken from the one well (TH-3A) screened across the full thickness of the Zone A sand immediately downgradient of the source areas. The variations likely reflect both fluctuations in source contributions and some shifting of the plume from west to east. Since one of the objectives of modeling is to simulate variable source-area contributions to the aquifer, a group of point sources placed in the area of the waste piles at the site was used to simulate the source. For the total cyanide current condition simulation, the mass loading of total cyanide into the Zone A aquifer was simulated with eleven point source wells each contributing 1 gpm of 1,200 mg/L total cyanide. The location of the source points represents the general area where SPL constituents reach the water table, and consequently, the area of highest concentrations of SPL constituents in groundwater.

Advection describes the process by which a dissolved chemical will be transported downgradient in groundwater. Dispersion is the process whereby the dissolved chemical mass is spread within groundwater beyond the area it would occupy due to advection alone. MT3D99 simulates dispersion in three dimensions, and thus requires inputs to describe longitudinal, lateral and vertical dispersion. The inputs for longitudinal and lateral dispersion were derived in part from the results of water quality modeling and dispersivity calibration performed by Vaccaro & Bolke (1983) in their study of groundwater quality and two-dimensional solute fate and transport in the Spokane Aquifer. Additional model calibration described below in Section 4.2 was used to identify a value of 150 ft for longitudinal dispersivity with 0.1 horizontal and 0.01 vertical dispersivity ratios used in this model.

Historical dissolved-phase concentration data collected from monitor wells HC-12 and TH-5 reveal that concentrations of total cyanide and fluoride have fluctuated between low and high concentrations with a pattern that suggests that downgradient total cyanide peak concentrations occur sooner relative to fluoride (Hart-Crowser, 1985). This information would indicate that total cyanide and fluoride transport rates are influenced by sorption to the aquifer matrix, provided that the concentration peaks are related to contemporaneous changes in total cyanide and fluoride loading at the source area. Sorption to the aquifer matrix causes an overall reduction in rate of chemical transport relative to the velocity of a non-sorbing particle within the aquifer. The chemical-specific soil-water partition coefficient (K_d) describes the propensity for a dissolved-phase chemical to adsorb to the aquifer matrix.

Based on an elapsed time of about 1,000 days between peak concentrations of total cyanide observed at HC-12 and TH-5 between 1984 and 1987, and an estimated groundwater particle velocity of 10 ft/day, a chemical-specific retardation of 5 was estimated for total cyanide. A chemical-specific K_d value of $3.5x10^{-7}$ L/mg was derived for use in the model using an assumed dry-bulk density of 1.7 kg/L. A K_d value of $7.0x10^{-7}$ (twice the value for total cyanide) was used for fluoride. The derivation of chemical-specific K_d values is premised on the assumption that the peak concentrations of total cyanide observed at HC-12 and TH-5 between 1984 and 1987 are related to a shift in the direction of the total cyanide plume after closure of Tharp Lake in 1981.

Given the uncertainty in aquifer physical parameters such as dry bulk density and total porosity, and the uncertainty in observed plume migration rates between HC-12 and TH-5, the estimates of K_d described above are also uncertain. Consequently, further discussion of the model sensitivity to K_d is provided below.

4.2 Calibration and Sensitivity Analysis

Calibration and sensitivity analysis were performed by varying mass loading rates, dispersivity and K_d values and observing the corresponding effects on plume growth. As discussed in Section 4.1, for the total cyanide current condition simulation, the mass loading of total cyanide into the Zone A aquifer was simulated with eleven point source wells each contributing 1 gpm of simulated leakage. For the calibration of current conditions, the concentrations of total cyanide and fluoride in the leakage were varied, through trial and error, until the model provided a good simulation of the observed concentrations at the source area and at the springs. As discussed in Section 4.3, concentrations of 1,200 mg/L total cyanide and 800 mg/L fluoride provided good simulations of the current condition plume.

Dispersivity values were varied between 150 and 1,500 feet for longitudinal dispersivity and 0.0001 to 0.1 for lateral and veritical dispersion. The results showed a correlation between increased dispersivity and increased plume length, width, and downgradient concentrations. The USGS regional water quality modeling report showed calibration results suggesting use of 300 feet and a ratio of 0.3 for lateral dispersivity (Vaccaro & Bolke, 1983). Calibration and sensitivity analysis for dispersivity inputs showed that the values of 150 feet for longitudinal dispersivity and ratios of 0.1 and 0.01 for lateral and vertical dispersivity resulted in a simulated plume width of about 2,400 to 2,800 feet for the 0.1 mg/L fluoride plume, which compares well with the apparent width of the 0.1 mg/L fluoride plume observed in 1992 based on data collected from wells located near Hastings Road (ReTec,1993). However, the simulated plume appears to overestimate the width of the plume downgradient from Hastings Road.

The method of deriving the K_d values used in the model is described above in Section 4.1. A sensitivity analysis for the simulation of total cyanide current conditions was performed in which the K_d value used in the current condition simulation was doubled. The results showed an increase in time for the plume to achieve steady-state; however, the simulated concentrations were unchanged. Since first order decay or chemical reaction kinetics are not simulated, the selection of K_d values primarily affects contaminant travel time such that plume migration is slower with larger K_d values.

4.3 Current Condition Simulations

Prior to performing simulations of groundwater remediation, the model was used to simulate the release of total cyanide and fluoride into Zone A and subsequent downgradient transport in order to provide a reasonable "initial condition" plume with which alternative treatment systems could be simulated and compared. As discussed in Section 4.1, the mass loading of total cyanide into the Zone A Sand was simulated with eleven point sources each contributing 1 gpm of 1,200 mg/L total cyanide. Likewise, the mass loading of fluoride into the Zone A Sand was simulated with the same eleven point sources each contributing 1 gpm of 800 mg/L fluoride. The point source locations are shown in Figure 16 and Figure 19. The loading rates reflect a mass loading of 72 kg/day and 48 kg/day for total cyanide and fluoride respectively.

The results of current condition simulations for the total cyanide and fluoride plumes are shown in Figures 16 through 21. Three concentration observation points were located at critical points in the model to record simulated concentrations over time (Figures 17,18,20 and 21). The first observation point (Obs 1) was located in model layer 1 (Zone A) at the Kaiser-Mead Facility northern perimeter, south of HC-12. The second observation point (Obs 2) was located in model layer 2 (Zone B) near S.H 2, downgradient from TH-5 on property owned by Kaiser. The third observation point (Obs 3) was placed in layer 3 in line with the axis of the simulated plume near spring No. W-195. The observation points were located so that Obs1 and Obs3 represent the locations of the conditional compliance points described in Section 1.3. Plots of simulated concentrations over time are included as Figures 22 and 23 for total cyanide and fluoride, respectively. Simulated dissolved-phase total cyanide and fluoride concentrations at these observation points were compared with dissolved-phase total cyanide and fluoride data collected between 1996 and 1999 at the Kaiser monitor wells and at the springs.

The results of the current condition simulation for total cyanide indicates that a mass loading of 72 kg/day produces a plume that reflects between 40 and 70 mg/L in the source area and about 1.6 mg/L at the springs. These simulated concentrations compare well with average concentrations observed at TH-3a (60 mg/L) near the source area and concentrations at Spring W-195 (between 0.9 and 1.3 mg/L) during 1997 and 1998. Steady state concentrations were achieved at Obs 1 after about 1,000 days. Steady state conditions at the springs were achieved at about 3,000 days. The results of the current condition simulation for fluoride indicates that a mass loading of 48 kg/day produces a plume that reflects between 30 and 50 mg/L at the source area and about 1.0 mg/L at the springs. Likewise, these simulated fluoride concentrations compare well with concentrations observed at the source area (45 mg/L, based on an average of fluoride concentration data from TH-3A, HC-9A, and HC-12, between 1996 and 1999) and concentrations at Spring W-195 (between 0.7 and 1.1 mg/L) during 1997 and 1998. Steady-state plume conditions at the springs were achieved after about 4,500 days for fluoride.

The results of current condition simulation indicate that the total cyanide model slightly overestimates concentrations of total cyanide near the springs while providing a good match to source area concentrations, whereas the fluoride model provides a reasonably accurate representation of concentrations observed at the springs and near the source area. However, since both of the models show elevated concentrations over a much larger area beneath the waste piles, both models provide a conservative characterization of current total cyanide and fluoride plumes.

4.4 Transient Model

The simulated current condition plumes described above were used as initial conditions for the evaluation of several different remedy options, including source area reduction alone and source area reduction coupled with pump-and-treat options that reflect alternative extraction and re-injection rates, well locations, and treatment levels for total cyanide and fluoride. For clarification, source reduction means remedial measures that reduce the transport of residual SPL constituents in the subsurface soils beneath portions of the piles and surrounding areas to the water table. These source reduction measures, which include consolidation/capping of waste piles and repair of water lines, can be characterized as infiltration controls.

4.4.1 Description and Rationale

The fate and transport models described in Section 4.3 were used to evaluate the relative effects of source reduction, groundwater extraction, and re-injection locations on the concentrations of total cyanide and fluoride in groundwater near the downgradient springs and at the source area so that alternative remedies (including source reduction and source reduction with groundwater extraction and treatment) could be identified that would achieve the cleanup goals for cyanide and fluoride presented in Section 1.3.

The first step in the modeling process was to evaluate the effects of reducing ongoing SPL constituent sources of concentrations of these constituents in downgradient aquifer areas. In this way, the effectiveness of source area controls alone could be evaluated without any level of groundwater extraction and treatment. A series of transient fate and transport simulations were performed in which the point source mass loading rates (identified during model calibration phase discussed in Section 4.3) were reduced to reflect varying degrees of source reduction measures (i.e. capping of the waste piles, repair of leaking water lines) proposed for the Site. For each simulation, the ongoing sources were reduced to reflect the percent reduction being evaluated (100%, 90%, and 80%) and the model was run to simulate the corresponding effect on downgradient concentrations. The results of the source area reduction simulations are discussed later in this section.

The next step was to evaluate the combined effects of source controls and groundwater extraction and treatment. As discussed earlier in Section 3.3, it is estimated that groundwater extraction rates greater than 300 gpm are required to hydraulically control the plume downgradient of the source. However, treating this much SPL-impacted groundwater likely exceeds the limits of economic and technical feasibility due to the cost of equipment, the amount of chemicals required, the amount of waste generated, and other system requirements. The results of the treatability testing performed at the Site suggest that attempting to treat more than 100 gpm of SPL-impacted groundwater would likely exceed the economic and technical limits of feasibility. However, some benefit may be realized through lower rates of groundwater extraction focused near the source areas to remove cyanide and fluoride mass from the aquifer system. Therefore, groundwater pumping and re-injection of treated water were simulated in addition to the source loading reduction so that the relative effects of pumping, treatment, and source reduction could be evaluated. For the pumping and re-injection scenarios, five extraction wells were placed in Layer 1 (Zone A) at locations shown in Figure 26 and pumped at either 5, 10 or 20 gpm each. Likewise, five injection wells were placed at upgradient locations in Layer 1 (Zone A) and Layer 5 (Zone C) and at downgradient locations in Layer 3 (Zone B). The model was used to re-inject treated water with concentrations of total cyanide ranging from 1 to 10 mg/L and concentrations of fluoride ranging from 10 to 15 mg/L into either Zone A, Zone B or Zone C so that the relative effects of re-injection location could be evaluated. Lastly, since the treatment process for total cyanide and fluoride will produce elevated levels of total dissolved solids (TDS) and iron in treated water prior to re-injection, the fate and transport of TDS and iron were simulated to estimate the downgradient levels of these treatment by-products due to re-injection.

4.4.2 Total Cyanide

Five different source reduction scenarios and eleven different source reduction and treatment options were simulated. The results are summarized in Table 4. First, a simulation of 100% source reduction was performed to evaluate the time to achieve the cleanup goals for total cyanide. Since total cyanide was simulated rather than free cyanide, the ratios of total cyanide concentrations to free cyanide concentrations observed at the source area and springs were used to develop surrogate goals of 19 mg/L and 0.1 mg/L for total cyanide at the source area and at the springs, respectively. The results indicate that the cleanup objective for the source area is achieved within the first year after a 100% reduction in source inputs (Figure 24). Whereas, due to the distance between the source area and the springs, a reduction in total cyanide concentration to levels close to the cleanup objective at the springs is not observed until after approximately 4 years.

The results of a series of different source reduction and extraction/re-injection simulations for a period of 2,500 days are summarized in Table 4. These results reveal three notable characteristics: 1) there is a linear relationship between source reduction and predicted concentrations at the observation points, 2) the relative reduction in predicted concentrations due to increased pumping rates is significantly less than that due to reduced source loading rates, and 3) the selection of re-injection interval (Zone A or Zone C) has little impact on predicted concentrations at the springs; however, re-injection of treated water to Zone C upgradient of the extraction wells or in Zone B downgradient from the extraction wells may result in a slightly lower concentration at the springs.

4.4.3 Fluoride

Three different source reduction scenarios and/or treatment options were simulated for fluoride. The results are summarized in Table 5. First, a simulation of 90% source reduction was performed to evaluate the time to achieve the cleanup goals for fluoride due to source controls in the absence of pumping. The results indicate that the cleanup goal of 4 mg/L is achieved at Obs 1 with 90% source reduction alone after about 2,700 days (Figure 25).

The results of a series of two different source reduction and extraction/re-injection simulations for a period of 4,500 days are summarized in Table 5. These simulations were performed primarily to evaluate the relative effects of re-injecting treated groundwater at locations situated both upgradient and downgradient from the extraction wells. The results indicate that there is a benefit of slightly lower concentrations at the springs from re-injection of treated groundwater in Zone B downgradient from the extraction wells. However, the simulations for both fluoride and total cyanide show that the cleanup goals are achieved at the springs with 90% source reduction regardless of the re-injection location.

4.4.4 Iron and TDS

As discussed briefly in Section 4.4.1, the fate and transport of TDS and iron was performed to estimate the downgradient concentrations of these constituents that will be introduced to the aquifer as a by-product of groundwater treatment. Two separate simulations of TDS and iron were performed based on the results of the groundwater treatability study, which indicate that the treatment of cyanide and fluoride could produce groundwater discharge with up to 23,300 mg/L TDS and 3,260 mg/L of iron. For these simulations, TDS and iron were simulated as conservative chemicals (i.e. no chemical reactions or sorption); therefore, the same model was used for both simulations. A background concentration of 0 mg/L was assumed for both TDS and iron and, therefore, the results reflect an incremental impact.

The model was used to estimate the concentrations of TDS and Iron at Obs 1, Obs 2, and Obs 3 due to the of injection of 25 gpm of water containing 23,300 mg/L TDS and 3,260 mg/L iron into Zone B. Since the model evaluated the injection of solute into Zone B, the results may underestimate concentrations that would occur at Obs 1. However, since the simulation does not account for the extraction of injected water in the vicinity of Obs 1, the simulation results provide an overall conservative estimation of potential concentrations at downgradient portions of the aquifer.

The results showed that there is a linear relationship between concentration injected and simulated concentrations at the observation points. Thus, the results of the two simulations described above were used to develop a table of possible concentrations at Obs 1, Obs 2 and Obs 3 based on a range of injected solute concentrations. The results are summarized in Table 6. The results indicate that re-injection of TDS and iron may cause an increase in respective concentrations at the springs that will not exceed 68 mg/L for TDS and 9 mg/L for iron.

4.5 Discussion of Modeling Results

The results of fate and transport modeling described in Section 4.4 indicate that the cleanup objectives may be achieved through a combination of source reduction and extraction/re-injection measures, or with source reduction alone. However, in order to further evaluate the benefit from extraction and treatment, further analysis of model output will focus on the 90% source reduction simulations for total cyanide where treated water (i.e. treated to 1 mg/L total cyanide) is re-injected to Zone A.

Table 7 presents a summary of mass-balance output at different time-steps in the transient fate and transport model for 25 gpm, 50 gpm, and 100 gpm extraction/re-injection scenarios. The results reveal that on a kilogram per day basis and for each simulated pumping rate, the greatest rate of mass removal occurs within the first 600 days of extraction, after which the mass removal rate decreases to a constant rate ranging from 0.54 kg/day to 1.92 kg/day. Furthermore, with less than 100% source reduction, after about 2,500 days for total cyanide, a steady-state plume is established, with reduced concentrations relative to current conditions.

Table 8 presents a summary of total concentration reduction at different time-steps in the transient fate and transport model for 25 gpm, 50 gpm, and 100 gpm extraction/re-injection scenarios. The results reveal that the net reduction in concentration at Obs 1 and Obs 3 is greatest due to source reduction, whereas, the additional reduction in concentrations at Obs 1 and Obs 3 with increased pumping rates is minimal (less than one percent of total reduction).

The results of fate and transport modeling show that source reduction (i.e., reducing the contaminant flux reaching the water table) will provide the greatest reduction in contaminant flux to the springs (points of groundwater discharge) along Little Spokane River. Groundwater extraction, treatment, and re-injection will provide additional reduction in mass near the source areas, and consequently, reduced contaminant mass transported downgradient; however, pump and treat would be cost effective during the first one to two years of operation. It was previously noted that an accumulation of highly-impacted, more saline, and less mobile water may exist at the base of the Zone A sand. If this is the case, groundwater extraction at the base of the Zone A sand near the source areas will likely accelerate achievement of cleanup goals.

5.0 RECOMMENDED ACTION

The results of groundwater fate and transport modeling presented in Section 4.6 suggest that the most effective remedy, in terms of both mass reduction and treatment costs, is source area controls to reduce contaminant flux to groundwater. Therefore, we recommend a phased, but interrelated, implementation of remedial measures be undertaken. The initial efforts will focus on the compression of the schedule for the consolidation/capping of the piles into the 2001 construction season and the expansion of the scope to eliminate water leaks. The latter program will be accelerated to complete the slip lining of gravity lines and revisions to pressure piping in the spring of 2001. In the interim, every effort should be made to halt water discharge into storm drains and to isolate, where possible, water mains in critical infiltration areas (i.e., areas in the general area of the piles where infiltration could drive residual contaminants in soil to the water table).

The groundwater monitoring systems, as described in Section 6.0, should be initiated by the summer of 2001 to facilitate collection of baseline (pre-remedy) data as well as data to document the effects of the source control measures. The fairly rapid and pronounced drop in contaminant concentrations in the Zone A sand following closure of Tharp Lake indicates the effects of the source control measures should become evident within about a year of implementation, followed by rapid improvements in water quality. Therefore, we recommend that the design of the extraction, treatment and re-injection system be completed, but a decision to install and operate a pump and treat system be deferred until late 2002 to allow time to demonstrate the effectiveness of the infiltration control measures. The criteria for proceeding with the groundwater system would be the failure to achieve a 50 percent reduction in total cyanide mass transport at the northern plant boundary, as indicated by the data from the conditional POC monitoring wells and the effectiveness calculations discussed in Section 6.1, unless non-technical factors dictate otherwise. A second decision point for implementation of groundwater pump and treat at four years (2006) would be based on achievement of an 80 percent reduction in contaminant mass transport.

The simulation results suggest that combined with effective source controls, an extraction/re-injection system designed to treat a smaller amount of water (i.e. 25 gpm) to the lowest achievable treatment level (i.e. 1.0 mg/L total cyanide and 15 mg/L fluoride) will provide a net reduction in contaminant flux to the river that is comparable to that achieved by a system pumping at a larger rate (i.e. 100 gpm). Therefore, we recommend a system designed to treat a maximum of 25 gpm of contaminated groundwater.

The proposed locations of the extraction and re-injection wells are shown in Figure 26. Figure 26 depicts five extraction wells situated about 200 feet downgradient from the waste piles and five injection wells located adjacent to the southeastern corner of the waste pile. The proposed extraction and injection well locations may be modified on the basis of initial data collected from the proposed groundwater monitoring systems. Although five extraction wells and five injection wells are shown, an alternative number of wells could be used, provided that they produce and re-inject a total of 25 gpm. The wells should be completed in the basal portion of the Zone A sand to recover the more highly contaminated water, resulting in greater mass removal than simulated for fully penetrating wells.

6.0 GROUNDWATER MONITORING RECOMMENDATIONS

A compliance monitoring plan is required for cleanup actions performed under the Model Toxics Control Act regulations (WAC 173-340). The specific requirements are provided in section 173-340-410 and compliance monitoring typically includes:

- Protection monitoring to confirm that human health and the environment are adequately protected during construction and the operation and maintenance period of a cleanup action
- Performance monitoring to confirm that the cleanup action has attained cleanup standards and, if appropriate, other performance standards
- Confirmational monitoring to confirm the long-term effectiveness of the cleanup action once cleanup standards, and, if appropriate, other performance standards have been attained

The cleanup action for the Kaiser Mead facility has two major components: 1) source control; and 2) groundwater extraction and treatment. The source control measures include pipeline retrofitting to eliminate leakage of water into the subsurface and consolidation and capping of the SPL Pile, the Rubble Pile and the Butt Tailings Pile. The pipeline retrofitting, which is currently underway and will be completed by spring of 2001, is designed to eliminate the suspected primary mechanism for transport of residual SPL constituents contained in the soils around and beneath the piles to groundwater. No specific protection or performance monitoring requirements are applicable to the pipeline retrofits. The consolidation and capping of the piles, which is detailed in the draft Engineering Design Report (August 2000), is planned for completion in 2001. Protection and performance monitoring methods for consolidation/capping are described in the EDR.

The groundwater monitoring recommendations presented here are intended to accomplish two purposes. The first is to track the effectiveness of the source control measures in reducing contaminant migration to groundwater. The second is to satisfy the requirements for performance (compliance) monitoring of the cleanup action.

6.1 Effectiveness Monitoring

As described in Sections 4 and 5, reducing the transport of residual SPL constituents in soils to groundwater by eliminating infiltration represents the primary means to achieve the cleanup goals downgradient of the site. Groundwater extraction, treatment and re-injection, if implemented, would have only a limited incremental benefit beyond that provided by source reduction. It is important, therefore, to institute a monitoring program to verify and document the effects of the source reduction components of the cleanup action.

The duration of the lag time between implementation of the source (infiltration) control measures and the elimination or substantial reduction in the migration of contaminants to groundwater is not known. Based on the characterizations of flow and contaminant transport in the unsaturated zone that were presented in the RI (Hart Crowser, 1988), however, the termination of transient and constant water leaks or seepage will in turn result in a fairly rapid decrease in the transport of contaminants to the water table. Given the relatively high groundwater flow velocity in the Zone A sand, the effects on groundwater quality should be evident within a relatively short period of time after the residual effects of ongoing seepage have dissipated. The distance across the current footprint of the piles in the Zone A flow direction is approximately 1000 feet. Assuming an average linear velocity of 8 to 16 feet per day, the travel time along that transect is about two to four months.

A network of six monitoring wells completed in the Zone A sand should be established around the perimeter of the consolidated pile (Figure 27) to facilitate tracking of the effects of source reduction measures. The proposed network includes existing wells KM-1 and HC-7, and four new wells. Wells along the northern side, coincident with the plant boundary, will also serve as conditional point of compliance wells, as discussed in Section 6.2. Monitoring of the perimeter wells should be initiated prior to completion of the consolidation/capping and continued on a bimonthly basis. Samples should be analyzed for total cyanide, fluoride, chloride, total dissolved solids and pH. The initial round of samples should include analysis of other general chemistry parameters to establish baseline geochemical conditions. The recommended additional parameters for the initial round of monitoring are calcium, magnesium, sodium, potassium, aluminum, total alkalinity, sulfate, nitrate, iron and manganese.

Additional groundwater monitoring is proposed downgradient of the extraction wells to facilitate evaluation of the combined effects of source reduction measures and the extraction system, as well as to better define the contaminant plume north of the plant boundary (Figure 27). Groundwater monitoring is proposed at the TH-6 well cluster (wells completed in Zones A, B and C), the TH-7 cluster (wells completed in Zones A and B) and three new well clusters north of the plant boundary. At the latter three locations, wells will be completed in Zones A (if present), B and C. These wells should be sampled once every four months for the same parameters as the pile perimeter wells.

Water quality changes will be evaluated by preparing time-concentration plots. Contaminant mass flux rates through the Zone A plume cross-sectional area near the plant boundary will be calculated for each monitoring period and compared to both the baseline condition and to historic data. In addition to groundwater sampling and analysis, water levels should be measured in all wells on a bimonthly basis, including the shallow aquitard monitoring wells, and potentiometric maps prepared.

The frequency of monitoring for the wells identified in this section should be reduced to semi-annual once the effectiveness of the source area controls, and groundwater extraction, treatment and re-injection if implemented, are demonstrated and relatively stable water quality conditions are attained.

6.2 Compliance Monitoring

The Department of Ecology has defined two conditional points of compliance (POCs) for the cleanup action, one at the northern plant boundary, which is generally coincident with the northern perimeter of the consolidated, capped pile, and one at the springs located above the Little Spokane River at and around 13607 North Minihdoka Trail. Ecology has also specified the cleanup standards to for each POC. The cleanup standards at the plant boundary conditional POC are the drinking water MCLs for free cyanide (200 µg/L) and fluoride (4 mg/L). The cleanup standards at the downgradient conditional POC are the chronic fresh water criteria for free (WAD) cyanide (5.2 µg/L) and the MTCA Method B value for fluoride (0.96 mg/L).

The conditional POC at the plant boundary is located upgradient of the proposed line of groundwater extraction wells. Three monitoring wells completed in Zone A (existing well KM-1 and two new wells) and one monitoring well completed in Zone B (existing well OB-1) are proposed for the plant POC. The proposed locations are shown on Figure 27. These wells will be monitored quarterly for total cyanide, free cyanide, fluoride, chloride, total dissolved solids and pH. The initial round of samples should include analysis of other general chemistry parameters to establish baseline geochemical conditions. The recommended additional parameters for the initial round of monitoring are calcium, magnesium, sodium, potassium, aluminum, total alkalinity, sulfate, nitrate, iron and manganese.

Three monitoring locations are recommended for the downgradient conditional POC at the springs near the Little Spokane River. These include locations W-195, W-2326, and W-7591. A quarterly monitoring frequency is recommended. Samples should be analyzed for total cyanide, free (WAD) cyanide, fluoride, chloride, total dissolved solids and pH. The initial round of samples should include analysis of other general chemistry parameters to establish baseline geochemical conditions. The recommended additional parameters for the initial round of monitoring are calcium, magnesium, sodium, potassium, aluminum, total alkalinity, sulfate, nitrate, iron and manganese.

7.0 REFERENCES

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TABLE 1

WELL CONSTRUCTION AND WATER LEVEL DATA

Well Number	Date Installed	Designed By	Drilling Method	Northing	Easting	Ground Surface Elevation (ft NGVD)	Top of Casing (TOL) Elevation (ft NGVD)	Boring Depth (ft bgs)	Well Depth (ft bgs)	Screened Interval (ft bgs)	Casing Inside Diameter (inches)	Casing Type	Unit(s) Screened	Static Water Level (ft below TOC)	Static Water Level Elevation (ft NGVD)	Date of Measurement
TH-1	3/78	R & N	NA	15,215.00	13,131.45	1,931.41	1,933.82	158	157	153-157	NA	Steel	A			
TH-2	3/78	R & N	NA	15,244.39	12,579.50	1,939.10	1,942.14	163	157	153-157	NA	Steel	A			
TH-3	3/78	R & N	NA	NA	NA	NA	NA	214	210	140-210	?	Steel	A,B,C			
TH-3A	3/78	R & N	NA	15,399.56	11,793.94	1,927.53	1,929.89	163	161	145-161	3	PVC	A	145.99	1,783.90	11/1/00
TH-4	3/78	R & N	NA	NA	NA	NA	NA	205	205	145-205	?	Steel	A,B,C			
TH-5	3/78	R & N	NA	16,823.25	10,805.52	1,907.50	1,910.87	214	186	135-186	6	Steel/PVC	B,C	144.82	1,766.05	11/2/00
TH-6A	3/78	R & N	NA	15,798.99	10,818.27	1,922.80	1,923.95	200	150	147-150	1.25	PVC	A	146.36	1,777.59	11/1/00
TH-6B	3/78	R & N	NA	15,798.99	10,818.27	1,922.80	1,923.95	200	172	167-172	1.25	PVC	B	156.14	1,767.81	11/1/00
TH-6C	3/78	R & N	NA	15,798.99	10,818.27	1,922.80	1,923.95	200	200	195-200	1.25	PVC	C	154.42	1,769.53	11/1/00
TH-7A	3/78	R & N	NA	15,669.46	10,746.16	1,924.37	1,926.41	199	151	146-151	1.25	PVC	A	148.3	1,778.11	11/1/00
TH-7B	3/78	R & N	NA	15,669.46	10,746.16	1,924.37	1,926.41	199	168	163-168	1.25	PVC	B	158.4	1,768.01	11/1/00
TH-7C	3/78	R & N	NA	15,669.46	10,746.16	1,924.37	1,926.41	199	199	194-199	1.25	PVC	C	obstruction		11/1/00
TH-8	7/79	R & N	NA	15,408.35	11,800.71	1,926.19	1,927.92	163	159	154-159	6	Steel	A	144.04	1,783.88	11/1/00
ES-1	8/82	ES	AR	NA	NA	NA	NA	125	NA	NA	6	Steel	?			
ES-2	8/82	ES	AR	NA	NA	NA	NA	80	NA	NA	6	Steel	SAQ			
ES-3	8/82	ES	AR	NA	NA	NA	NA	30	NA	NA	6	Steel	?			
ES-4	8/82	ES	AR	NA	NA	NA	NA	64	NA	NA	6	Steel	SAQ			
ES-5	8/82	ES	AR	14,691.43	12,403.97	1,941.53	1,942.32	170	NA	NA	6	Steel	A	155.86	1,786.46	11/1/00
ES-6	8/82	ES	AR	NA	NA	NA	NA	68	NA	NA	6	Steel	SAQ			
ES-7	8/82	ES	AR	14,702.67	12,717.03	1,942.11	1,943.54	165	NA	NA	6	Steel	A	lock stuck		11/1/00
ES-8	8/82	ES	AR	NA	NA	NA	NA	160	NA	NA	6	Steel	A			
ES-9	12/5/80	HC	CT	NA	NA	NA	NA	197.5	159	153-158	4	Steel	A			
ES-10	1/16/81	HC	CT	14,937.60	12,160.23	1,943.01	1,946.16	209	170	165-170	4	Steel	A	obstruction		11/1/00
HC-1A	4/20/81	HC	HSA	NA	NA	NA	NA	48.2	47	43-47	1.5	PVC	SAQ			
HC-1	4/15/81	HC	HSA	15,242.55	13,041.63	1,929.67	1,932.35	157	156	152-156	1.5	PVC	A	144.9	1,787.45	11/1/00
HC-2A	4/10/81	HC	HSA	14,913.99	12,921.66	1,938.82	1,941.93	168.5	167	162-167	1.5	PVC	A	154.29	1,787.64	11/1/00
HC-2	3/17/81	HC	HSA	NA	NA	NA	NA	65.5	60.5	56-61	1.5	PVC	SAQ			
HC-3	3/25/81	HC	HSA	NA	NA	NA	NA	70	68.5	63.5-67.5	1.5	PVC	SAQ			
HC-4	3/23/81	HC	HSA	15,341.64	12,504.83	1,927.97	1,929.11	53.5	52.5	47.5-52.5	1.5	PVC	SAQ			
HC-5	3/20/81	HC	HSA	NA	NA	NA	NA	72	68	63-68	1.5	PVC	SAQ			
HC-6	2/22/81	HC	HSA	15,042.48	12,923.60	1,931.71	1,933.14	51	50	48-50	1.5	PVC	SAQ			
HC-7	4/29/81	HC	HSA	14,949.48	11,457.68	1,941.13	1,942.52	170	169	159-169	1.5	PVC	A	158.71	1,783.81	11/1/00
HC-8	5/8/81	HC	HSA	15,168.71	11,627.74	1,937.16	1,938.66	164.5	162.5	157.5-162.5	1.5	PVC	A	obstruction		11/1/00
HC-9A	4/1/81	HC	HSA	15,062.06	12,401.81	1,942.14	1,943.36	164.5	162	157-162	1.5	PVC	A	157.74	1,785.62	11/1/00
HC-9	3/27/81	HC	HSA	15,067.79	12,416.71	1,943.43	1,945.20	68.5	67	67-67	1.5	PVC	SAQ			
HC-10	5/15/81	HC	HSA	NA	NA	NA	NA	184	181	176-181	1.5	PVC	?			
HC-11	5/26/81	HC	HSA	16,930.34	13,092.27	1,915.47	1,917.86	165	165	157-162	1.5	PVC	B or C	151.01	1,766.85	11/1/00
HC-12	7/8/81	HC	HSA	15,730.15	12,058.36	1,922.55	1,925.04	150	148	145-148	1.5	PVC	A	141.51	1,783.53	11/1/00
HC-13	7/17/81	HC	HSA	14,445.16	12,904.94	1,941.63	1,942.07	162	162	157.5-162	1.5	PVC	A	154.27	1,787.80	11/1/00
HC-14	7/23/81	HC	HSA	13,314.44	16,356.99	1,946.58	1,948.12	162.5	160	156-160	1.5	PVC	A?	151.68	1,796.44	11/2/00
HC~~-15~~	7/8/82	HC	HSA	15,056.81	14,568.02	1,933.35	1,936.48	156	145.5	140.5-145.5	1.5	PVC	A?	144.47	1,792.01	11/2/00
HC-16	7/12/82	HC	HSA	15,646.44	14,161.33	1,926.08	1,929.04	149	141.5	136.5-141.5	1.5	PVC	A?	139.38	1,789.66	11/1/00
HC-17	7/21/82	HC	HSA	15,026.24	13,484.00	1,942.56	1,945.47	168	163.5	153.5-163.5	1.5	PVC	A?	sand		11/2/00
KM-1	8/18/00	MFG	Tubex	15,383.41	11,796.50	1,927.06	1,929.84	162	161	140.3-159.6	4	PVC	A	145.72	1,784.12	11/1/00
OB-1	8/15/00	MFG	Tubex	15,382.57	11,786.79	1,927.27	1,929.96	185	185	173.3-182.3	2	PVC	B	160.4	1,769.56	11/1/00
A-4	9/26/89	HC	HSA	14,920.22	12,165.21	1,944.24	1,947.01	NA	NA	NA	2	PVC	SAQ			
A-5	9/15/89	HC	HSA	NA	NA	NA	NA	69	68	57-67	2	PVC	SAQ			
A-6	9/26/89	HC	HSA	14,570.17	12,580.01	1,942.49	1,942.39	67.5	66	56-66	2	PVC	SAQ			
A-7	9/22/89	HC	HSA	14,531.73	12,856.98	1,941.72	1,941.24	63.5	63	51-61	2	PVC	SAQ			
A-8	9/21/89	HC	HSA	NA	NA	NA	NA	59	57	47-57	2	PVC	SAQ			
A-9	0/21/89	HC	HSA	15,099.62	12,985.63	1,930.25	1,930.10	49	49	38-48	2	PVC	SAQ			

TABLE 1

WELL CONSTRUCTION AND WATER LEVEL DATA

Well Number	Date Installed	Designed By	Drilling Method	Northing	Easting	Ground Surface Elevation (ft NGVD)	Top of Casing (TOL) Elevation (ft NGVD)	Boring Depth (ft bgs)	Well Depth (ft bgs)	Screened Interval (ft bgs)	Casing Inside Diameter (inches)	Casing Type	Unit(s) Screened	Static Water Level (ft below TOC)	Static Water Level Elevation (ft NGVD)	Date of Measurement
A-11	6/19/90	HC	HSA	NA	NA	NA	NA	66	66	54-64	2	PVC	SAQ			
A-12	6/19/90	HC	HSA	14,714.77	12,794.34	1,942.28	1,944.20	64.5	64.5	54-64	2	PVC	SAQ			
A-13	6/20/90	HC	HSA	15,197.59	12,835.03	1,939.14	1,939.29	63	63	53-63	2	PVC	SAQ			

Notes:

1) Well Design: R&N is Robinson Noble, Inc; ES is Engineering Science, Inc.; HC is Hart-Crowser, Inc.; MFG is MFG, Inc.

2) Drilling Method: AR is air rotary; HSA is hollow stem auger; Tubex is double-wall percussion air rotary, CT is cable tool

3) NA = not available

4) Units Screened: A = Zone A; B = Zone B; C = Zone C; SAQ = sand overlying shallow aquitard.

TABLE 2

GROUNDWATER FLOW MODEL CALIBRATION DATA

Calibration Point	Observed Head (ft)	Simulated Head (ft)	Head Difference (ft)
7G2	1706	1704	-2
HW#1	1755	1743	-12
TH-5	1761	1760	-1
KM-1	1776	1776	-0.2
17J1	1779	1777	-3
Summary Statistics[1]	Mean error		-3.3 (feet)
	Normalized RMS[2]		7.3%

Notes:

[1] statistics calculated using MODFLOW Calibration Package

[2] root mean squared

TABLE 3

RESULTS OF SENSITIVITY ANALYSIS

Heads (ft)	Baseline	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16	Minimum	Maximum	St.Dev.
7G2	1702.6	1702.6	1701	1701.8	1713.7	1691.2	1702.7	1702.8	1702.3	1701	1702.4	1702.4	1702.7	1702.5	1702.4	1702.4	1704.4	1691.2	1713.7	4.045133
HW#1	1741.9	1742	1741	1741.2	1743.4	1741.8	1742	1742.3	1741.5	1740.6	1741.6	1741.63	1742	1741.8	1741.6	1741.8	1743.5	1740.6	1743.45	0.717849
TH-5	1759.6	1759.9	1759.9	1759.9	1760.9	1759.2	1759.7	1760.1	1759	1760.4	1759.2	1759.3	1759.7	1759.6	1759.2	1759.5	1760.1	1759	1760.9	0.489416
KM-1	1775.8	1775.8	1776.2	1776.3	1776.4	1775.7	1775.9	1777	1774.8	1776.8	1775.4	1775.4	1775.9	1775.8	1775.4	1775.8	1775.8	1774.8	1777	0.534164
17J1	1776.5	1776.6	1776.9	1776.9	1777.5	1775.8	1776.6	1777.1	1775.9	1777.4	1776.1	1776.1	1776.5	1776.5	1776.1	1776.5	1776.5	1775.8	1777.5	0.486131
Average Head Difference		0.1	0.28	0.06	3.1	2.54	0.1	0.58	0.58	0.04	0.34	0.314	0.08	0.04	0.34	0.08	0.775			

Mass Balance (ft^3/day)	Baseline	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16
Heads In	8488996	8502668	16711600	8335762	13474707	5080819	4224579	8553588	8418105	8189482	8716405	8713038	8466587	8508956	8717341	8519101	8047385
Recharge In	90070	90070	90070	90070	90070	90070	90070	90070	90070	90070	90070	90070	138488	44926	90070	22707	21516
Storage In	0	0	0	0	0	0	0	0	0	0	1656	7357	0	0	45.3	0	0
Heads Out	8579066	8592739	16801670	8425832	13564777	5170890	4314649	8643658	8508175	8279552	8529011	8531326	8605076	8553882	8528369	8541808	7791879
Well Out	0	0	0	0	0	0	0	0	0	0	279140	279140	0	0	279140	0	279140
Balance	0.000	-1.000	0.000	0.000	0.000	-1.000	0.000	0.000	0.000	0.000	-20.000	-1.000	-1.000	0.000	-52.700	0.000	0.000
%	0.00E+00	1.16E-05	0.00E+00	0.00E+00	0.00E+00	1.93E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.27E-04	1.14E-05	1.16E-05	0.00E+00	5.98E-04	0.00E+00	0.00E+00

Notes:

Run 1	Increase Hydraulic Conductivity (K) in Zone B to 1000 ft/day
Run 2	Double K in Entire Domain
Run 3	Decrease K in Zone B from 750 to 400 ft/day
Run 4	Increase K of Zone C 50%
Run 5	Decrease K of Zone C 50%
Run 6	Decrease K in Entire Domain 50%
Run 7	Increase K of Zone A 50%
Run 8	Decrease K of Zone A 50%
Run 9	Decrease K of Zone B 50%
Run 10	Add Supply Well in Zone C for 30 yrs, at 1450 gpm (transient run)
Run 11	Increase Storage in Sands 50% (transient run)
Run 12	Increase Recharge 50%
Run 13	Decrease Recharge 50%
Run 14	Decrease Storage 50% (transient run)
Run 15	Decrease Recharge to 0.1 inch/yr over site and 1 inch/yr elsewhere over model
Run 16	Add no-flow nodes at location of Dart Hill, steady-state simulation with Supply Well. This flow model was used for fate and transport simulations.

TABLE 4

RESULTS OF CYANIDE EXTRACTION/RE-INJECTION MODELING

Remedy Option	Simulation Obs. Wells (1) (mg/L)		
	Obs 1	**Obs 2**	**Obs 3**
Estimated Current Conditions Based on Historical Data	60(2)	n/a	0.921
Simulated Current Conditions	51.41	16.59	1.584
100% source reduction without pumping	*0.0002*	*0.0014*	*0.005* (3)
90% source reduction without pumping	*5.142*	*1.659*	*0.166*
90% source reduction, pump/inject 25gpm, 1mg/L into Zone A	4.960	1.595	0.162
90% source reduction, pump/inject 25gpm, 1mg/L into Zone C	4.976	1.583	0.159
90% source reduction, pump/inject 25gpm, 1mg/L into Zone B, Downgradient	4.981	1.514	0.157
90% source reduction, pump/inject 50gpm, 1mg/L into Zone C	4.819	1.497	0.136
90% source reduction, pump/inject 50gpm, 1mg/L into Zone A	4.797	1.530	0.150
90% source reduction, pump/inject 100gpm, 1mg/L into Zone A	4.519	1.407	0.136
90% source reduction, pump/inject 100gpm, 1mg/L into Zone C	4.536	1.337	0.118
80% source reduction without pumping	*10.28*	*3.316*	*0.328*
80% source reduction, pump/inject 50gpm, 1mg/L into Zone A	9.408	3.000	0.291
80% source reduction, pump/inject 50gpm, 1mg/L into Zone C	9.637	2.999	0.268
80% source reduction, pump/inject 25gpm, 1mg/L into Zone A	9.821	3.156	0.308
80% source reduction, pump/inject 25gpm, 1mg/L into Zone C	9.949	3.156	0.286
50% source reduction, pump/inject 100gpm, 1mg/L into Zone C	*22.68*	*6.685*	*0.582*
20% source reduction, pump/inject 100gpm, 1mg/L into Zone C	*36.29*	*10.70*	*0.931*
Cleanup Objectives	**18**(4)		**0.170**(5)

Notes:

(1) Model Observations wells. Obs 1 and Obs 3 correspond with the proposed conditional POCs. Obs 2 is situated in Zone B between TH-5 and S.H. 2. The simulated initial conditions concentration in Zone C at Obs 2 is 1.234 mg/L. Note that Zone A is dry at Obs 2 and Obs 3.

(2) Represents average of total cyanide data from TH-3a between 1996 and 1999.

(3) Results reflect simulation of 100% source reduction through 3,000 days (8.2 yrs).

(4) Total CN cleanup objective for Obs 1 (i.e. plant perimeter) was calculated by multiplying the cleanup objective for free cyanide (0.2 mg/L) by the observed total CN/free CN ratio (i.e. 90) in the source area (Obs 1).

(5) Obs 3 is representative of W-195 location. Based on 1983-99 data for W-195, mean tot. CN is 921 ppb, min is 651 ppb and max is 1450 ppb. Therefore, the estimated total CN cleanup objective at Obs 3 was adjusted to account for the results of fate and transport modeling that overestimate the average concentrations of total cyanide observed at W-195. Thus, the total cyanide cleanup objective at W-195 (Obs 3) was calculated as follows: 0.0052 x 19 x (1.584/0.921), where 0.0052 is the cleanup objective for free cyanide at the springs.

TABLE 5

RESULTS OF FLUORIDE EXTRACTION/RE-INJECTION MODELING

Remedy Option	Simulation Obs. Wells (1) (mg/L)		
	Obs 1	Obs 2	Obs 3
Estimated Current Conditions Based on Historical Data	45(2)		0.9
Simulated Current Conditions	34.07	11.05	1.065
90% source reduction without pumping	*3.407*	*1.108*	*0.117*
90% source reduction, pump/inject 25gpm, 15mg/L and 3 mg/L[3] into Zone A, Upgradient[4]	3.307	1.196	0.122
90% source reduction, pump/inject 25gpm, 15mg/L and 3 mg/L[3] into Zone B, Downgradient[4]	3.303	1.037	0.109
Cleanup Objectives	**4**		**0.960**

Notes:

(1) Observations wells. Obs 1 and Obs 3 correspond with the Regulatory Compliance Points. Obs 2 is situated between TH-5 and S.H. 2.

(2) Represents average of fluoride data from TH-3a, HC-9a, and HC-12 between 1996 and 1999.

(3) Results of 90% reduction simulation show that concentrations are reduced to below 15 mg/L after about 2 years of pumping and source reduction. Therefore, for this simulation, treated water with 15 mg/L fluoride was injected for the first 750 days, followed by injection of 3 mg/L for the remainder of the simulation (assuming no further treatment of groundwater for fluoride after 750 days).

(4) Reinjection upgradient or downgradient from extraction wells.

TABLE 6

SUMMARY OF TDS AND IRON INJECTION SIMULATION RESULTS

Injection Concentration (mg/L)	Simulated Concentration (mg/L)			Notes
	Obs 1	Obs 2	Obs 3	
23,300	1545	661	68	Maximum TDS Concentration
20,000	1326	568	58	
15,000	995	426	44	
11,600	769	329	34	
10,000	663	284	29	
9,000	597	255	26	
8,000	530	227	23	
7,000	464	199	20	
6,000	398	170	17	
5,000	332	142	15	
4,000	265	114	12	
3,260	216	93	9	Maximum Iron Concentration
2,000	133	57	6	
1,000	66	28	3	
500	33	14	1	
10	1	0.3	0.03	
1	0.1	0.03	0.003	

TABLE 7

SUMMARY OF TOTAL CYANIDE MASS-BALANCE[1] OUTPUT - 90% SOURCE REDUCTION WITH EXTRACTION

90% Source Reduction - 1mg/L total cyanide re-injection

		25 GPM			50 GPM			100 GPM		
Remediation Time (days)	In Source (kg/day)	In Inj. Well (kg/day)	Out Ext. Well		In Inj. Well (kg/day)	Out Ext. Well		In Inj. Well (kg/day)	Out Ext. Well	
			(kg/day)	(kg)		(kg/day)	(kg)		(kg/day)	(kg)
1	7.2	0.13	5.50	5.50	0.26	11.0	11.0	0.54	22.0	22.0
50	7.2	0.13	5.50	275	0.26	11.0	548	0.54	21.6	1081
175	7.2	0.13	5.06	908	0.26	9.92	1788	0.54	18.9	3442
365	7.2	0.13	3.58	1588	0.26	6.74	3068	0.54	12.0	5714
500	7.2	0.13	2.19	1884	0.26	3.99	3607	0.54	6.72	6621
600	7.2	0.13	1.55	2039	0.26	2.79	3886	0.54	4.61	7082
1000	7.2	0.13	0.71	2404	0.26	1.30	4549	0.54	2.28	8206
1300	7.2	0.13	0.58	2586	0.26	1.11	4892	0.54	2.00	8823
1750	7.2	0.13	0.54	2832	0.26	1.03	5363	0.54	1.92	9695
2500	7.2	0.13	0.54	3233	0.26	1.03	6134	0.54	1.92	11130

[1] Excludes mass removal through constant-head nodes. Mass-balance error in each simulation was less than 0.01%

TABLE 8

MMARY OF TOTAL CYANIDE CONCENTRATION AND MASS REDUCTION OUTPUT - 90% SOURCE REDUCTION REMEDY OPTIONS

90% Source Reduction - 1 mg/L total cyanide re-injection

	90% Source Reduction[1]		Total Reduction with 90% Source Reduction and Pumping[2]						Cumulative Mass Reduction[3]	Cumulative Mass Removal[4]		
	0 GPM		25 GPM		50 GPM		100 GPM					
Remediation Time (days)	Obs 1 mg/L	Obs 3 mg/L	Obs 1 mg/L	Obs 3 mg/L	Obs 1 mg/L	Obs 3 mg/L	Obs 1 mg/L	Obs 3 mg/L	0 GPM kg	25 GPM kg	50 GPM kg	100 GPM kg
1	--	--	--	--	--	--	--	--	64.80	5.50	11	22
50	1.642	0	2.046	0	2.469	0	3.399	0	3240	275	548	1081
175	15.721	0	17.18	0	18.56	0	21.11	0	11340	908	1788	3442
365	31.974	0	33.45	0	34.74	0	36.93	0	23652	1588	3068	5714
500	38.264	0	39.41	0	40.39	0	41.98	0	32400	1884	3607	6621
600	41.086	0	42.00	0	42.76	0	43.99	0	38880	2039	3886	7082
1000	45.371	0.013	45.74	0.025	46.04	0.038	46.53	0.064	64800	2404	4549	8206
1300	46.024	0.289	46.26	0.326	46.47	0.362	46.81	0.431	84240	2586	4892	8823
1750	46.229	0.964	46.42	1.005	46.58	1.042	46.88	1.106	113400	2832	5363	9695
2500	46.261	1.386	46.44	1.400	46.60	1.411	46.89	1.431	162000	3233	6134	11130

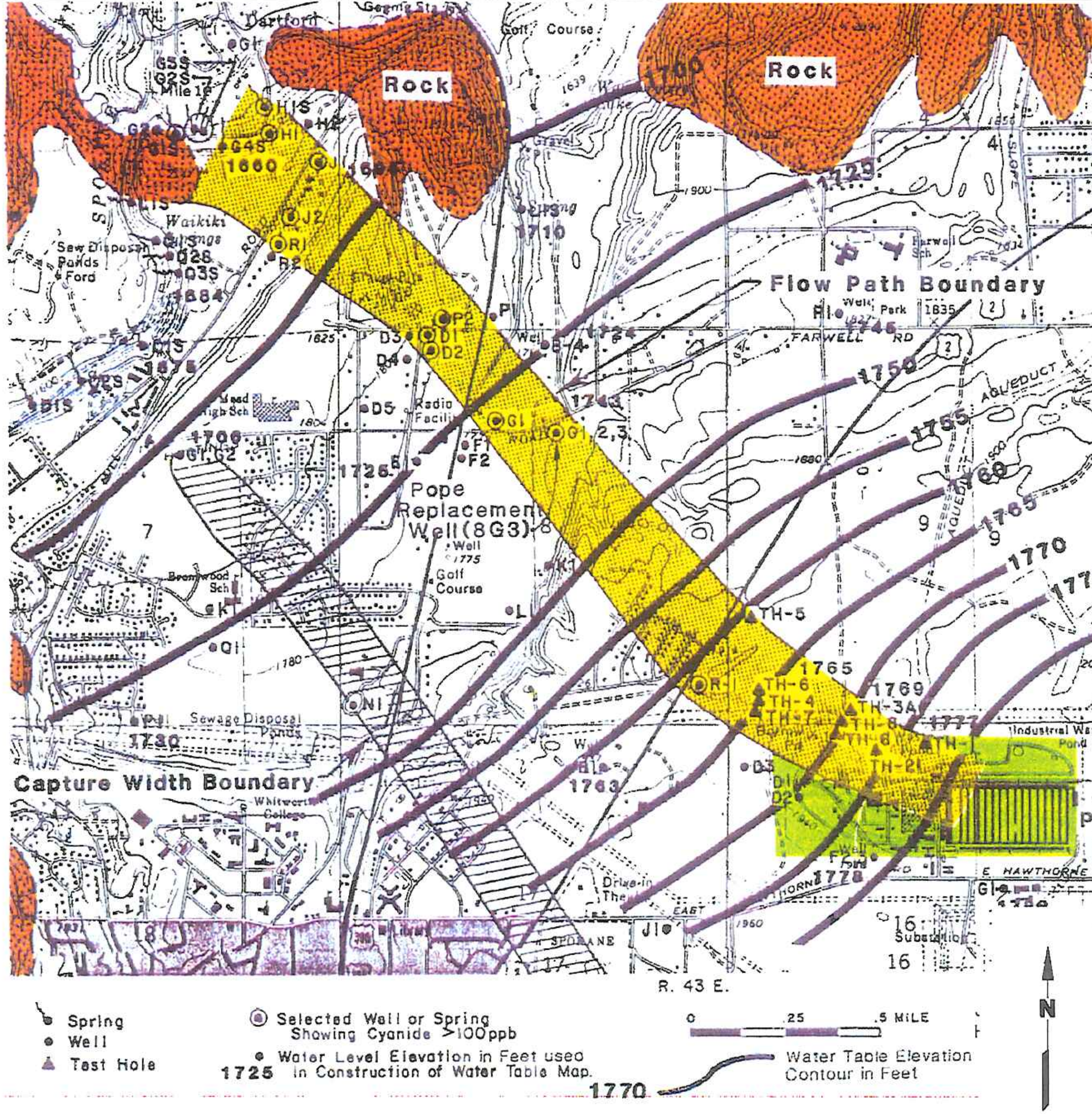
Notes:

[1] Represents total reduction in concentrations due to 90% source reduction only.

[2] Represents total reduction in concentrations due to both pumping and 90% source reduction.

[3] Represents cumulative reduction in mass loading. Calculated as follows: 0.9 x 72 kg/day x remediation time, where 72 kg/day is total loading before source reduction and 0.9 represents percent reduction in source loading.

[4] Derived from Table 7.



Source: Hart-Crowser and Associates, 1988.

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Figure 1

SITE MAP WITH CONTAMINANT PLUME

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DATE: DEC., 2000	CHECKED: PGP	

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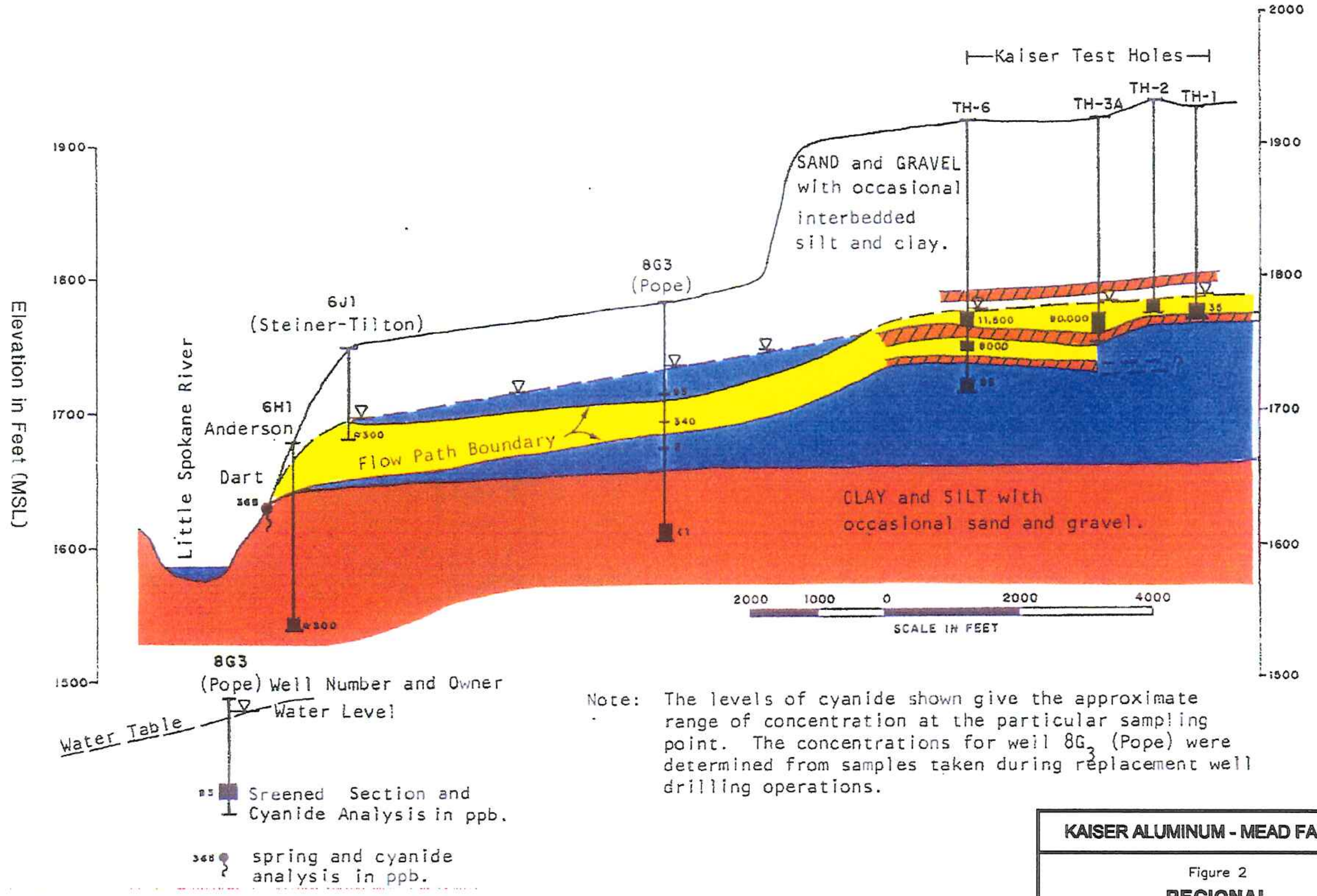

Note: The levels of cyanide shown give the approximate range of concentration at the particular sampling point. The concentrations for well $8G_3$ (Pope) were determined from samples taken during replacement well drilling operations.

Source: Hart-Crowser and Associates, 1988.

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Figure 2

REGIONAL CROSS SECTION

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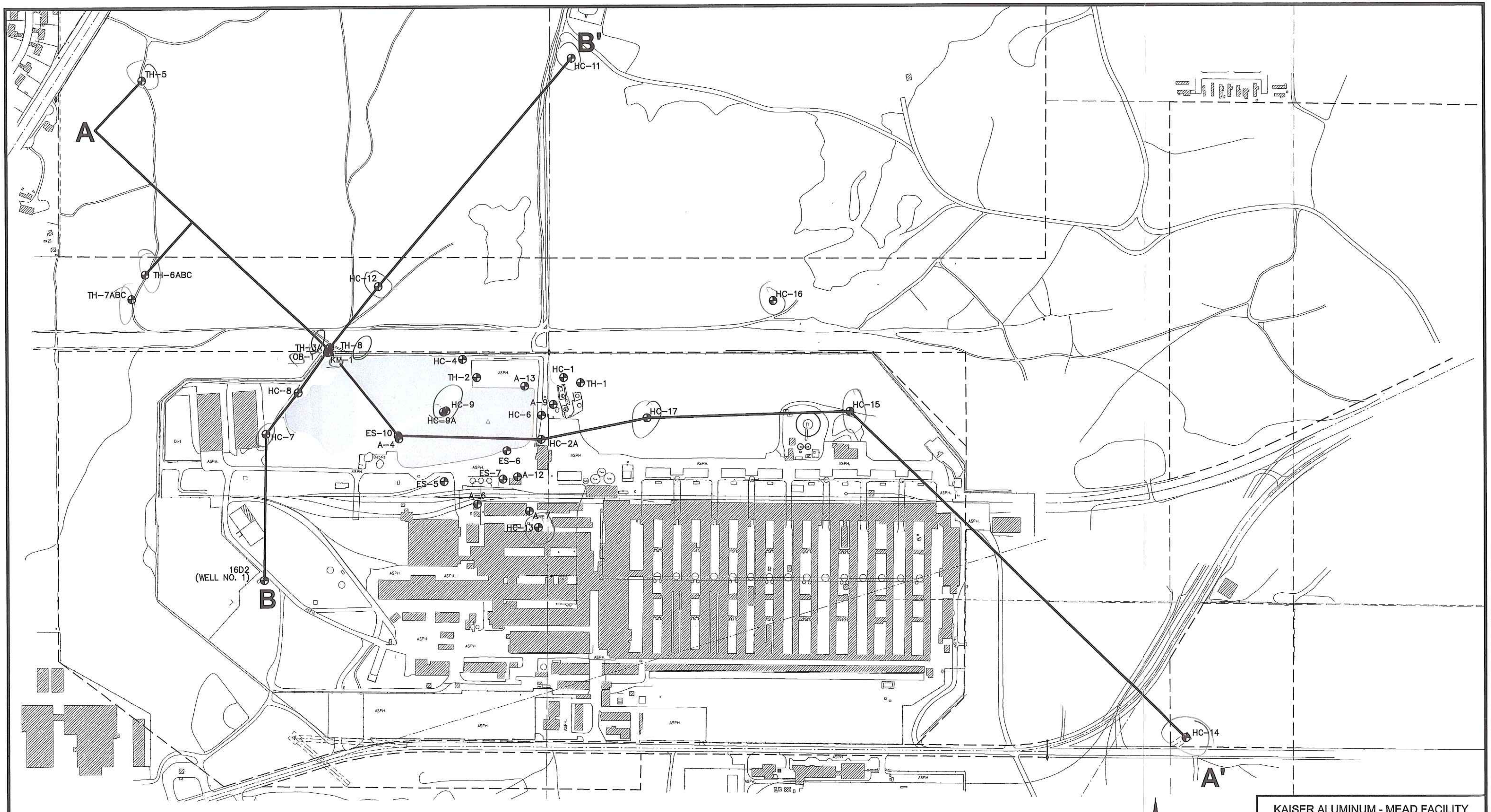

EXPLANATION

HC-8⊕ Monitoring Well

A___A' Cross Section Line

▨ Locations of Butt Tailing, Rubble and SPL Piles

N

Scale in Feet

0 250 500

Source: Base map taken from Adams & Clark, Inc. Surveyed Map, November 8, 2000.

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Figure 3

SURVEYED WELL LOCATIONS AND CROSS SECTION LOCATIONS

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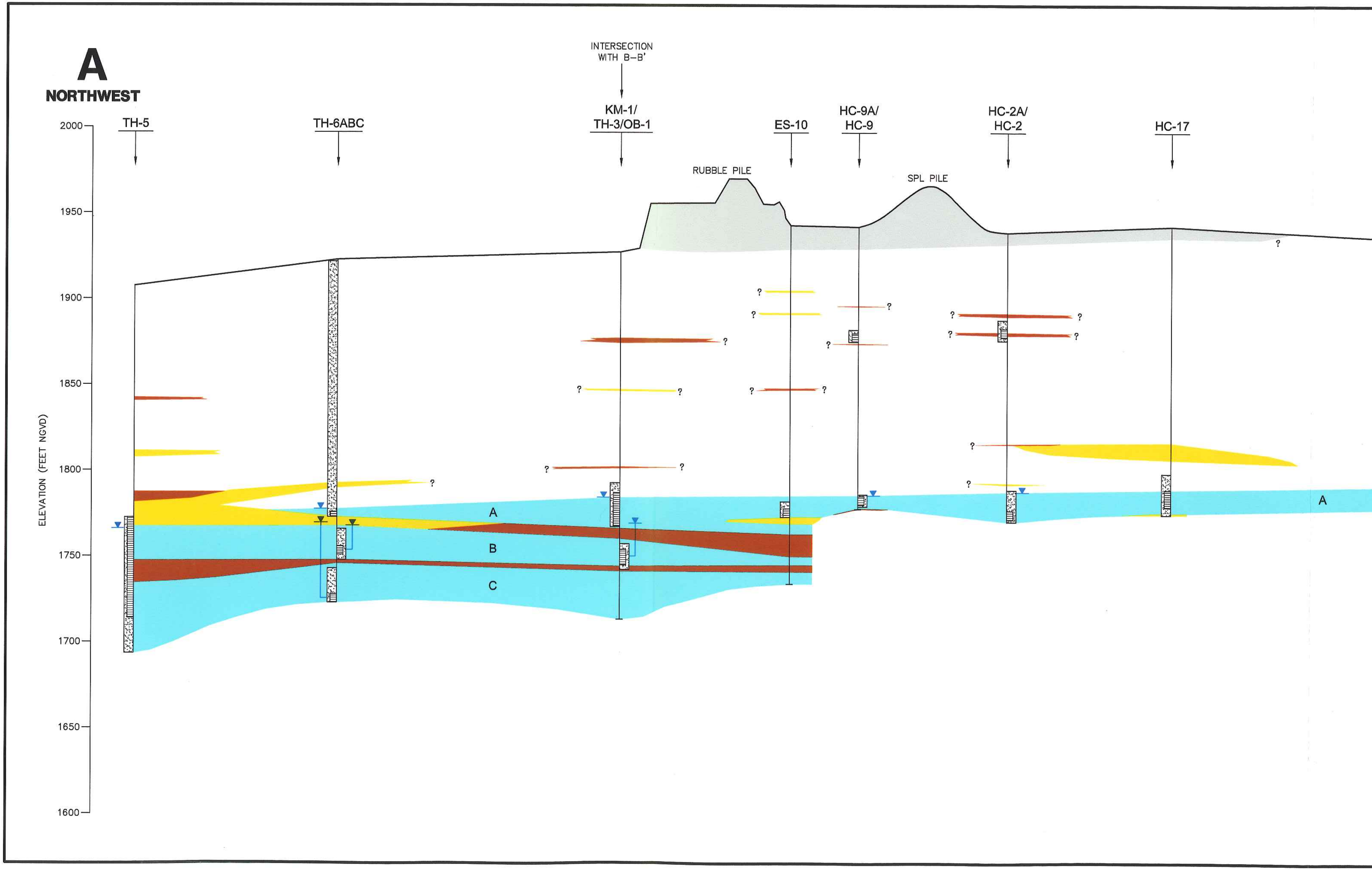
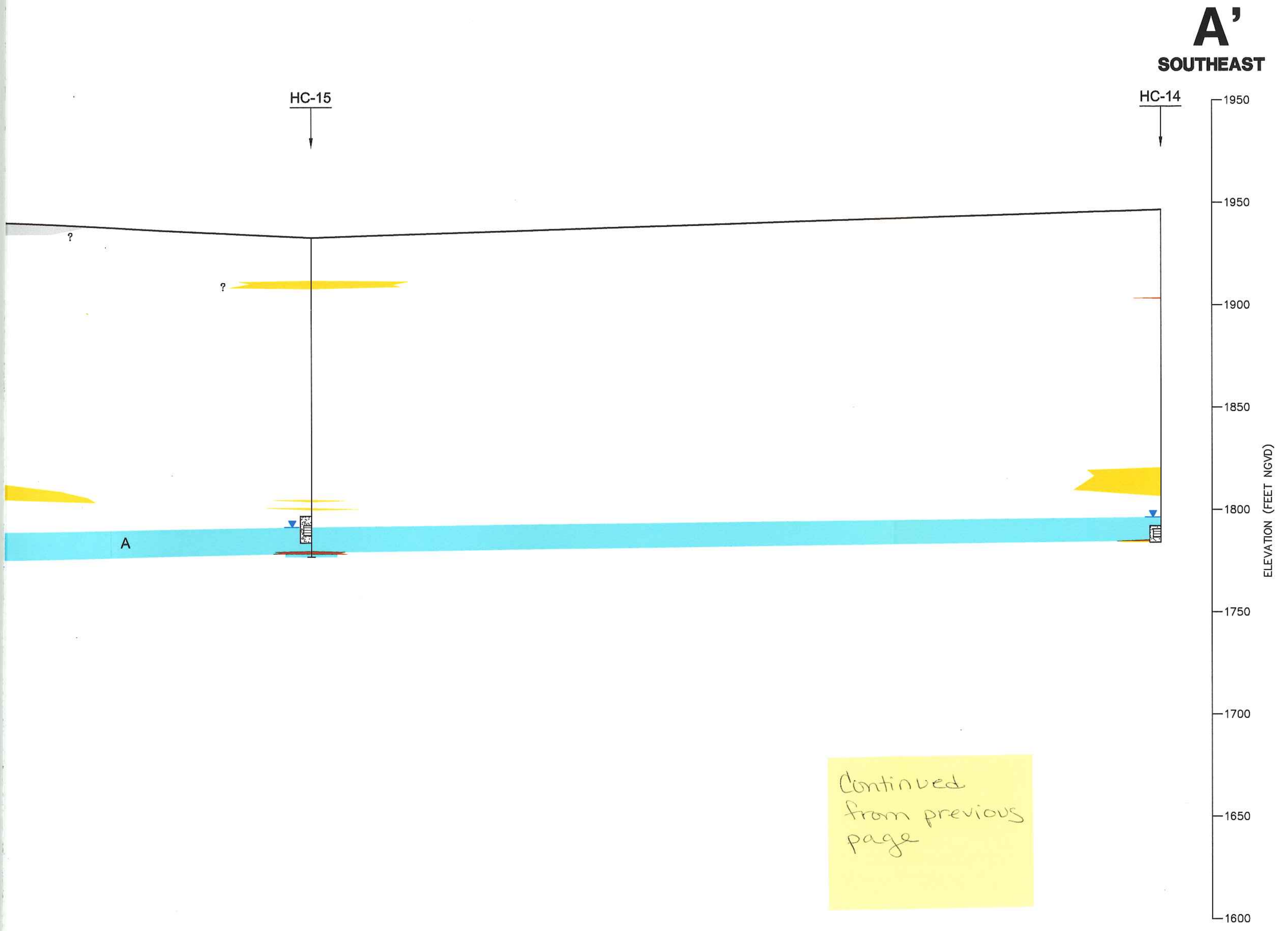

A
NORTHWEST
INTERSECTION WITH B–B'
TH-5
TH-6ABC
KM-1/ TH-3/OB-1
ES-10
HC-9A/ HC-9
HC-2A/ HC-2
HC-17
RUBBLE PILE
SPL PILE
ELEVATION (FEET NGVD)
2000
1950
1900
1850
1800
1750
1700
1650
1600
A
B
C
A
?



Continued from previous page

EXPLANATION

- ▒ Fill or Pile Material
- ☐ Sand with Some Gravel and Silt
- 🟨 Sand with Fine-Grained Interbeds
- 🟥 Clay, Silty Clay, Clayey Silt
- 🟦 A Saturated Sand with Zone Designation

MONITORING WELL CONSTRUCTION

- Ground Level at Well Location
- ▼ Water Level (ft NGVD) Measured 11/1-2/00
- Artificial or Natural Filter Pack
- Well Screen

SCALE IN FEET

VERTICAL 50

HORIZONTAL 300

6x Vertical Exaggeration

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Figure 4

GEOLOGIC CROSS SECTION A-A'

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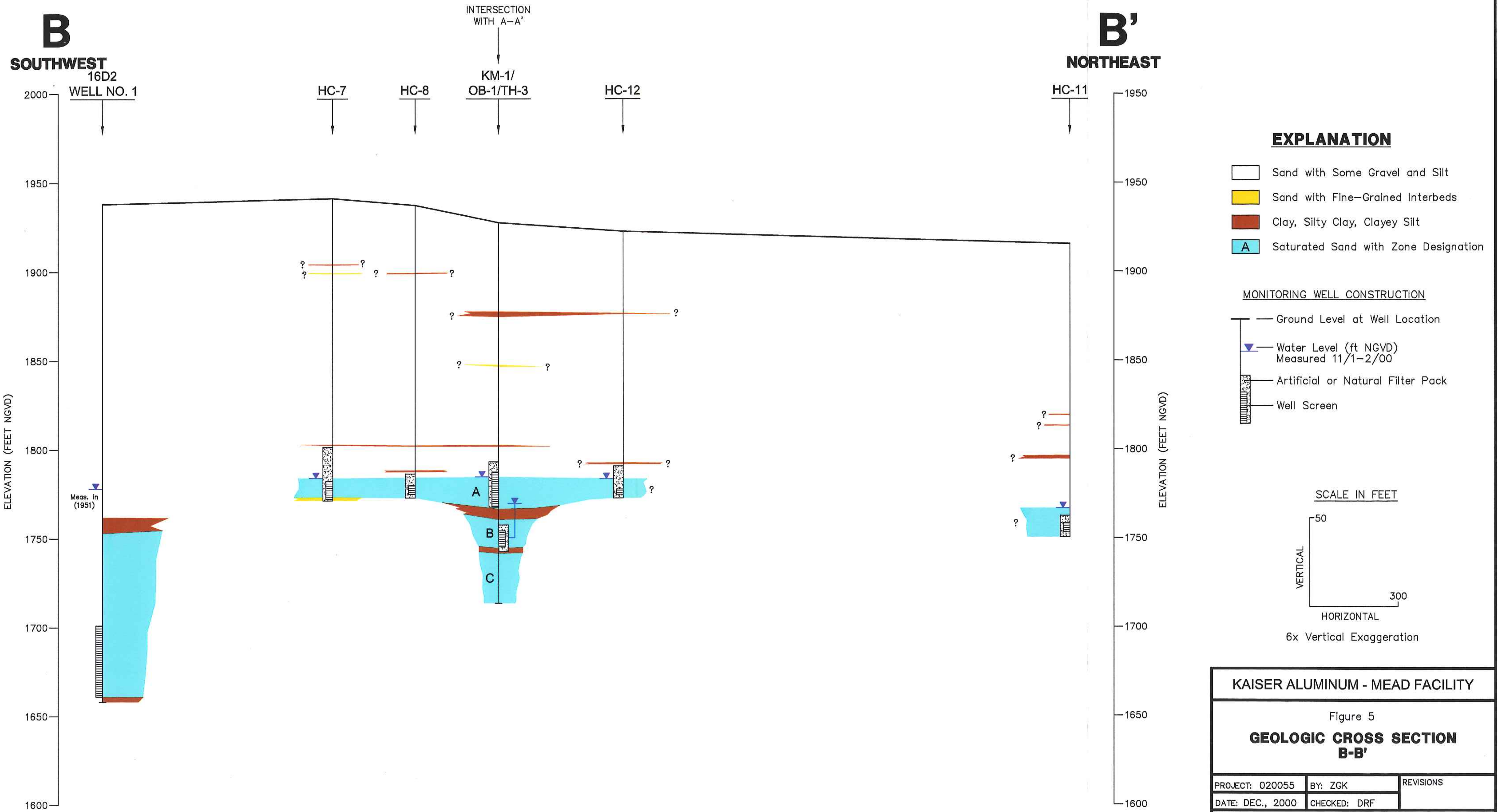

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Figure 5

GEOLOGIC CROSS SECTION B-B'

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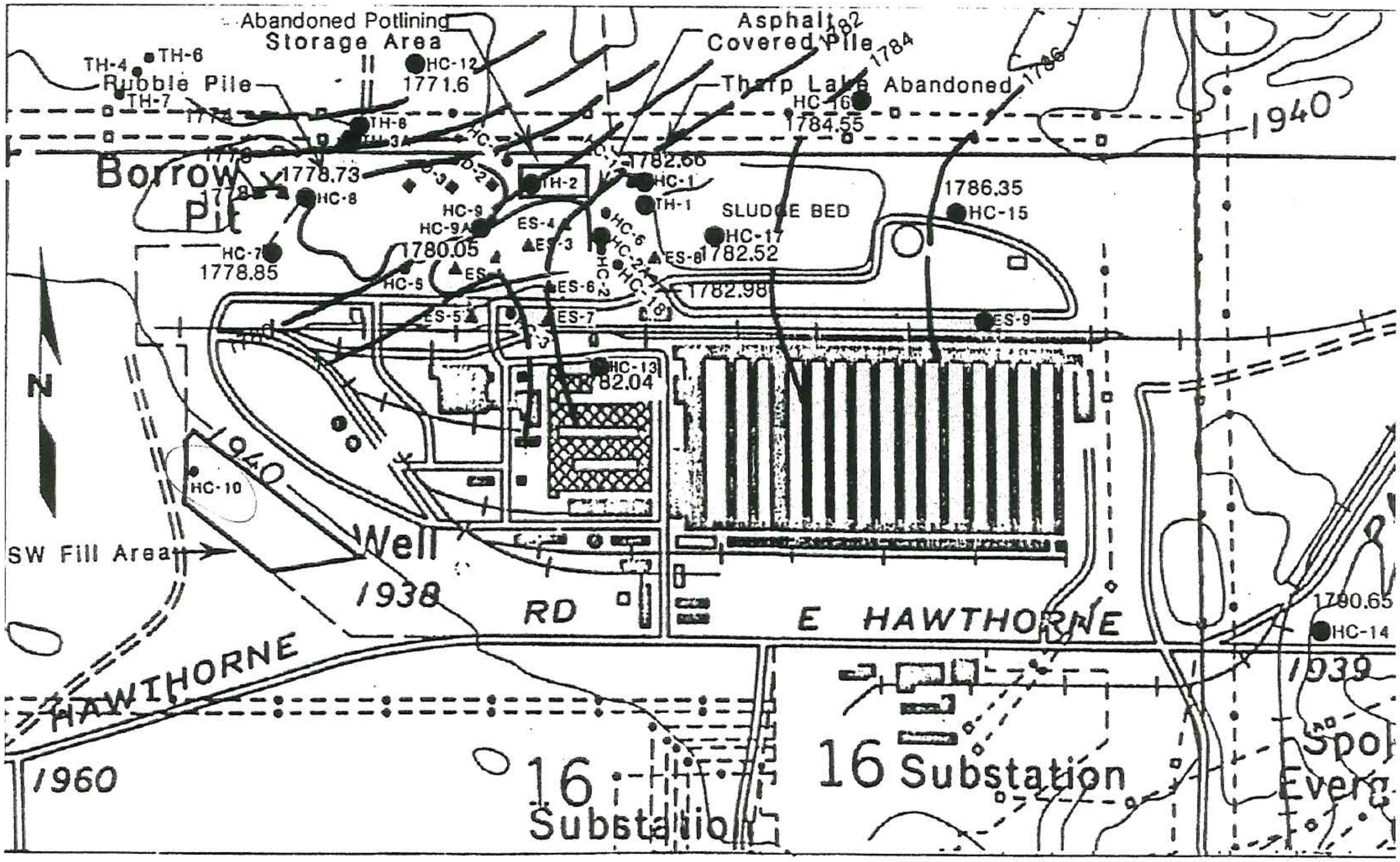

Dartford and Mead Quadrangles

● HC-8 Observation Well Location and Number Finished In A-Zone

1786.35 Spot Water Level Elevation in Feet

1786 Groundwater Elevation Contour in Feet

SCALE 1"=700'

Source: Hart-Crowser and Associates, 1988.

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Figure 6

GROUNDWATER ELEVATION CONTOUR MAP - ZONE A AUGUST 1988

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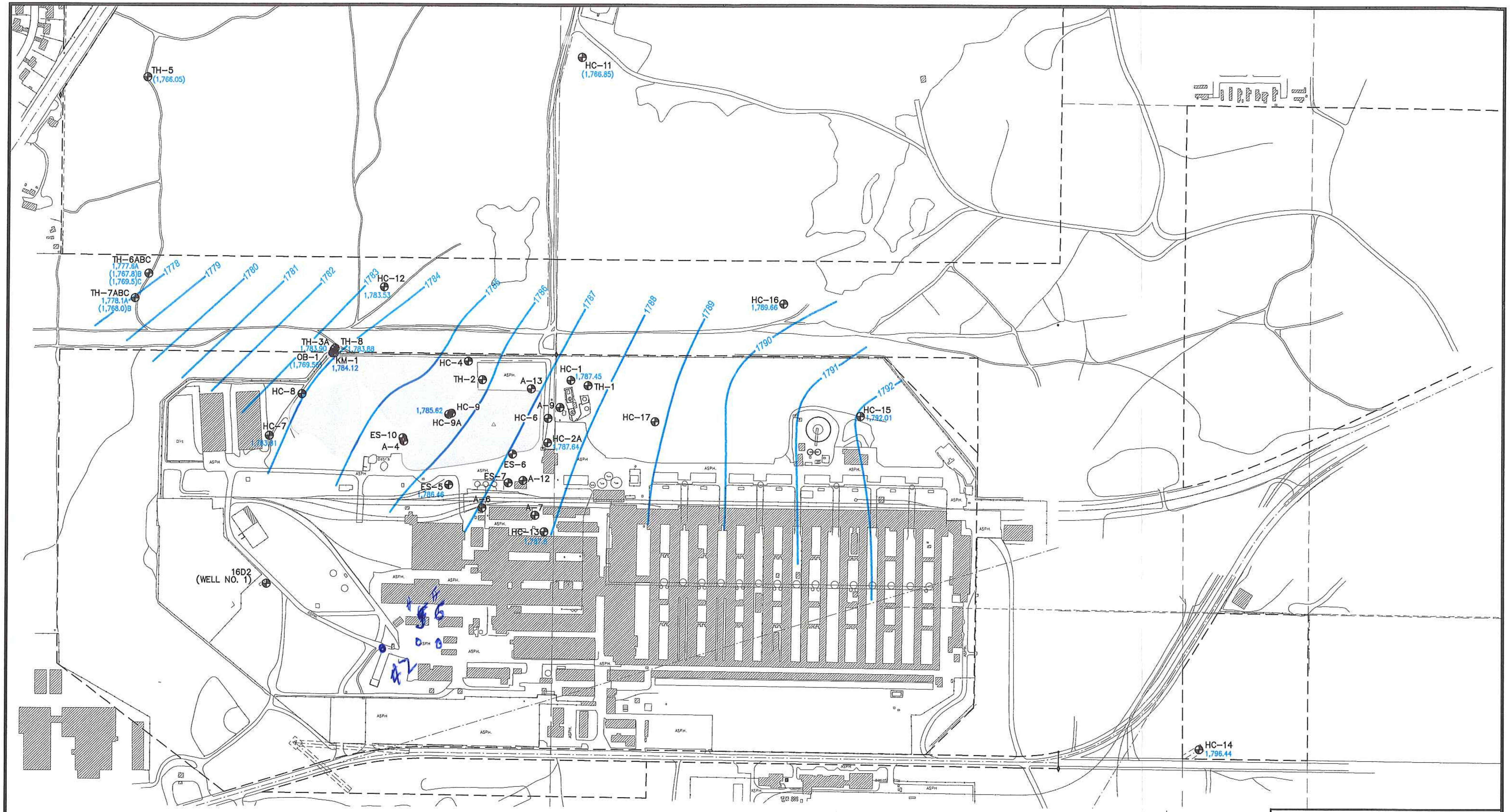

Scale in Feet

0 250 500

EXPLANATION

HC-11⊕ Monitoring Well

Locations of Butt Tailing, Rubble and SPL Piles

1,784.12 Water Level Elevation in Feet Measured Nov. 1-2, 2000

—1789— Groundwater Elevation Contour in Feet

Note:
Values in ( )-water level elevation for wells completed in Zone B and/or C not used in constructing contours.

Source:
Base map taken from Adams & Clark, Inc. Surveyed Map, November 8, 2000.

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Figure 7

POTENTIOMETRIC SURFACE MAP ZONE A, NOVEMBER 1-2, 2000

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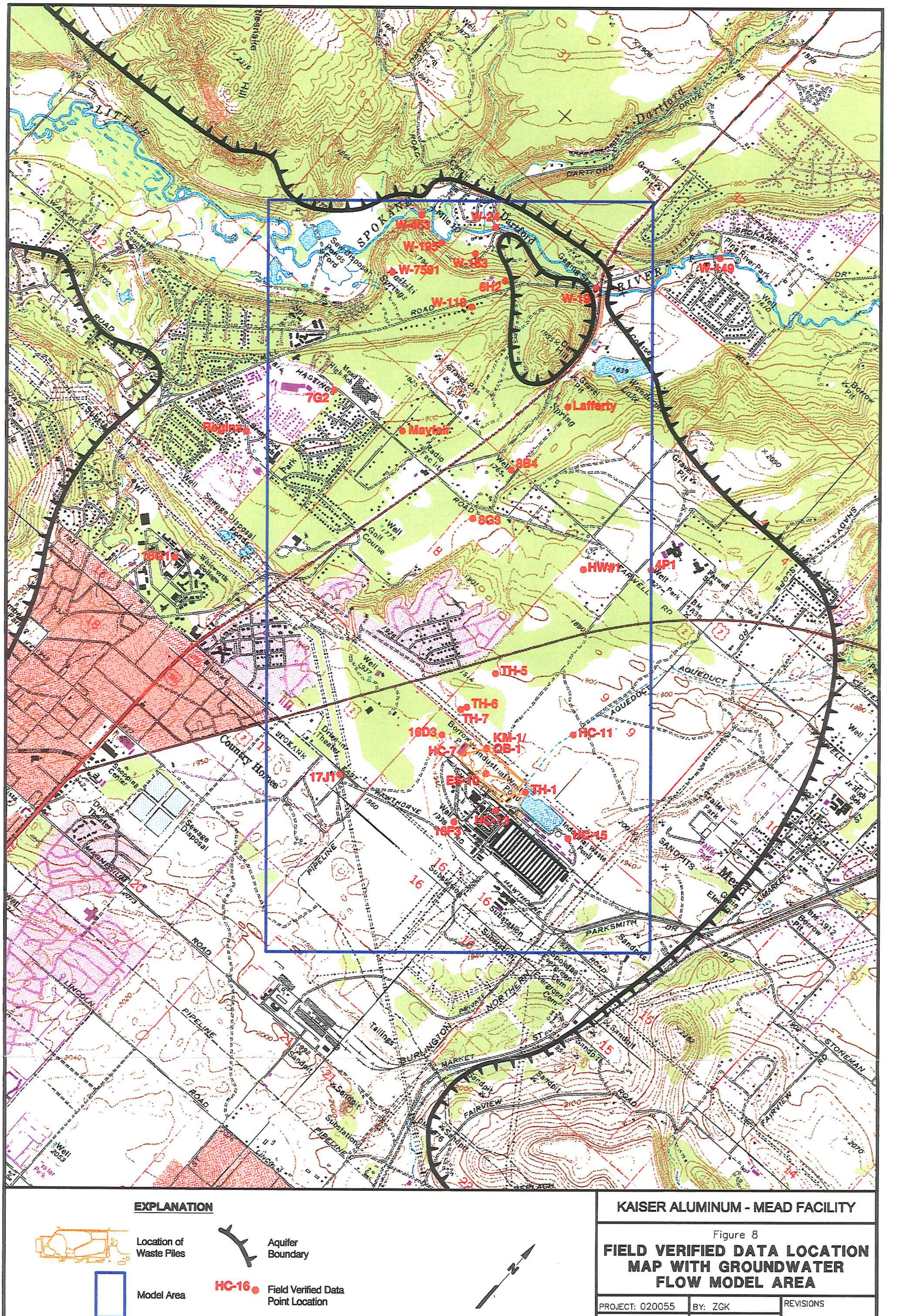

EXPLANATION

Location of Waste Piles

Aquifer Boundary

Model Area

HC-16 ● Field Verified Data Point Location

Sources:
U.S.G.S. 7.5-minute quads (Dartford, Wash. 1973 rev. 1986; Mead, Wash. 1973 rev. 1986; Spokane NW, Wash. 1974 rev. 1986; Spokane NE, Wash. 1973 rev. 1986) downloaded from www.gisdatadepot.com 9/2000. Aquifer boundary taken from Hart-Crowser (1988) Figure 26.

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Figure 8

FIELD VERIFIED DATA LOCATION MAP WITH GROUNDWATER FLOW MODEL AREA

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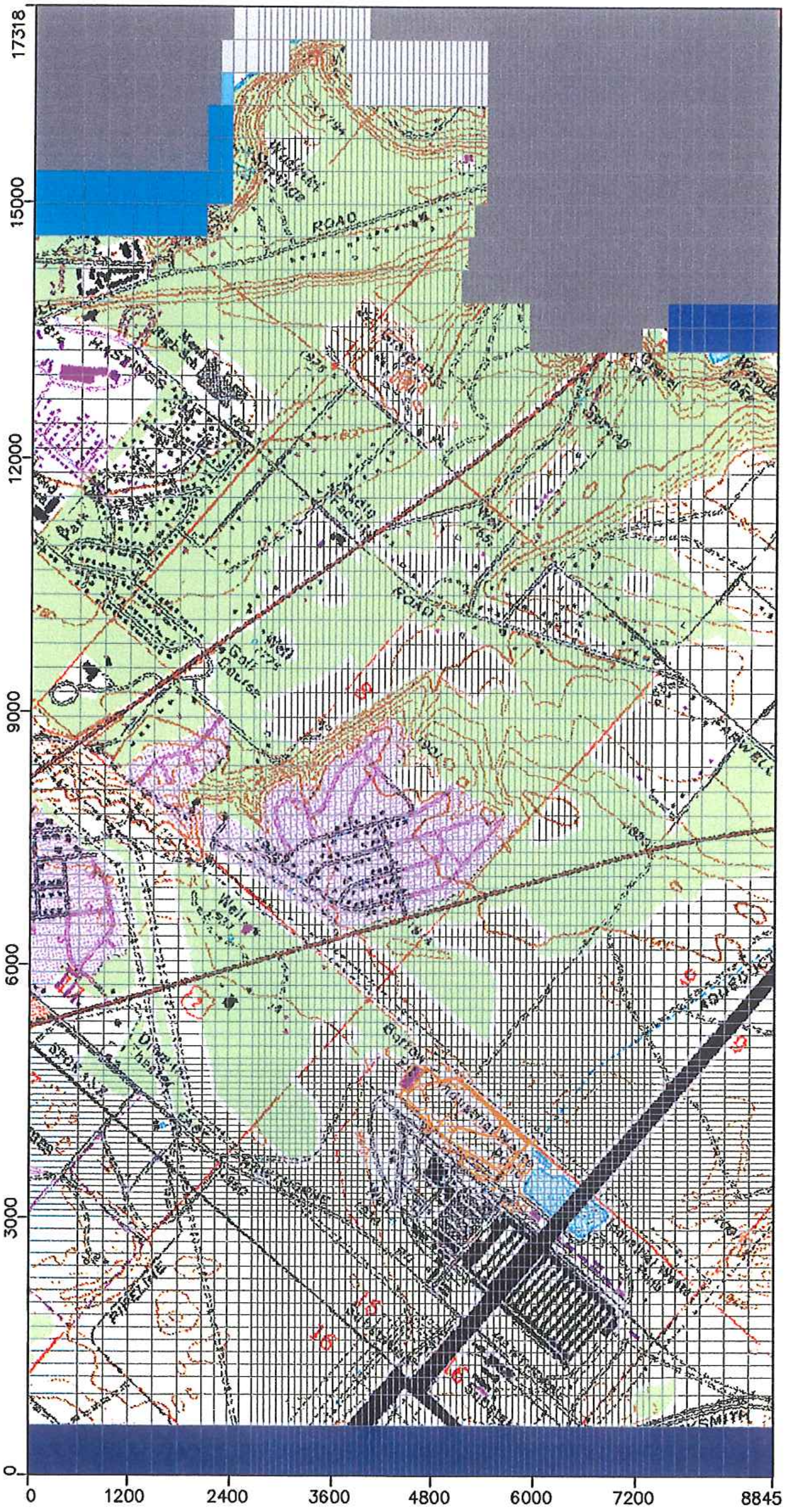

Note:
The sides of the grid are no-flow boundaries.

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Figure 9

FINITE DIFFERENCE GRID

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DATE: DEC., 2000
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Sources:
U.S.G.S. 7.5-minute quads (Dartford, Wash. 1973 rev. 1986; Mead, Wash. 1973 rev. 1986; Spokane NW, Wash. 1974 rev. 1986; Spokane NE, Wash. 1973 rev. 1986) downloaded from www.gisdatadepot.com 9/2000.

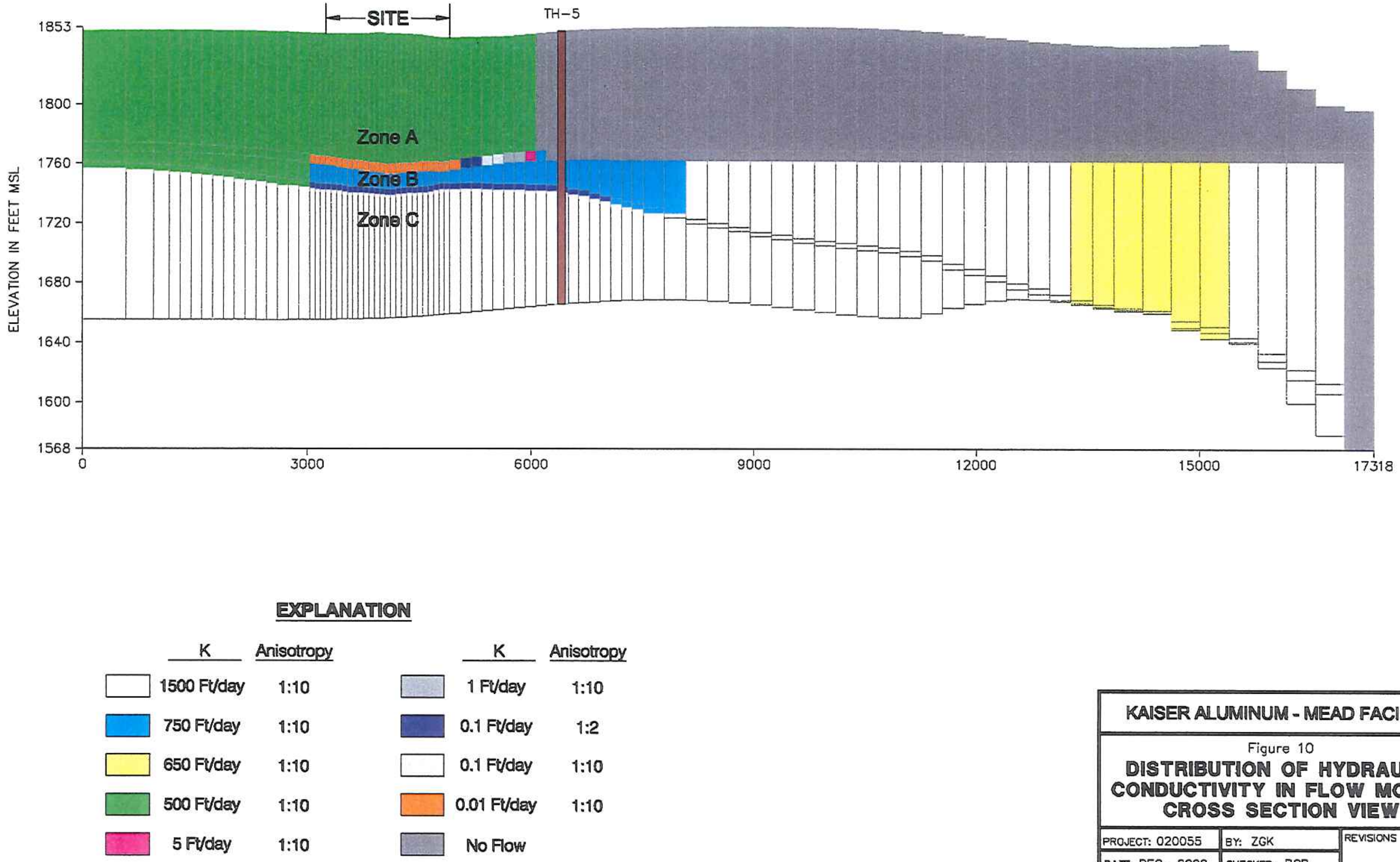

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Figure 10

DISTRIBUTION OF HYDRAULIC CONDUCTIVITY IN FLOW MODEL: CROSS SECTION VIEW

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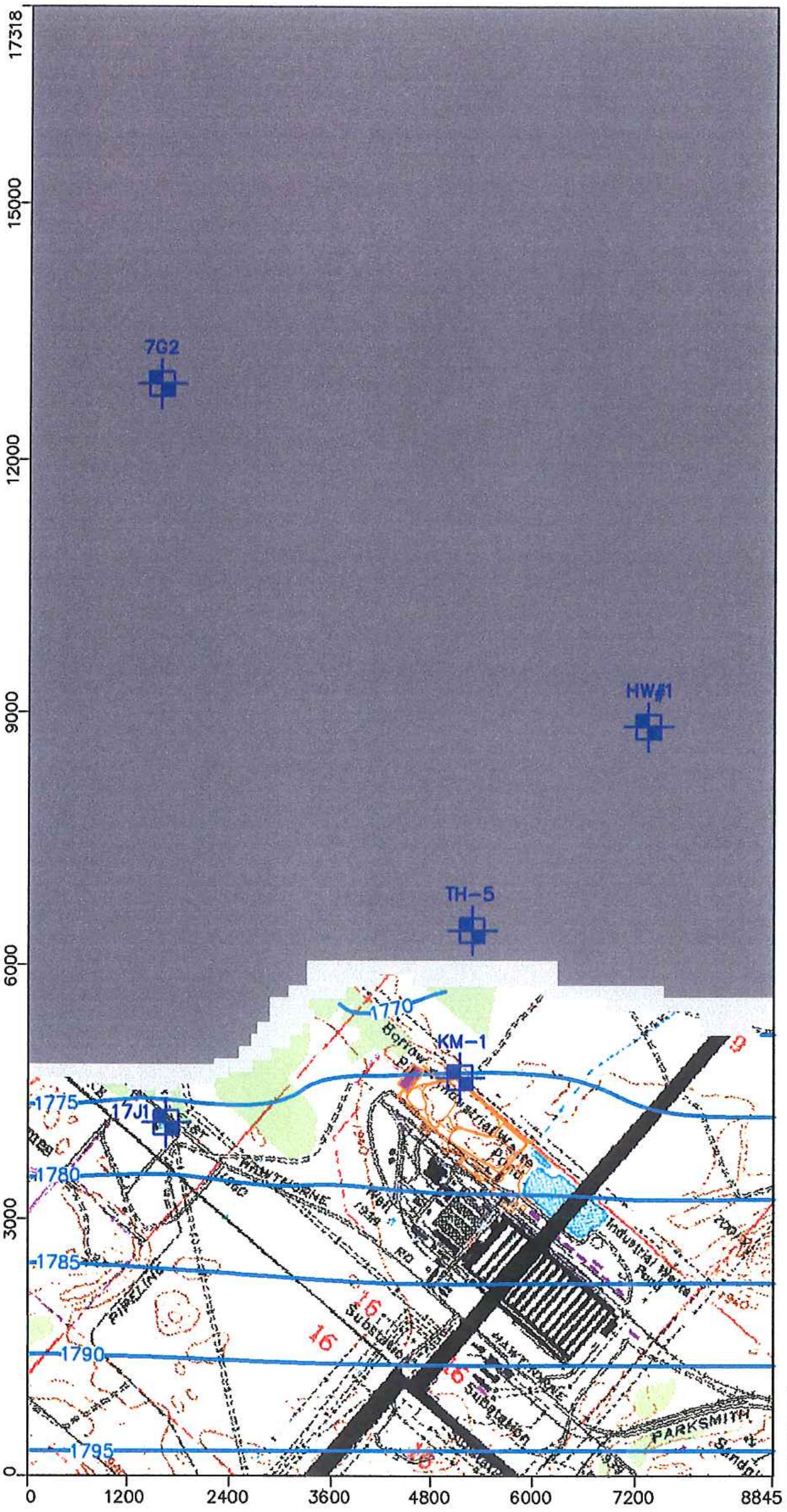

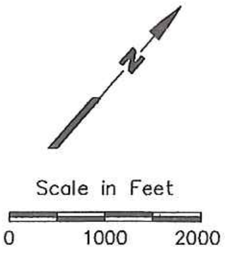

EXPLANATION

Location of Waste Piles

Dry Cell

▨ No Flow Cell

HW#1 Head Observation Well

1780 Zone A Simulated Potentiometric Surface C. I. = 5 Feet

Note:
The water table flows below layer 1 (Zone A) in the model. Therefore the model grid-nodes become "dry" between KM-1 and TH-5.

Sources:
U.S.G.S. 7.5-minute quads (Dartford, Wash. 1973 rev. 1986; Mead, Wash. 1973 rev. 1986; Spokane NW, Wash. 1974 rev. 1986; Spokane NE, Wash. 1973 rev. 1986) downloaded from www.gisdatadepot.com 9/2000.

KAISER ALUMINUM - MEAD FACILITY

Figure 11

ZONE A SIMULATED POTENTIOMETRIC SURFACE

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DATE: NOV., 2000	CHECKED: PGP	

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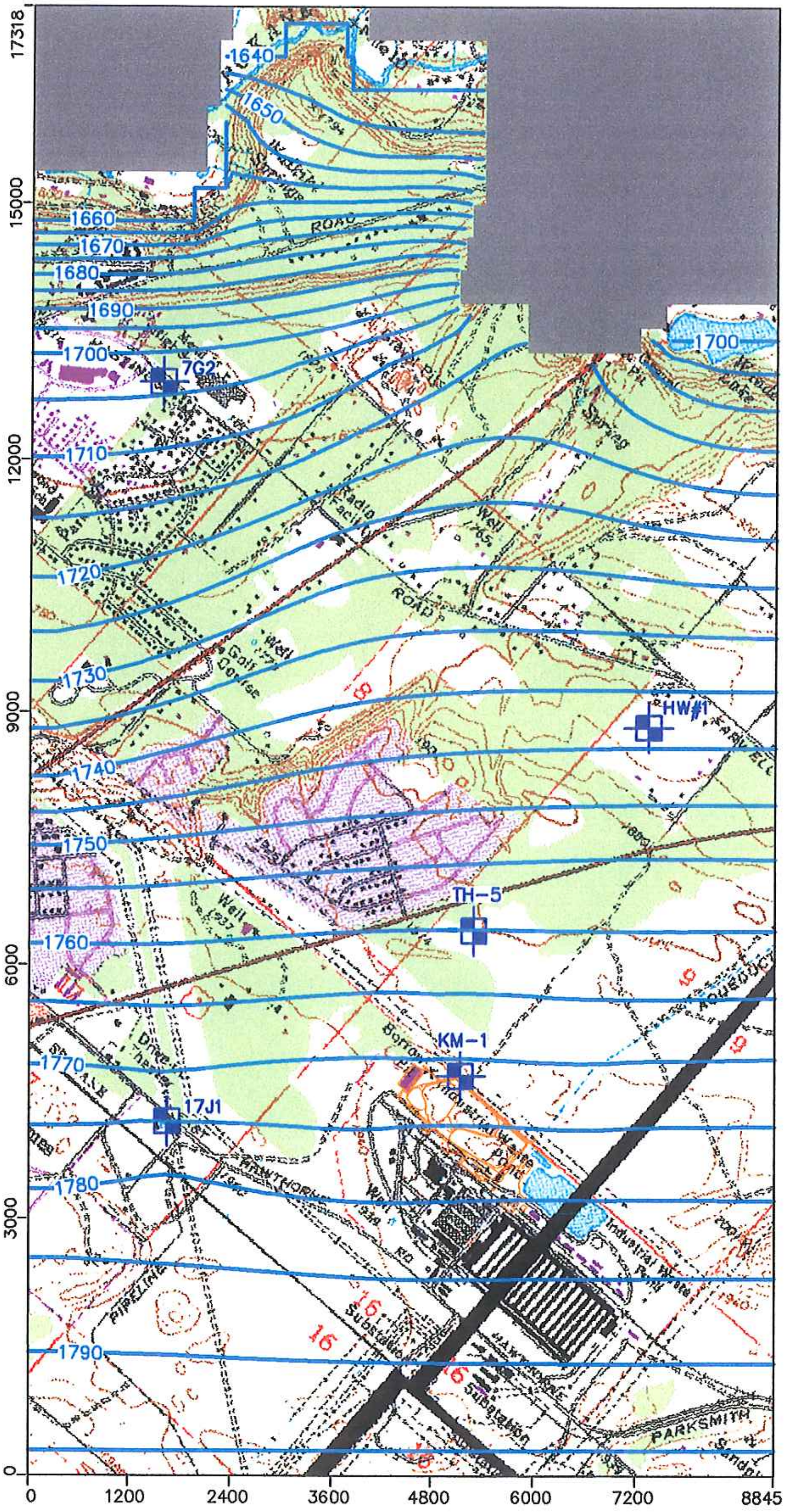

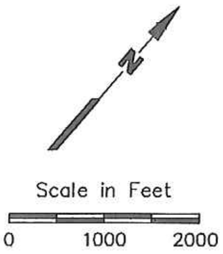

EXPLANATION

Location of Waste Piles

▨ No Flow Cell

HW#1 Head Observation Well

1780 Zone B Simulated Potentiometric Surface C. I. = 5 Feet

KAISER ALUMINUM - MEAD FACILITY

Figure 12

ZONE B SIMULATED POTENTIOMETRIC SURFACE

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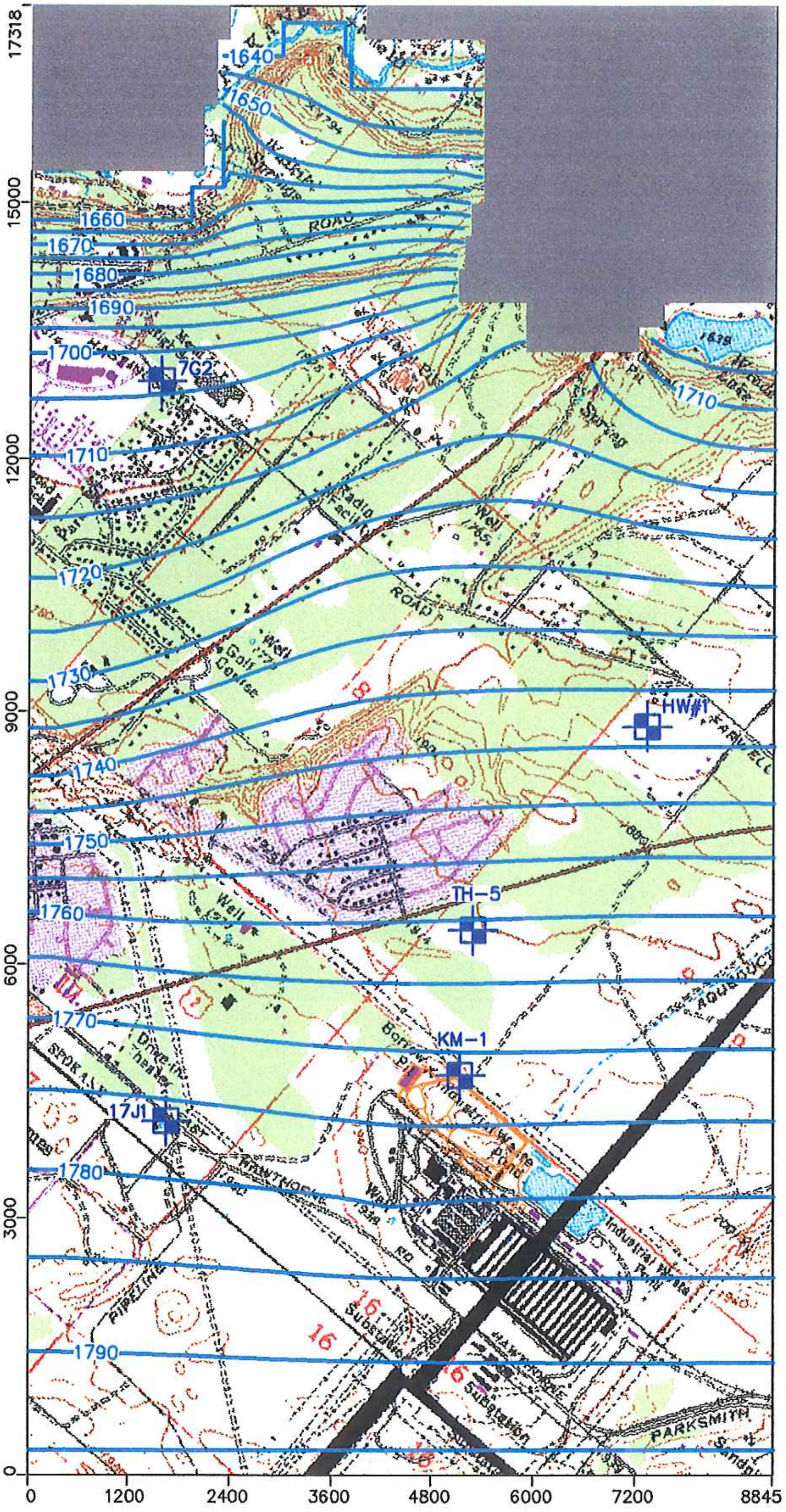
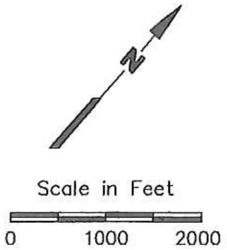
Sources:
U.S.G.S. 7.5-minute quads (Dartford, Wash. 1973 rev. 1986; Mead, Wash. 1973 rev. 1986; Spokane NW, Wash. 1974 rev. 1986; Spokane NE, Wash. 1973 rev. 1986) downloaded from www.gisdatadepot.com 9/2000.





EXPLANATION

	Location of Waste Piles
▨	No Flow Cell
HW#1 ⊞	Head Observation Well
1780	Zone C Simulated Potentiometric Surface C. I. = 5 Feet

KAISER ALUMINUM - MEAD FACILITY

Figure 13

ZONE C SIMULATED POTENTIOMETRIC SURFACE

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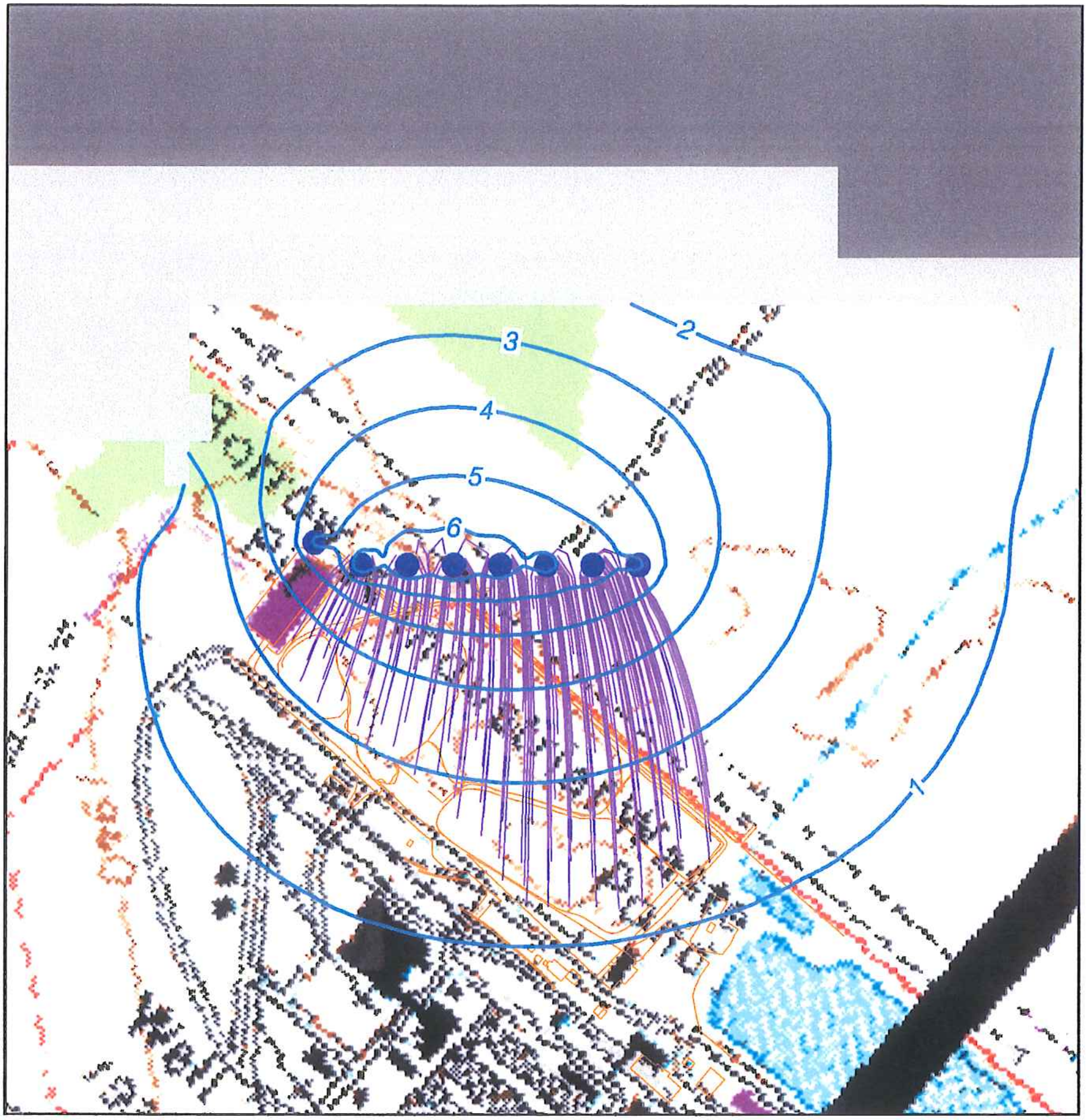
Sources:
U.S.G.S. 7.5-minute quads (Dartford, Wash. 1973 rev. 1986; Mead, Wash. 1973 rev. 1986; Spokane NW, Wash. 1974 rev. 1986; Spokane NE, Wash. 1973 rev. 1986) downloaded from www.gisdatadepot.com 9/2000.



EXPLANATION

Location of Waste Piles

Dry Cell

▨ No Flow Cell

● Pumping Well (8 Wells with total of 330 gpm)

Particle Trace

Simulated Drawdown C. I. = 1 Foot

N

Scale in Feet

0 250 500

Source:
U.S.G.S. 7.5-minute quad Dartford, Wash. 1973
rev. 1986 downloaded from
www.gisdatadepot.com 9/2000.

KAISER ALUMINUM - MEAD FACILITY

Figure 14

CAPTURE ZONE ANALYSIS- COMPLETE CAPTURE IN ZONE A

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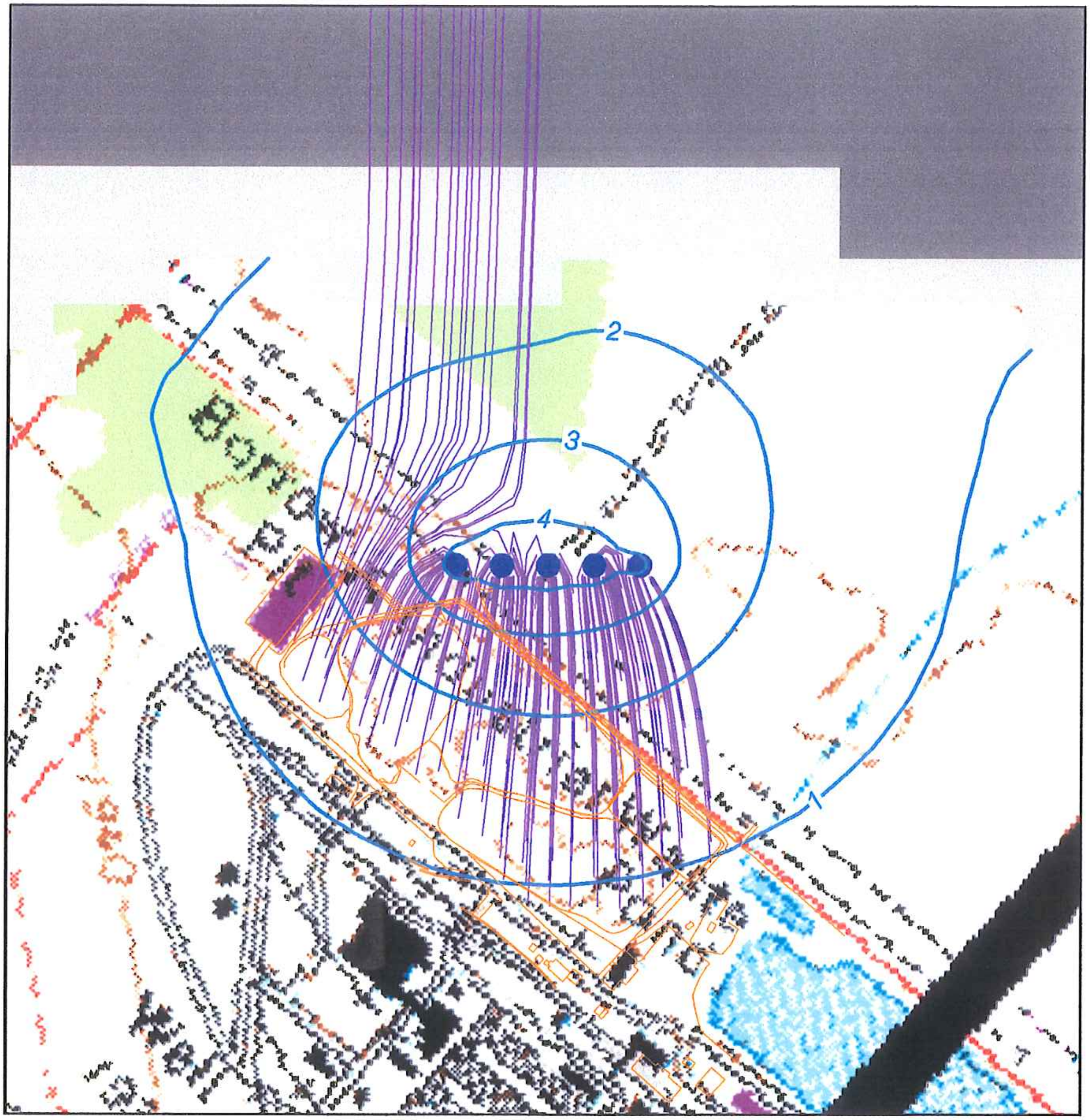


EXPLANATION

Location of Waste Piles

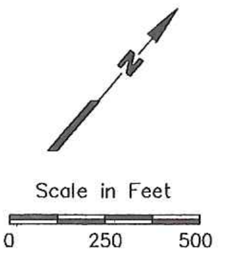
Dry Cell

▨ No Flow Cell

● Pumping Well (5 Wells with total of 250 gpm)

Particle Trace

—4— Simulated Drawdown C. I. = 1 Foot



Source:
U.S.G.S. 7.5–minute quad Dartford, Wash. 1973 rev. 1986 downloaded from www.gisdatadepot.com 9/2000.

KAISER ALUMINUM - MEAD FACILITY

Figure 15

CAPTURE ZONE ANALYSIS- PARTIAL CAPTURE IN ZONE A

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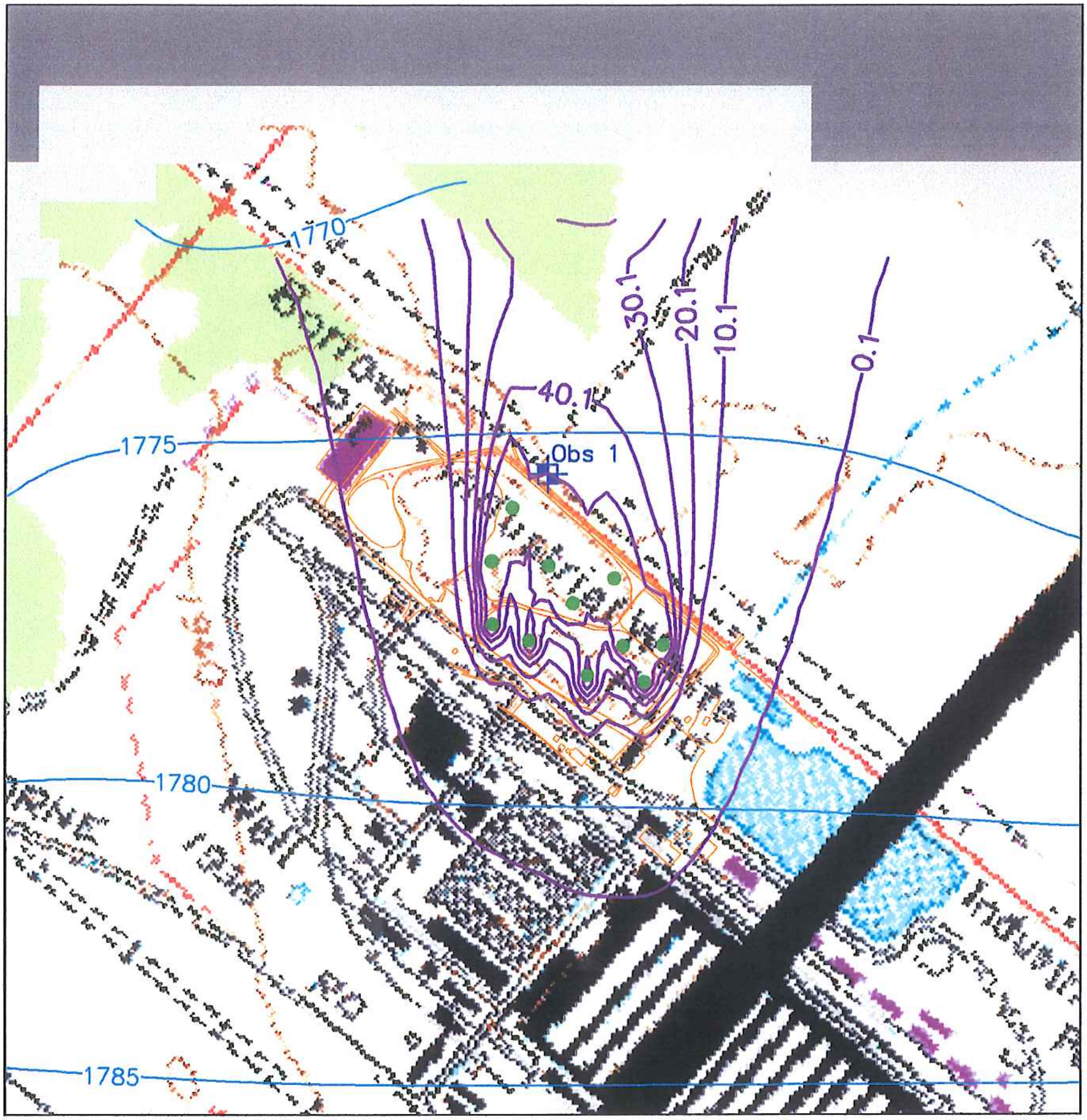

EXPLANATION

Location of Waste Piles

Dry Cell

▨ No Flow Cell

Obs 1 ⊞ Concentration Observation Well

● Simulated Point Source Location

1780 Zone A Simulated Potentiometric Surface C. I. = 5 Feet

0.1 Total Cyanide Concentration Contour C. I. = 10 mg/L

N

Scale in Feet

0 300 600

Source:
U.S.G.S. 7.5–minute quad Dartford, Wash. 1973
rev. 1986 downloaded from
www.gisdatadepot.com 9/2000.

KAISER ALUMINUM - MEAD FACILITY

Figure 16

ZONE A TOTAL CYANIDE, CURRENT CONDITIONS

PROJECT: 020055	BY: ZGK	REVISIONS
DATE: DEC., 2000	CHECKED: PGP	

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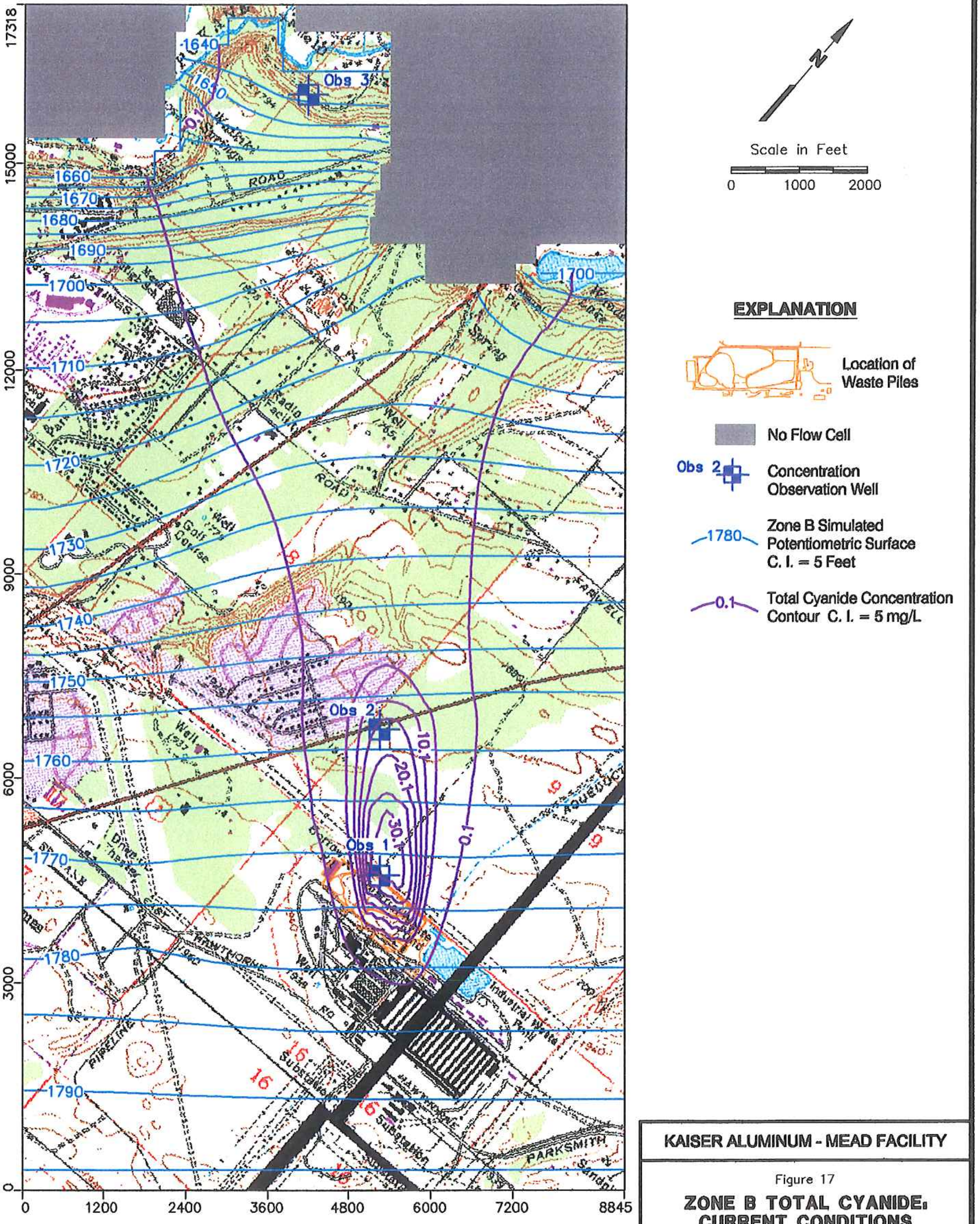

Sources:
U.S.G.S. 7.5-minute quads (Dartford, Wash. 1973 rev. 1986; Mead, Wash. 1973 rev. 1986; Spokane NW, Wash. 1974 rev. 1986; Spokane NE, Wash. 1973 rev. 1986) downloaded from www.gisdatadepot.com 9/2000.

KAISER ALUMINUM - MEAD FACILITY

Figure 17

ZONE B TOTAL CYANIDE, CURRENT CONDITIONS

PROJECT: 020055	BY: ZGK	REVISIONS
DATE: DEC., 2000	CHECKED: PGP	

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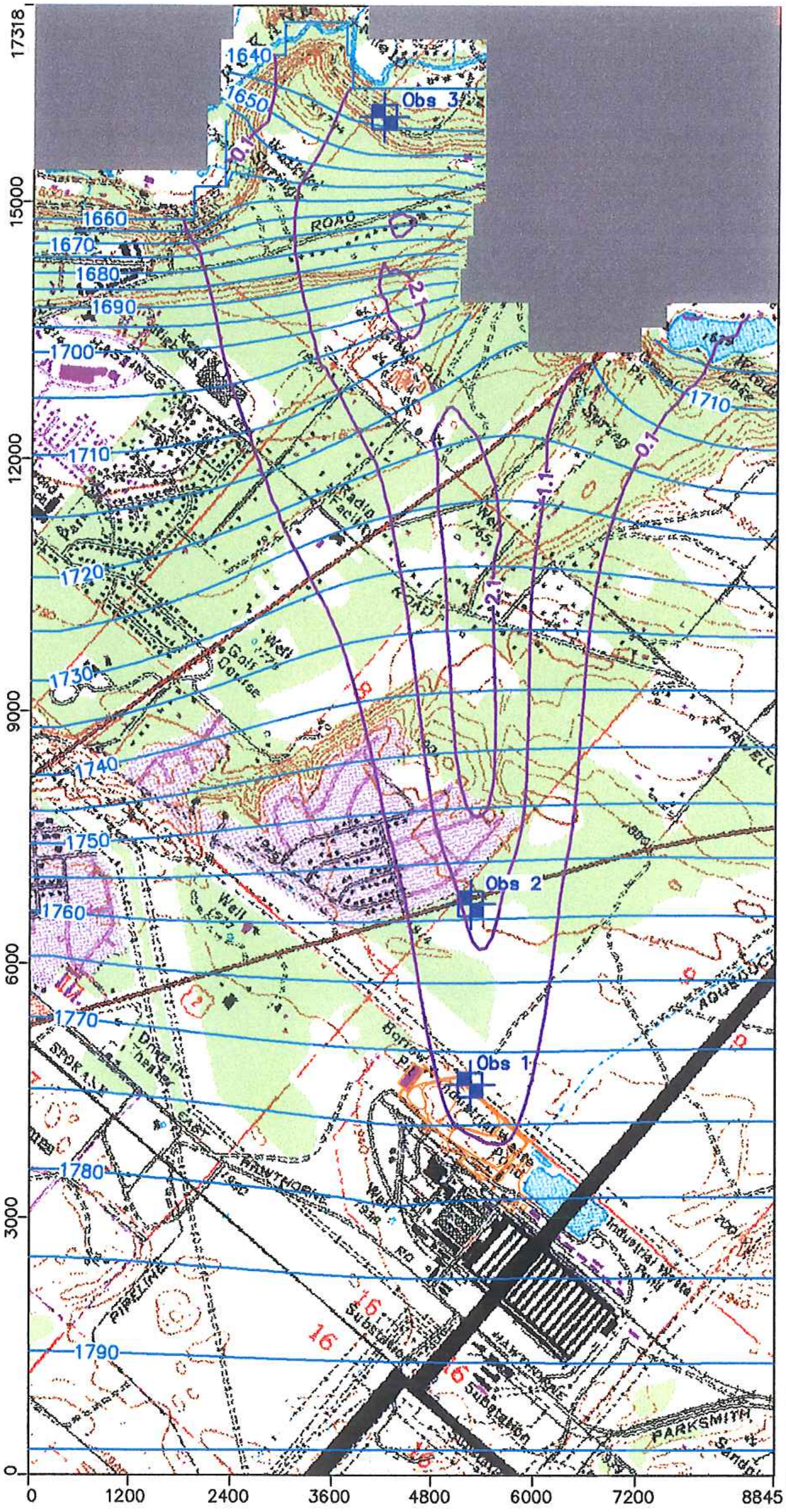

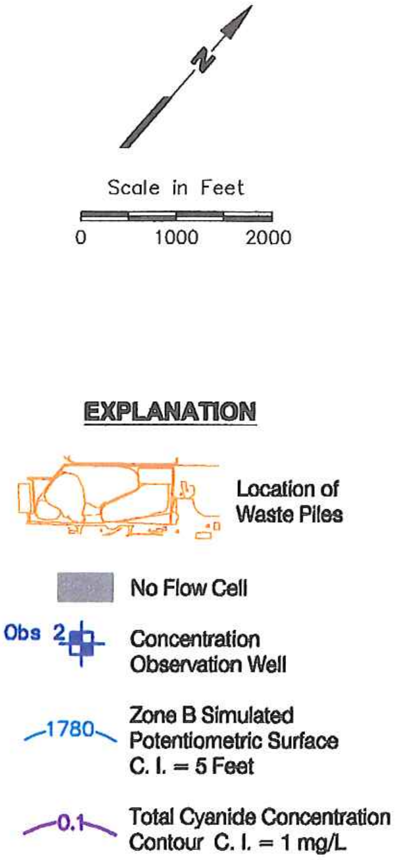

EXPLANATION

KAISER ALUMINUM - MEAD FACILITY

Figure 18

ZONE C TOTAL CYANIDE, CURRENT CONDITIONS

PROJECT: 020055	BY: ZGK	REVISIONS
DATE: DEC., 2000	CHECKED: PGP	

MFG, INC.
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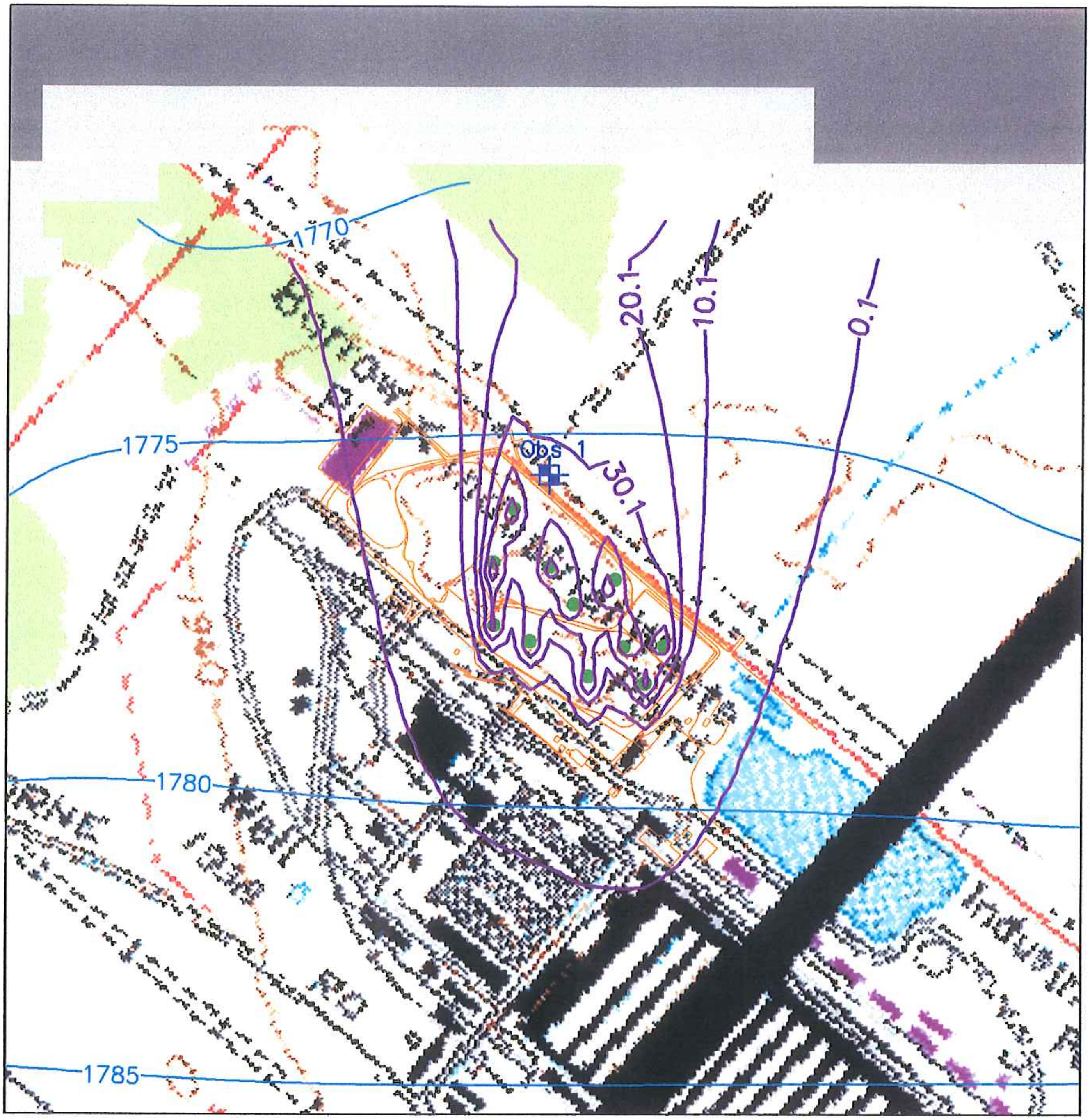
Sources:
U.S.G.S. 7.5-minute quads (Dartford, Wash. 1973 rev. 1986; Mead, Wash. 1973 rev. 1986; Spokane NW, Wash. 1974 rev. 1986; Spokane NE, Wash. 1973 rev. 1986) downloaded from www.gisdatadepot.com 9/2000.



EXPLANATION

Location of Waste Piles

Dry Cell

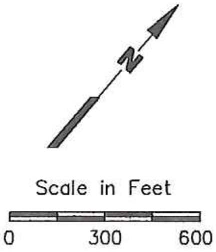
▨ No Flow Cell

Obs 1 ⊞ Concentration Observation Well

● Simulated Point Source Location

—1780— Zone A Simulated Potentiometric Surface C. I. = 5 Feet

—0.1— Fluoride Concentration Contour C. I. = 10 mg/L



Source:
U.S.G.S. 7.5-minute quad Dartford, Wash. 1973 rev. 1986 downloaded from www.gisdatadepot.com 9/2000.

KAISER ALUMINUM - MEAD FACILITY

Figure 19

ZONE A FLUORIDE: CURRENT CONDITIONS

PROJECT: 020055
BY: ZGK
REVISIONS
DATE: DEC., 2000
CHECKED: PGP

MFG, INC.
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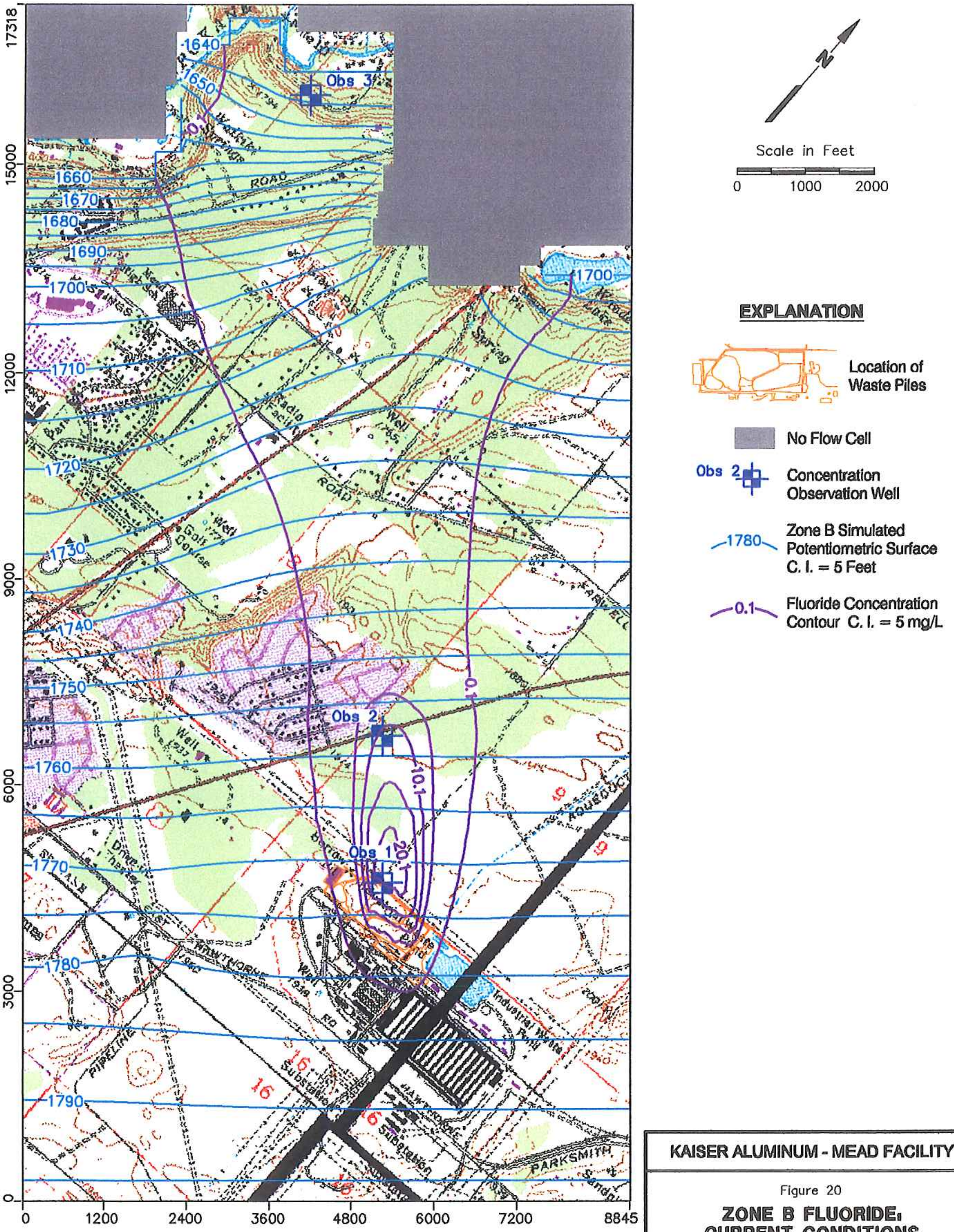

KAISER ALUMINUM - MEAD FACILITY

Figure 20

ZONE B FLUORIDE, CURRENT CONDITIONS

PROJECT: 020055	BY: ZGK	REVISIONS
DATE: DEC., 2000	CHECKED: PGP	

MFG, INC.
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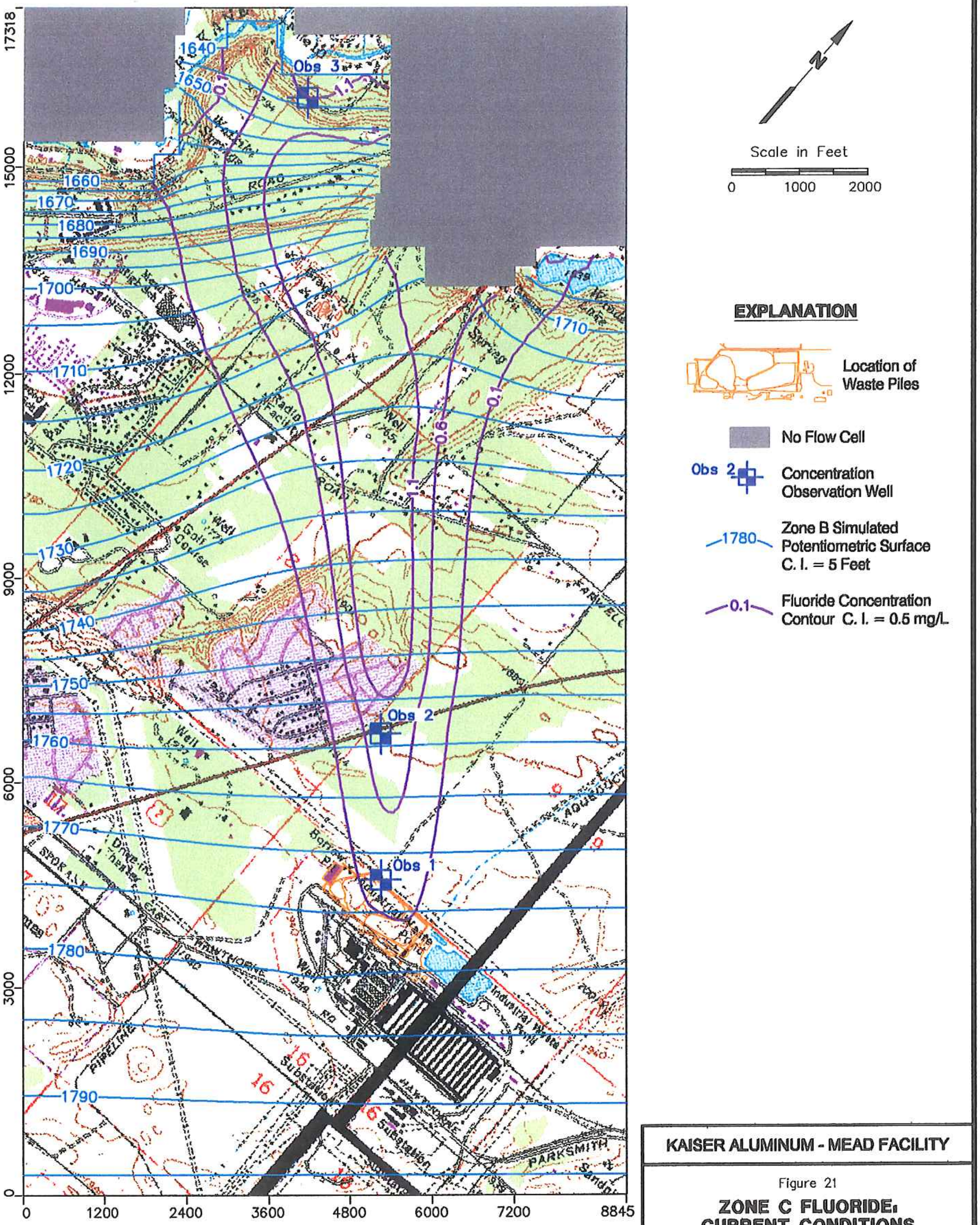
Sources:
U.S.G.S. 7.5-minute quads (Dartford, Wash. 1973 rev. 1986; Mead, Wash. 1973 rev. 1986; Spokane NW, Wash. 1974 rev. 1986; Spokane NE, Wash. 1973 rev. 1986) downloaded from www.gisdatadepot.com 9/2000.



Sources:
U.S.G.S. 7.5–minute quads (Dartford, Wash. 1973 rev. 1986; Mead, Wash. 1973 rev. 1986; Spokane NW, Wash. 1974 rev. 1986; Spokane NE, Wash. 1973 rev. 1986) downloaded from www.gisdatadepot.com 9/2000.

KAISER ALUMINUM - MEAD FACILITY

Figure 21

ZONE C FLUORIDE: CURRENT CONDITIONS

PROJECT: 020055	BY: ZGK	REVISIONS
DATE: DEC., 2000	CHECKED: PGP	

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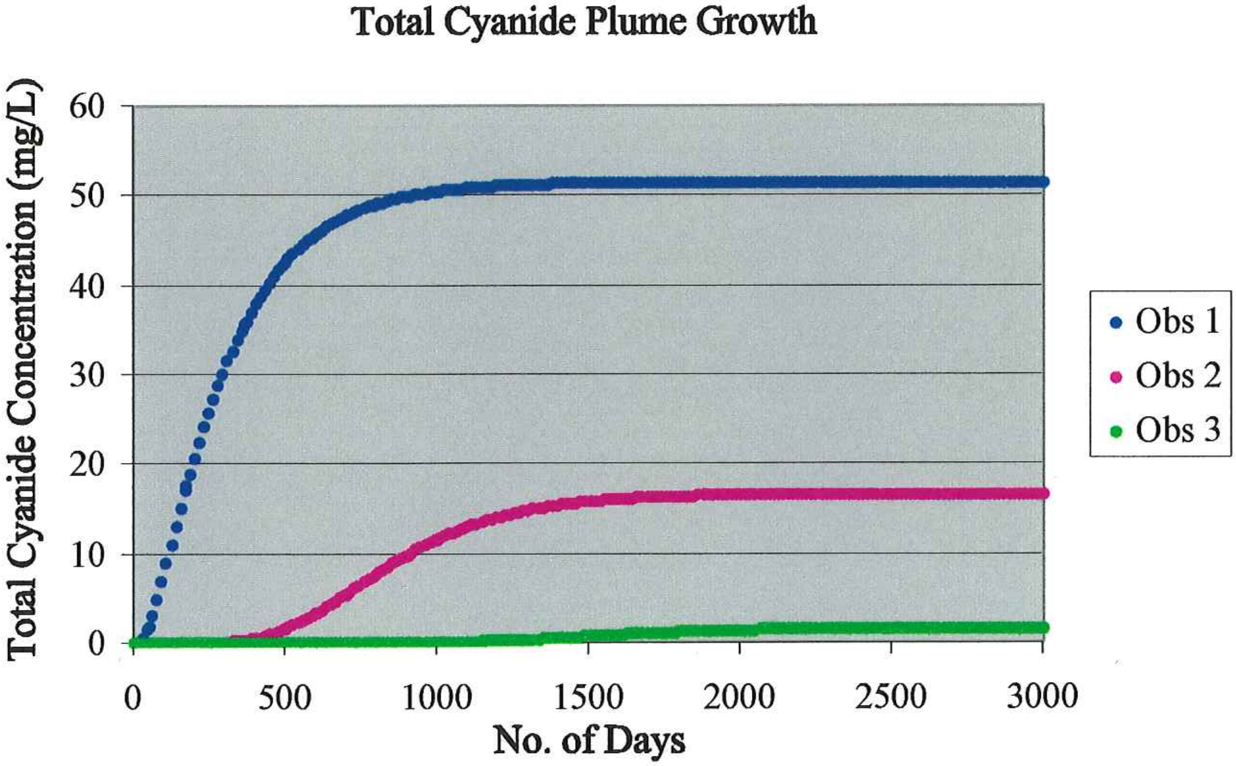

KAISER ALUMINUM - MEAD FACILITY

Figure 22

TIME SERIES PLOT OF CYANIDE PLUME GROWTH

PROJECT: 020055	BY: ZGK	REVISIONS
DATE: DEC., 2000	CHECKED: PGP	

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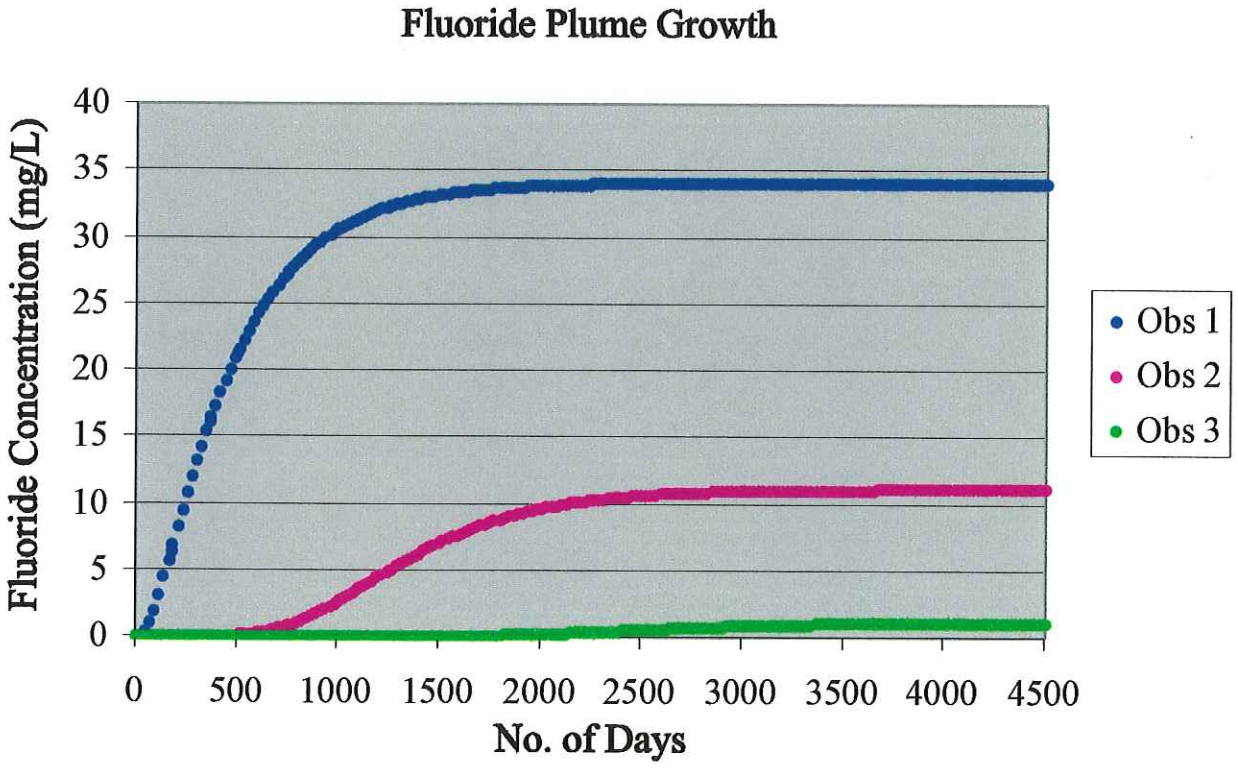

KAISER ALUMINUM - MEAD FACILITY

Figure 23

TIME SERIES PLOT OF FLUORIDE PLUME GROWTH

PROJECT: 020055	BY: ZGK	REVISIONS
DATE: DEC., 2000	CHECKED: PGP	

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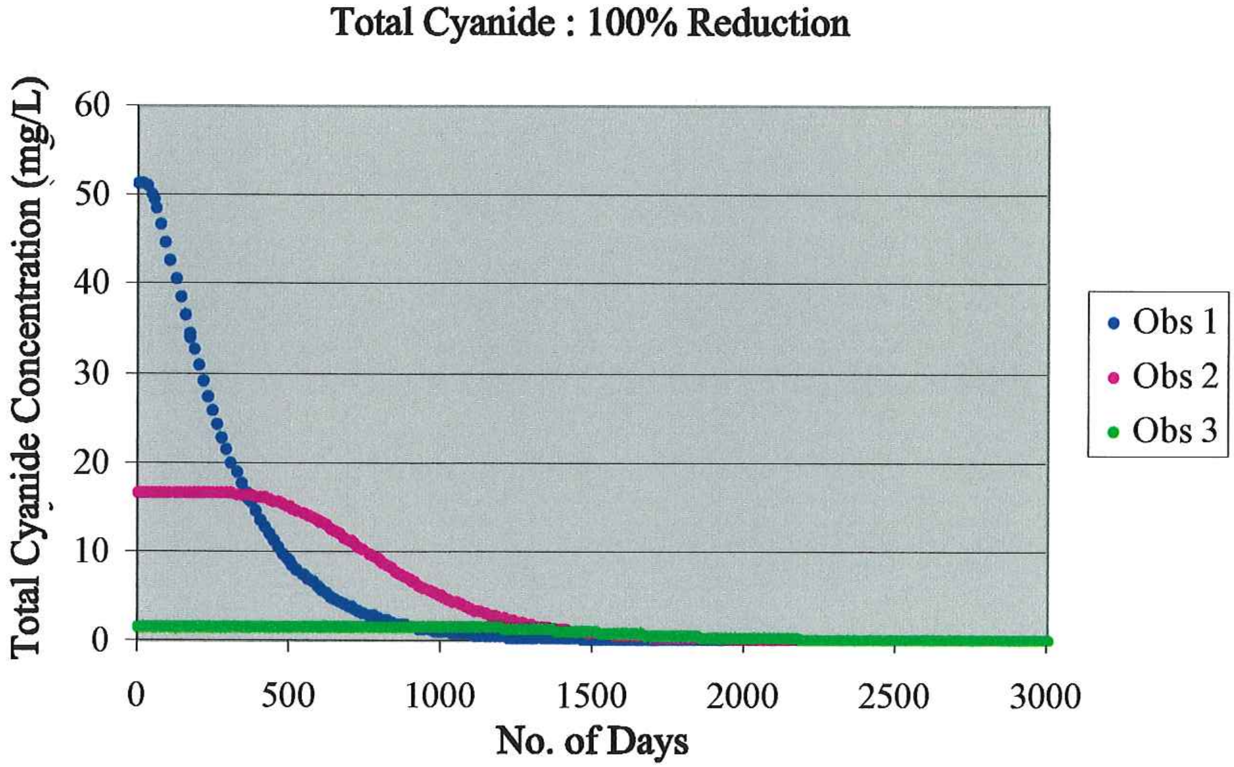

KAISER ALUMINUM - MEAD FACILITY

Figure 24

TIME SERIES PLOT OF
CYANIDE PLUME DECAY
100% SOURCE REDUCTION

PROJECT: 020055	BY: ZGK	REVISIONS
DATE: DEC., 2000	CHECKED: PGP	

MFG, INC.
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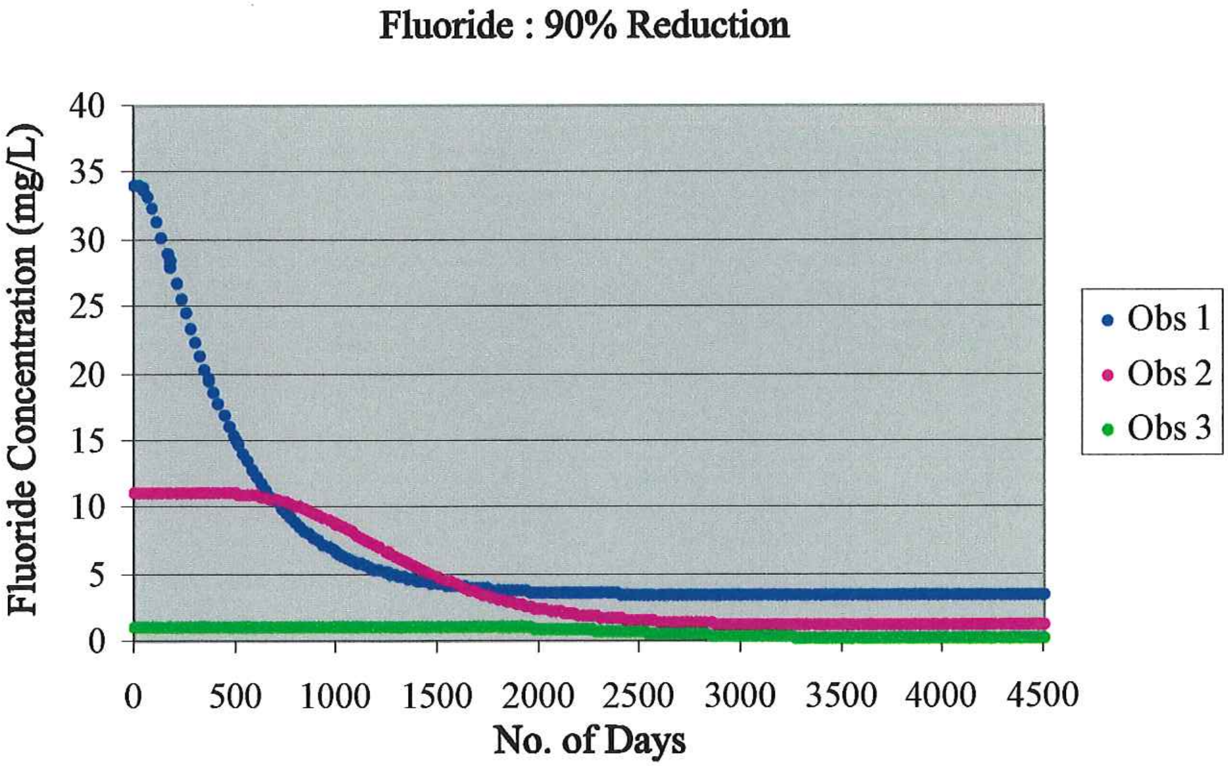

KAISER ALUMINUM - MEAD FACILITY

Figure 25

TIME SERIES PLOT OF FLUORIDE PLUME DECAY 90% SOURCE REDUCTION

PROJECT: 020055	BY: ZGK	REVISIONS
DATE: DEC., 2000	CHECKED: PGP	

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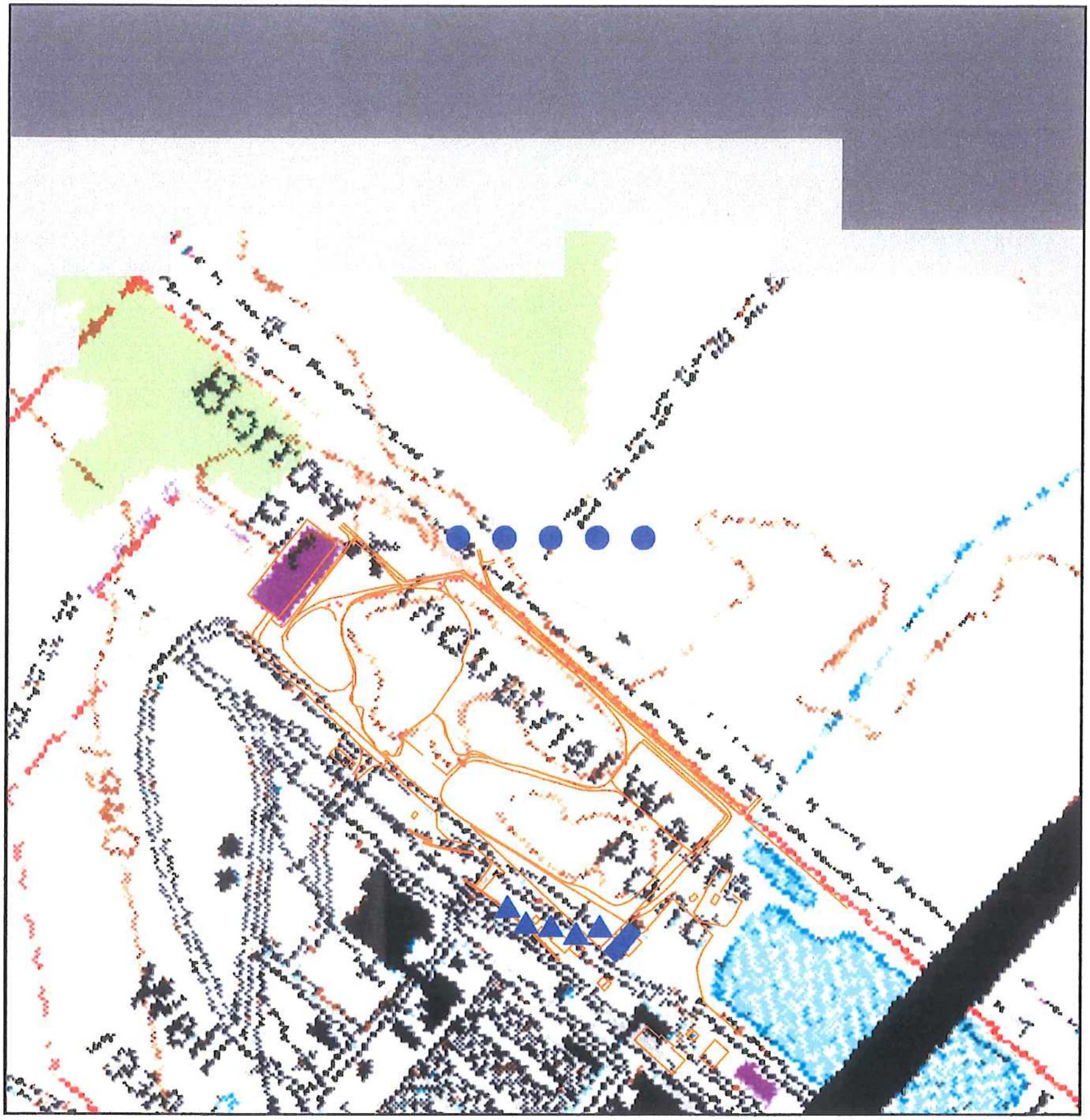


EXPLANATION

Location of Waste Piles

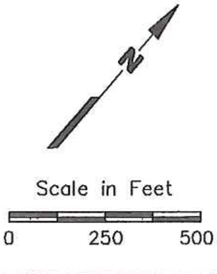
Dry Cell

▨ No Flow Cell

● Proposed Extraction Well

▲ Proposed Injection Well

◆ Proposed Treatment System Location



Source:
U.S.G.S. 7.5-minute quad Dartford, Wash. 1973 rev. 1986 downloaded from www.gisdatadepot.com 9/2000.

KAISER ALUMINUM - MEAD FACILITY

Figure 26

PROPOSED EXTRACTION/ RE-INJECTION SYSTEM LAYOUT

PROJECT: 020055	BY: ZGK	REVISIONS
DATE: DEC., 2000	CHECKED: PGP	

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EXPLANATION

HC-11⊕ Monitoring Well

▨ Locations of Butt Tailing, Rubble and SPL Piles

◎ Compliance Monitoring Well

● Effectiveness Monitoring Well A Zone Unless Otherwise Specified

* Indicates Well Only if Saturated Zone is Present

Source:
Base map taken from Adams & Clark, Inc. Surveyed Map, November 8, 2000.

N

Scale in Feet
0 250 500

KAISER ALUMINUM - MEAD FACILITY

Figure 27

PROPOSED LOCATIONS FOR EFFECTIVENESS MONITORING AND COMPLIANCE MONITORING

PROJECT: 020055	BY: ZGK	REVISIONS
DATE: DEC., 2000	CHECKED: PGP	

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APPENDIX A

AQUIFER TEST INFORMATION

APPENDIX A

As discussed in Section 1.1 Purpose and Objectives, MFG, Inc. performed a 24-hour pumping test, a 3-hour pumping test and an injection test in the Zone A sand at the Kaiser Mead Facility. The selected aquifer test site was at the location of monitoring wells TH-8 and TH-3A, adjacent to the northern side of the plant boundary near the center of the contaminant plume. One 4" PVC test well (KM-1) was installed in the Zone A sand and one 2' PVC observation well was completed in the Zone B sand. Well completion diagrams are included as Attachment A-1. Existing Zone A monitoring wells TH-8 and TH-3A were used as observation wells. The well completions and aquifer testing were accomplished during the period of August 14-26, 2000. The following sections describe the aquifer tests performed at pumping well KM-1.

Pump Test No. 1: 24-Hour Constant Discharge Pumping Test – Zone A Sand

A 24-hour pumping test was initiated at KM-1 on August 23, 2000. Recovery data were collected on August 24, 2000. A Hermit 3000™ data logger and 50-psi transducers were used to measure the drawdown in the pumping and observation wells. The transducers were factory-calibrated; therefore, the calibration data for each transducer (offset, linearity, scale) were entered into the data collection software prior to running the pumping test. The transducers were tested during the evening of August 22, 2000.

Pumping in KM-1 began at 09:40 hours on August 24, 2000. Drawdown in KM-1, TH-8 and TH-3A relative to elapsed pumping time was monitored on a computer. A pumping rate of 16.75 gallons per minute was maintained during the pumping test. Water levels measured in OB-1 during the pumping test revealed no measurable drawdown in the Zone B sand.

At about 10 hours into the pumping test, the water level data from TH-8 and TH-3A reveal a significant increase in rate of drawdown in the Zone A sand. Likewise, hand-measured data from OB-1 reveal measurable drawdown in the Zone B sand at about ten hours into the pumping test. It is likely that the observed change in drawdown rate reflects the influence of an industrial water supply well that temporarily produces about 1,500 gpm from the lower portion of the Zone C sand during periods of demand at the Kaiser Mead Facility. Alternatively, a hydrologic boundary related to aquifer heterogeneity may influence drawdown if the boundary is situated near the pumping well. Therefore, only the early data for the 24-hour pump test (i.e. the first 10 hours of data) were used to estimate hydraulic conductivity of the Zone A sand. The pump was turned off at 09:49 on August 24, 2000. Recover data were collected between 09:49 and 14:10 hours.

The results of aquifer test data analysis for the 24-hour pumping test (Pumping Test No. 1 and Recovery Test No. 1) are summarized in Attachment A-2. The drawdown data and type curve matching plots are included in Attachment A-3. The pumping test data were analyzed using the Theis unconfined method and the Cooper-Jacob straight-line. Likewise, the recovery data were analyzed using the Theis recovery method and the Cooper-Jacob straight-line method. The data reveal an average hydraulic conductivity ranging from 280 ft/day (KM-1) to 900 ft/day (TH-3a) and storage value ranging from 0.06 (TH-8) to 0.14 (TH-3A).

Pump Test No. 2: Three-Hour Constant Discharge Pumping Test – Zone A Sand

A 3-hour pumping test was performed at KM-1 on August 24, 2000. A Hermit 3000™ data logger and 50-psi transducers were used to measure the drawdown in the pumping and observation wells. Pumping in KM-1 began at 11:24 hours on August 25, 2000. Drawdown in KM-1, TH-8 and TH-3A relative to elapsed pumping time was monitored on a computer. A pumping rate of 28.74 gallons per minute was maintained during the pumping test. The pump was turned off at 14:47 on August 24, 2000. Recovery data were collected between 14:47 and 15:20 hours.

The results of aquifer test data analysis for Pump Test No.2 and Recovery Test No. 2 are summarized in Attachment A-2. The drawdown data and type curve matching plots are included in Attachment A-3. The data were analyzed using the same methodology used for Pump Test No. 1 data analysis. The data reveal an average hydraulic conductivity ranging from 241 ft/day (KM-1) to 890 ft/day (TH-3A) and storage value between 0.05 (TH-8) and 0.11 (TH-3A).

Injection Test – Zone A Sand

A 20-hour injection test was initiated at KM-1 on August 25, 2000. A Hermit 3000™ data logger and 50-psi transducers were used to measure the drawdown in the pumping and observation wells. A grunfos pump was used to return discharged groundwater (which was collected during the pumping test) to the Zone A aquifer through KM-1 with an injection rate of 20.5 gallons per minute. Pumping into KM-1 began at 16:25 hours on August 25, 2000. Depth to water in KM-1, TH-8 and TH-3a relative to elapsed pumping time was monitored on a computer. The pumping rate of 20.5 gpm was maintained throughout the injection test. The injection test ended at 12:11 hours on August 26, 2000.

The results of aquifer test data analysis for the 3-hour pumping test are summarized in Attachment A-2. The data were analyzed using the same methods used to analyze Pump Test No. 1 data. The drawdown data and type curve matching plots are included in Attachment A-3. The data from TH-3A and TH-8 reveal a change in drawdown rate at about 10 hours into the injection test similar to that seen during the 24-hour pumping test. The data reveal an average hydraulic conductivity ranging from 219 ft/day (TH-8) to 320 ft/day (KM-1).

Summary of Aquifer Test Results

The results of aquifer tests data analysis are summarized in Attachment A-3. Based on the aquifer test results described above, a value of 500 ft/day and a value of 0.1 were used to describe hydraulic conductivity and storage, respectively, in the groundwater flow model discussed in Section 3. Groundwater quality data collected during the aquifer test are presented in Attachment A-4.

ATTACHMENT A-1

Well Completion Diagrams

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Consulting Scientists and Engineers

LOG OF BORING KM-1

(Page 1 of 6)

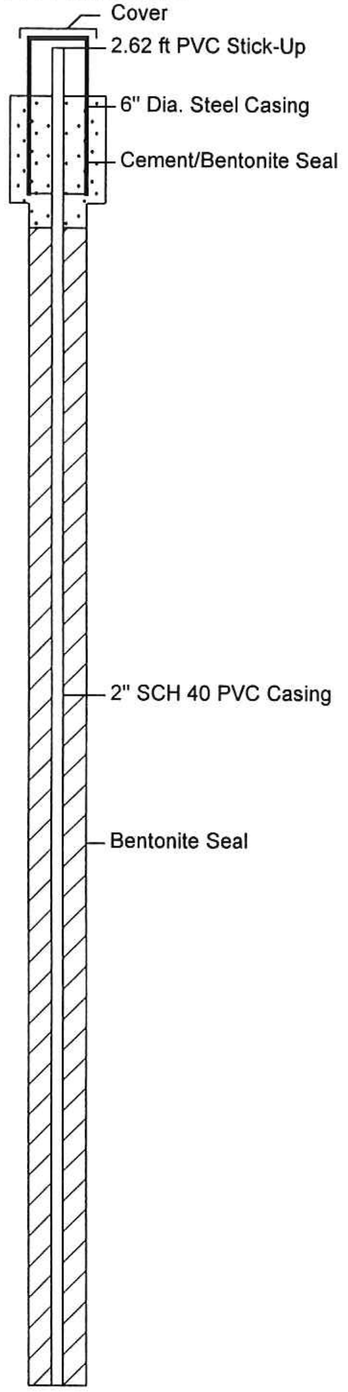
Kaiser Aluminum
Mead Works
Mead, Washington

MFG Project No.: 020055

Drilling Agency	: Environmental West Exploration
Drill Rig	: Foremost Mobile B-90
Drilling Method	: Air Rotary
Drill Bit Type	: Tubex (DHH)
Sampler Type	: 2.5" SPT Split-Spoon
Start/Complete Date	: 8-16-00 / 8-18-00
Northing/Easting Coord:	15383.41 / 11796.50
Surface Elevation	: 1927.06 ft AMSL
Logged / Reviewed By	: T. Mullen

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Samples	Blow Count	Recov. (ft)	REMARKS
0	SAND, very fine to fine sand, dry, dusty.	SP					Lithology based on cuttings return over 10-foot intervals 0-147 ft bgs and 5-foot intervals 147-161 ft bgs.
1							
2							
3							
4							
5							
6							
7							
8	SAND, medium- to coarse-grained sand; 5% to 10% gravel up to 1 inch size, rounded to subrounded, slightly moist.						
9							
10							
11							
12							
13							
14							
15							
16							
17	SAND, medium- to coarse-grained sand; <5% gravel up to 1/2 inch size.						
18							
19							
20							
21							
22							
23							
24							
25							
26							
27	SAND, grayish brown (2.5Y 4/2), medium-grained sand, some coarse-grained sand (<15%) and fine-grained sand (<20%).						
28							
29							

Well: KM-1
TOC Elev.: 1929.84



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Consulting Scientists and Engineers

LOG OF BORING KM-1

(Page 2 of 6)

Kaiser Aluminum
Mead Works
Mead, Washington

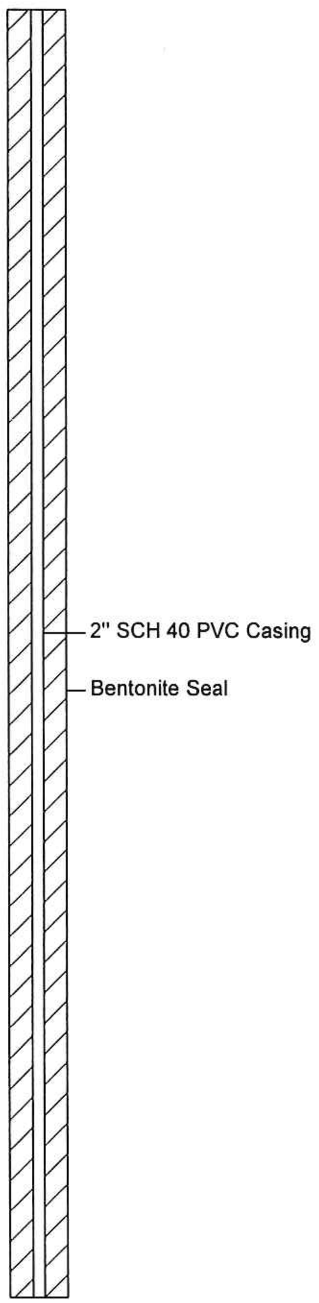
MFG Project No.: 020055

Drilling Agency : Environmental West Exploration
Drill Rig : Foremost Mobile B-90
Drilling Method : Air Rotary
Drill Bit Type : Tubex (DHH)
Sampler Type : 2.5" SPT Split-Spoon

Start/Complete Date : 8-16-00 / 8-18-00
Northing/Easting Coord: 15383.41 / 11796.50
Surface Elevation : 1927.06 ft AMSL
Logged / Reviewed By : T. Mullen

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Samples	Blow Count	Recov. (ft)	REMARKS
29							
30							
31							
32							
33							
34							
35							
36							
37	SAND, fine- to medium-grained sand, <5% coarse-grained sand and gravel, dusty.						Inject water to lift cuttings.
38							
39							
40		SP					
41							
42							
43							
44							
45							
46							
47							
48	SAND, fine- to medium-grained.						
49							
50	CLAY, light olive brown (2.5Y 5/3), low plasticity, moist.						
51		CL					
52							
53	GRAVELLY SAND, well graded, fine- to coarse-grained sand with 15-20% subrounded gravel up to 1/2 inch size, some silt.						
54							
55		SW					
56							
57							57 ft to 67 ft bgs, dusty return.
58							

Well: KM-1
TOC Elev.: 1929.84



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LOG OF BORING KM-1

(Page 3 of 6)

Kaiser Aluminum
Mead Works
Mead, Washington

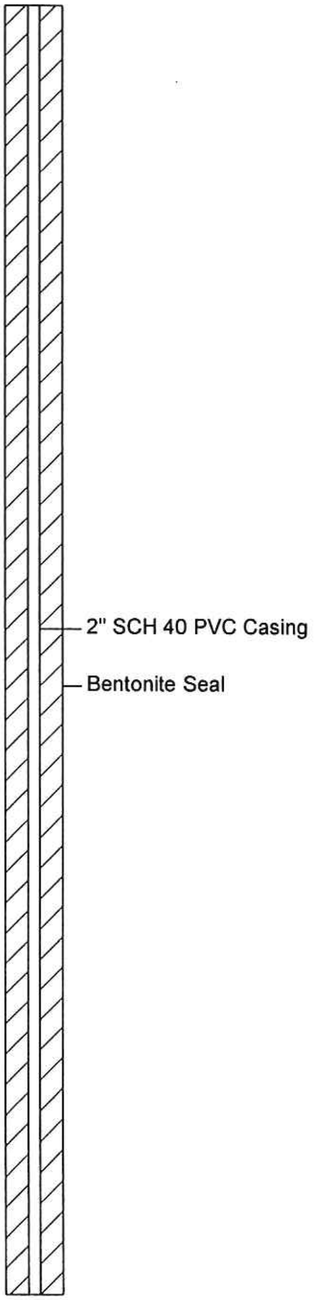
MFG Project No.: 020055

Drilling Agency : Environmental West Exploration
Drill Rig : Foremost Mobile B-90
Drilling Method : Air Rotary
Drill Bit Type : Tubex (DHH)
Sampler Type : 2.5" SPT Split-Spoon

Start/Complete Date : 8-16-00 / 8-18-00
Northing/Easting Coord: 15383.41 / 11796.50
Surface Elevation : 1927.06 ft AMSL
Logged / Reviewed By : T. Mullen

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Samples	Blow Count	Recov. (ft)	REMARKS
58		SW					
65	SAND, fine- to medium-grained sand, slightly moist.	SP					
82	SILT, light olive brown (2.5Y 5/3), low plasticity, moist.	ML					
83	SAND, medium- to coarse-grained.	SP					
87							

Well: KM-1
TOC Elev.: 1929.84



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LOG OF BORING KM-1

(Page 4 of 6)

Kaiser Aluminum
Mead Works
Mead, Washington

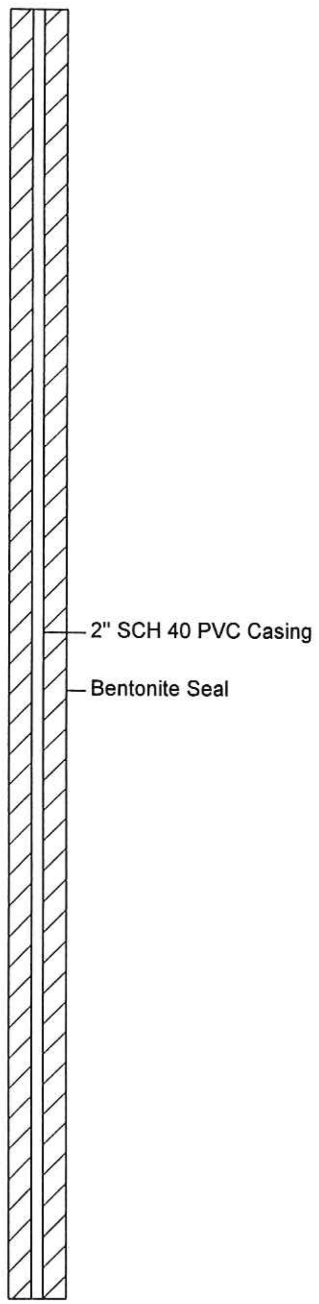
MFG Project No.: 020055

Drilling Agency : Environmental West Exploration
Drill Rig : Foremost Mobile B-90
Drilling Method : Air Rotary
Drill Bit Type : Tubex (DHH)
Sampler Type : 2.5" SPT Split-Spoon

Start/Complete Date : 8-16-00 / 8-18-00
Northing/Easting Coord: 15383.41 / 11796.50
Surface Elevation : 1927.06 ft AMSL
Logged / Reviewed By : T. Mullen

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Samples	Blow Count	Recov. (ft)	REMARKS
87	GRAVELLEY SAND, medium- to coarse-grained sand, 25% subrounded to rounded gravel up to 1/2 inch size.						
88							
89							
90							
91							
92		SP					
93							
94							
95							
96							
97	SAND, medium- to coarse-grained sand, <5% rounded gravel up to 1/4 inch size, wet						
98							
99							
100							
101							
102							
103							
104							
105							
106							
107		SP					
108							
109							
110							
111							
112							
113							
114							
115							
116							

Well: KM-1
TOC Elev.: 1929.84



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LOG OF BORING KM-1

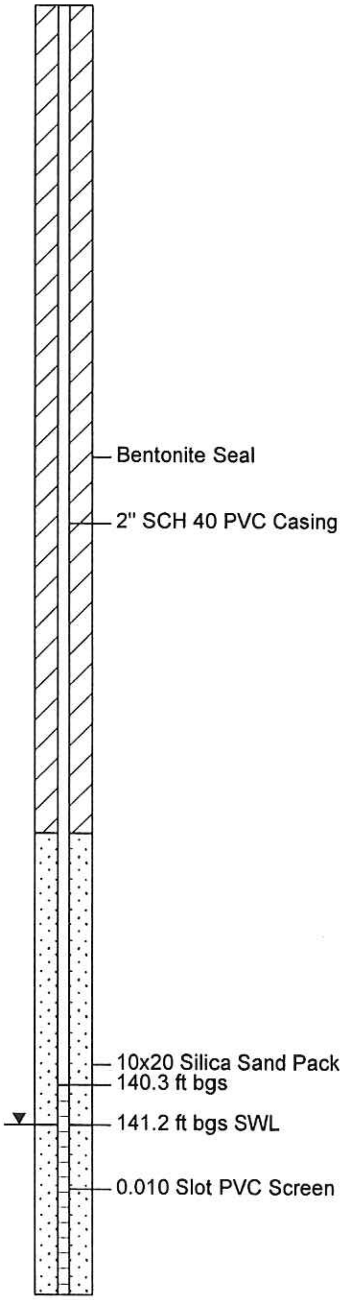
(Page 5 of 6)

Kaiser Aluminum
Mead Works
Mead, Washington
MFG Project No.: 020055

Drilling Agency	: Environmental West Exploration	Start/Complete Date	: 8-16-00 / 8-18-00
Drill Rig	: Foremost Mobile B-90	Northing/Easting Coord:	15383.41 / 11796.50
Drilling Method	: Air Rotary	Surface Elevation	: 1927.06 ft AMSL
Drill Bit Type	: Tubex (DHH)	Logged / Reviewed By	: T. Mullen
Sampler Type	: 2.5" SPT Split-Spoon		

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Samples	Blow Count	Recov. (ft)	REMARKS
116							
117							117 ft to 127 ft bgs, dusty.
118							
119							
120							
121							
122							
123							
124							
125							
126							
127	Coarse sand fraction increases.	SP					
128							
129							
130							
131							
132							
133							
134							
135							
136							
137	SAND, medium- to coarse-grained sand, <5% rounded gravel up to 1/4 inch size, wet.						
138							
139							
140							Driler notes cool, damp air return. SWL 141.2 ft bgs at completion of borehole.
141		SW					
142	At 142 ft bgs, SILT, light yellowish brown, platy.						
143							
144							
145							

Well: KM-1
TOC Elev.: 1929.84



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LOG OF BORING KM-1

(Page 6 of 6)

Kaiser Aluminum
Mead Works
Mead, Washington

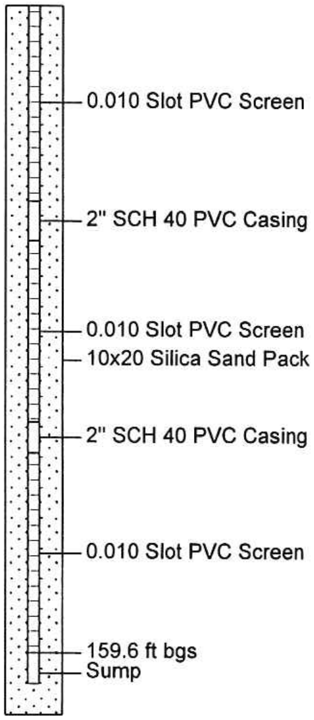
MFG Project No.: 020055

Drilling Agency : Environmental West Exploration
Drill Rig : Foremost Mobile B-90
Drilling Method : Air Rotary
Drill Bit Type : Tubex (DHH)
Sampler Type : 2.5" SPT Split-Spoon

Start/Complete Date : 8-16-00 / 8-18-00
Northing/Easting Coord: 15383.41 / 11796.50
Surface Elevation : 1927.06 ft AMSL
Logged / Reviewed By : T. Mullen

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Samples	Blow Count	Recov. (ft)	REMARKS
145							
146		SW					
147	SAND, medium- to coarse-grained sand, <5% rounded gravel up to 1/4 inch size, wet.	SP					
148							
149							
150	SAND, fine- to medium-grained sand, saturated.						1st water encountered at 150 ft bgs. 150 ft to 161 ft bgs, heaving sands.
151				1	5/ 2"		
152							
153							
154							
155							
156							
157							
158							
159							
160	CLAY, gray (H6), to dark greenish gray (5.6Y 4/1), soft consistency, high plasticity, tough threat, high dry strength, moist.	CL					
161							
162							
163	Total depth of borehole = 162.0 feet below ground surface.						
164							
165							
166							
167							
168							
169							
170							
171							
172							
173							
174							

Well: KM-1
TOC Elev.: 1929.84



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LOG OF BORING OB-1

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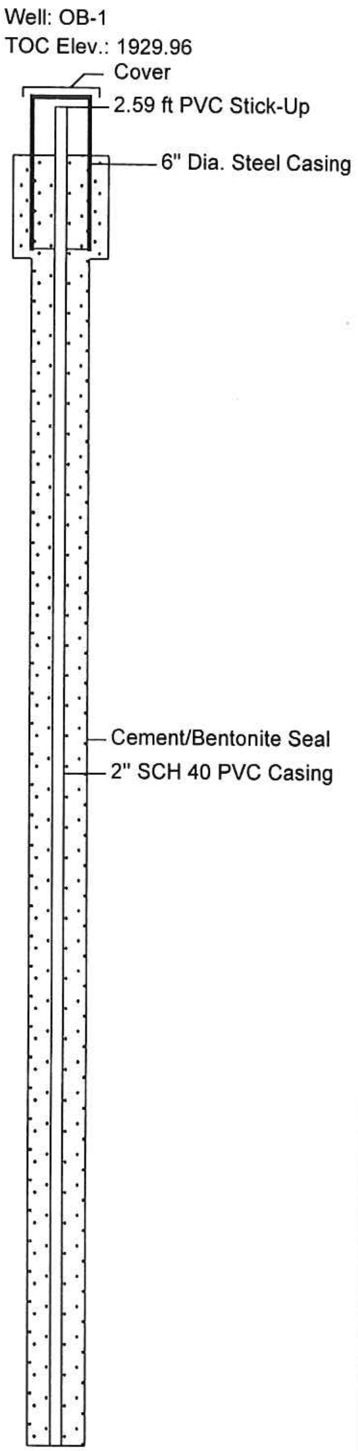
Kaiser Aluminum
Mead Works
Mead, Washington

MFG Project No.: 020055

Drilling Agency : Environmental West Exploration
Drill Rig : Foremost Mobile B-90
Drilling Method : Air Rotary
Drill Bit Type : Tubex (DHH)
Sampler Type : 2" SPT Split-Spoon

Start/Complete Date : 8-14-00 / 8-14-00
Northing/Easting Coord: 15382.57 / 11786.79
Surface Elevation : 1927.27
Logged / Reviewed By : T. Mullen

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Samples	Blow Count	Recov. (ft)	REMARKS
0	SAND, olive brown (2.5Y 4/3), very fine- to fine- grained sand, trace silt,<5%; rounded, gravel 1/8 inch to 1/2 inch size.						
1							
2							
3							
4							
5							
6							
7							
8							
9							
10	SAND, olive brown (2.5Y 4/3), medium grained sand, <5% subrounded to subangular gravel, up to 3/8 inch size, dry.						
11							
12							
13							
14							
15							
16		SP					
17							
18							
19							
20	SAND, fine- to medium-grained sand.						
21							
22							
23							
24							
25							
26							
27							
28							
29							
30	SAND, olive brown (2.5Y 4/3), fine- to medium-grained sand, subangular to subrounded, slightly weathered grains, dry to slightly moist.						
31							
32							



LOG OF BORING OB-1

(Page 2 of 6)

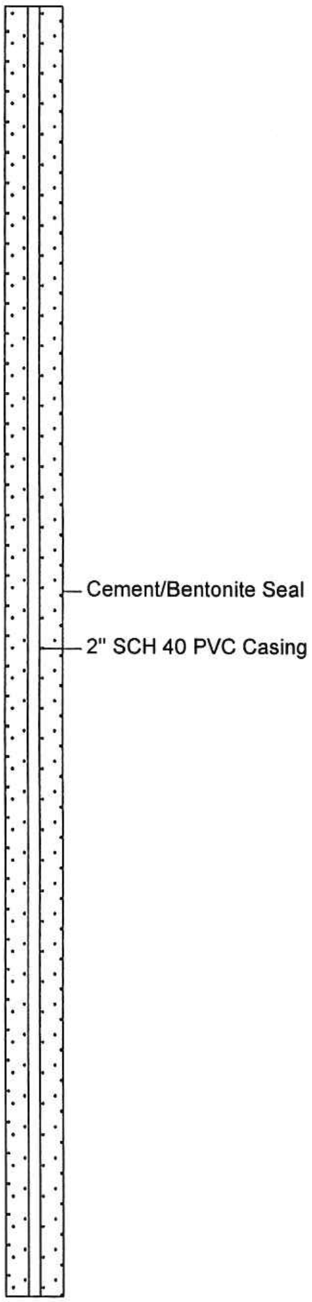
Kaiser Aluminum
Mead Works
Mead, Washington
MFG Project No.: 020055

Drilling Agency : Environmental West Exploration
Drill Rig : Foremost Mobile B-90
Drilling Method : Air Rotary
Drill Bit Type : Tubex (DHH)
Sampler Type : 2" SPT Split-Spoon

Start/Complete Date : 8-14-00 / 8-14-00
Northing/Easting Coord: 15382.57 / 11786.79
Surface Elevation : 1927.27
Logged / Reviewed By : T. Mullen

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Samples	Blow Count	Recov. (ft)	REMARKS
32							
33							
34							
35							
36							
37							
38							
39							
40	SAND, dark gray (5Y 4/1), fine- to medium-grained sand, slightly moist.	SP					
41							
42							
43							
44							
45							
46							
47							
48							
49							
50	CLAY, light olive brown (2.5Y 5/3), trace silt/very fine sand, low plasticity, weak thread, moist.	CL					
51							
52							
53	SAND, dark grayish brown (2.5Y 4/2), fine- to coarse-grained, subrounded to rounded, slightly elongated grains, <5% gravel, up to 1/8 inch size.	SW					
54							
55							
56							
57							
58							
59							
60	SANDY GRAVEL, gray (2.5Y 6/1), subrounded, up to 1/2 inch size; coarse-grained sand with some medium-grained sand, dry.	GP					
61							
62							
63							
64							

Well: OB-1
TOC Elev.: 1929.96



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LOG OF BORING OB-1

(Page 3 of 6)

Kaiser Aluminum
Mead Works
Mead, Washington

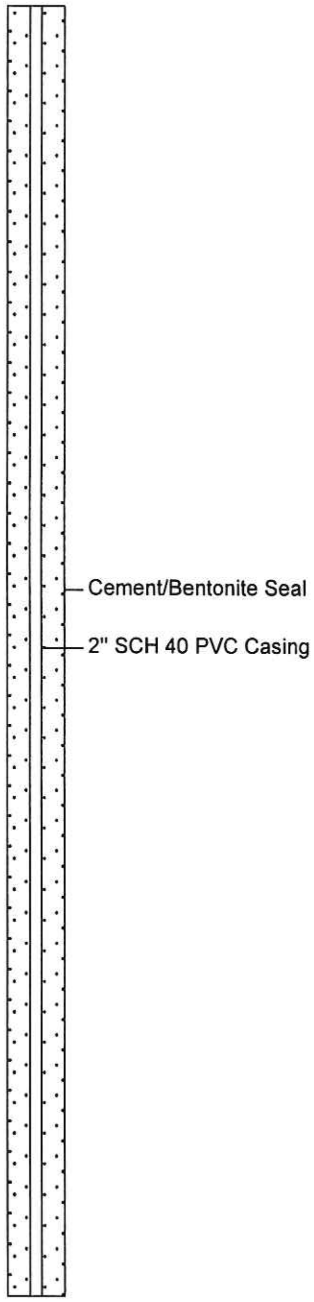
MFG Project No.: 020055

Drilling Agency : Environmental West Exploration
Drill Rig : Foremost Mobile B-90
Drilling Method : Air Rotary
Drill Bit Type : Tubex (DHH)
Sampler Type : 2" SPT Split-Spoon

Start/Complete Date : 8-14-00 / 8-14-00
Northing/Easting Coord: 15382.57 / 11786.79
Surface Elevation : 1927.27
Logged / Reviewed By : T. Mullen

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Samples	Blow Count	Recov. (ft)	REMARKS
64							
65							
66							
67		GP					
68							
69							
70	SAND, dark gray (10YR 4/1), fine-grained sand, dry to slightly moist.						
71							
72							
73							
74							
75		SP					
76							
77							
78							
79							
80	SILT, light olive brown (2.5 Y 5/8), <5% medium- to coarse-grained sand, slightly plastic, no thread, moist to wet.	ML					
81							
82							
83	SAND, dark gray (2.5Y 4/1), medium- to coarse-grained sand, <5% subangular to subrounded gravel up to 1/4 inch size.						
84							
85							
86							
87							
88		SP					
89							
90							
91							
92							
93							
94							
95							
96							

Well: OB-1
TOC Elev.: 1929.96



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LOG OF BORING OB-1

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Kaiser Aluminum
Mead Works
Mead, Washington

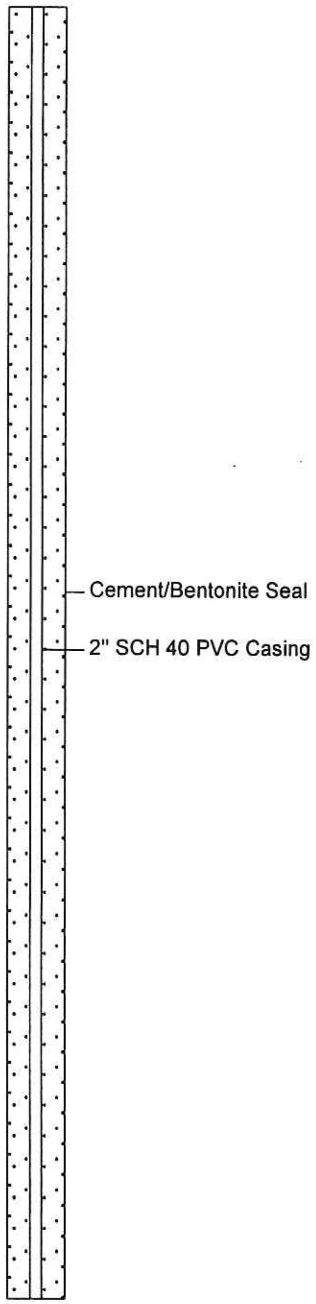
MFG Project No.: 020055

Drilling Agency : Environmental West Exploration
Drill Rig : Foremost Mobile B-90
Drilling Method : Air Rotary
Drill Bit Type : Tubex (DHH)
Sampler Type : 2" SPT Split-Spoon

Start/Complete Date : 8-14-00 / 8-14-00
Northing/Easting Coord: 15382.57 / 11786.79
Surface Elevation : 1927.27
Logged / Reviewed By : T. Mullen

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Samples	Blow Count	Recov. (ft)	REMARKS
96		SP					
97							
98							
99							
100	SAND, dark grayish brown (2.5Y 4/2), fine- to medium-grained sand, grades to fine sand, slightly moist.						
101							
102							
103							
104							
105							
106							
107							
108							
109							
110	SAND, dark grayish brown (2.5Y 4/2), fine- to medium- grained sand, well sorted, slightly moist.						
111							
112							
113							
114							
115							
116							
117							
118							
119							
120	SAND, dark gray (2.5Y 4/1), very fine- to fine-grained sand, dry.						
121							
122							
123							
124							
125	CLAY, light yellowish brown (2.5Y 6/3), low plasticity, moderate dry strength.	CL					
126		SP					
127							
128							

Well: OB-1
TOC Elev.: 1929.96



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LOG OF BORING OB-1

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Kaiser Aluminum
Mead Works
Mead, Washington

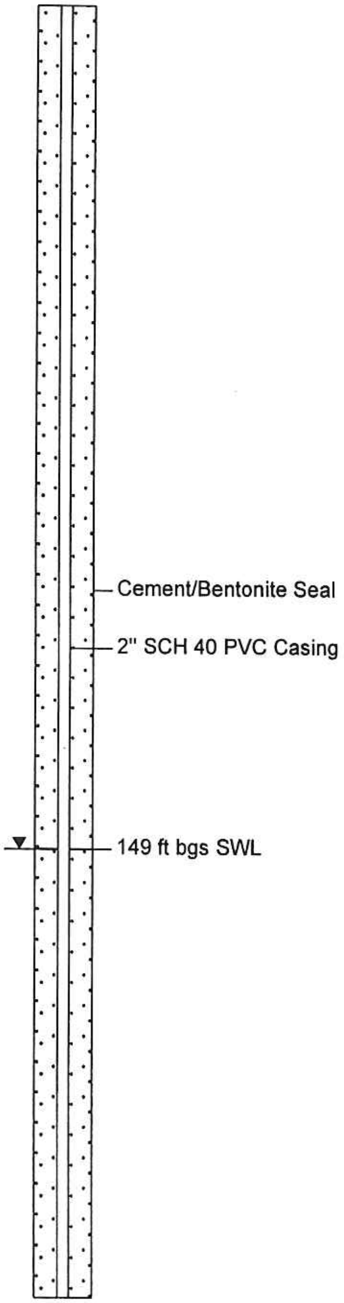
MFG Project No.: 020055

Drilling Agency : Environmental West Exploration
Drill Rig : Foremost Mobile B-90
Drilling Method : Air Rotary
Drill Bit Type : Tubex (DHH)
Sampler Type : 2" SPT Split-Spoon

Start/Complete Date : 8-14-00 / 8-14-00
Northing/Easting Coord: 15382.57 / 11786.79
Surface Elevation : 1927.27
Logged / Reviewed By : T. Mullen

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Samples	Blow Count	Recov. (ft)	REMARKS
128	SAND, dark gray (2.5Y 4/1), very fine- to fine-grained sand, trace silt, slightly moist.						
129							
130							
131							
132							
133							
134							
135	SAND, dark grayish brown (2.5Y 4/2), fine- to medium-grained sand, slightly moist.						
136							
137							
138							
139							
140	At 140 ft bgs, SILT, light yellowish brown (2.5Y 6/3), soft consistency, low plasticity.						
141							
142							
143							
144		SP					
145	SAND, dark grayish brown (2.5Y 4/1), medium- to coarse-grained sand, moist to wet.						
146							
147							
148							
149							First water at 149 feet bgs
150	SAND, dark grayish brown (2.5Y 4/2), fine grained sand, dark grayish brown, wet to saturated.						
151							
152							
153							Minimal air return. Loss of ari circulation. Sand heave.
154							
155							
156				1	10/ 24"		
157							
158							
159							
160							

Well: OB-1
TOC Elev.: 1929.96



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LOG OF BORING OB-1

(Page 6 of 6)

Kaiser Aluminum
Mead Works
Mead, Washington

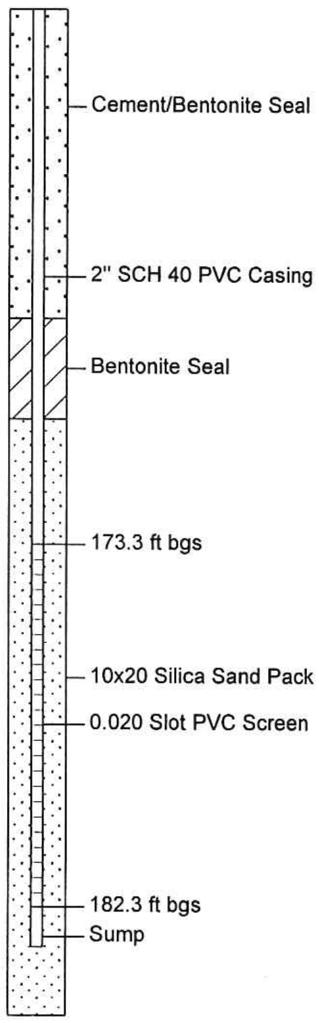
MFG Project No.: 020055

Drilling Agency : Environmental West Exploration
Drill Rig : Foremost Mobile B-90
Drilling Method : Air Rotary
Drill Bit Type : Tubex (DHH)
Sampler Type : 2" SPT Split-Spoon

Start/Complete Date : 8-14-00 / 8-14-00
Northing/Easting Coord: 15382.57 / 11786.79
Surface Elevation : 1927.27
Logged / Reviewed By : T. Mullen

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Samples	Blow Count	Recov. (ft)	REMARKS
160		SP					~~Sand heave 98~~ feet up inside casing)
161	CLAY, gray (H6) to dark greenish gray (5.6Y 4/1), soft consistency, high plasticity, tough thread, high dry strength, moist.						
162							
163							
164		CH					
165							Loss of air circulation. Inject water to clean inside of casing.
166							
167	SAND, gray (H5), medium- to coarse-grained sand, <5% silt.						
168							
169							
170							
171							
172							
173							
174							
175	SAND, dark gray (5Y 4/1), fine- to medium-grained sand, well sorted, wet.	SP					
176							
177							
178							
179							
180							No sand heave.
181							
182							
183	CLAY, greenish gray (5.6Y 8/1), soft consistency, moist.						
184		CH					
185							
186	Total depth of borehole = 185.0 feet below ground surface.						
187							
188							
189							
190							
191							
192							

Well: OB-1
TOC Elev.: 1929.96



ATTACHMENT A-2

Tables

TABLE A-1
Pump Test No. 1 Data Analysis
Kaiser Aluminum, Mead Washington

Pumping Well	Distance from KM-1 (ft)	Hydrostratigraphic Zone	Screen Length (ft)
KM-1	0	A	18.4
OB-1	9.7	B	9.0
TH-3A	16.4	A	16.0
TH-8	25.3	A	5.0

Pump Test No. 1 8/23/00 (0940)- 8/24/00 (0949)	Pumping Rate (gpm)	Transmissivity (sq. ft/day)	Saturated Thickness (ft)	Hydraulic Conductivity (ft/day)	Storativity	Storage Coefficient Ratio
Theis (unconfined)						
Pumping Well KM-1	16.75	NA	18.4	NA	NA	NA
TH-3A	16.75	8575.63	16	536.0	0.13	NA
TH-8	16.75	14101.5	19.3	730.6	0.06	NA
Cooper & Jacob (straight line)						
Pumping Well KM-1	16.75	NA	18.4	NA	NA	NA
TH-3A	16.75	8485.2	16	530.3	0.14	NA
TH-8	16.75	14349.2	19.3	743.5	0.07	NA

Recovery Test No. 1 8/24/00 (0949)- 8/24/00 (1410)	Pumping Rate (gpm)	Transmissivity (sq. ft/day)	Saturated Thickness (ft)	Hydraulic Conductivity (ft/day)	Storativity	Storage Coefficient Ratio
Theis (recovery)						
Pumping Well KM-1	16.75	3826.01	18.4	207.9	NA	NA
TH-3A	16.75	16684.3	16	1042.8	NA	3.30E-07
TH-8	16.75	17190.1	19.3	890.7	NA	1.80E-07
Cooper & Jacob (straight line)						
Pumping Well KM-1	16.75	6419.66	18.4	348.9	NA	NA
TH-3A	16.75	12008.4	16	750.5	0.11	NA
TH-8	16.75	13668.3	19.3	708.2	0.06	NA

TABLE A-2
Pump Test No. 2 Data Analysis
Kaiser Aluminum, Mead Washington

Pumping Well	Distance from KM-1 (ft)	Hydrostratigraphic Zone	Screen Length (ft)
KM-1	0	A	18.4
OB-1	9.7	B	9.0
TH-3A	16.4	A	16.0
TH-8	25.3	A	5.0

Pump Test No. 2 8/25/00 (1124)- 8/25/00 (1447)	Pumping Rate (gpm)	Transmissivity (sq. ft/day)	Saturated Thickness (ft)	Hydraulic Conductivity (ft/day)	Storativity	Storage Coefficient Ratio
Theis (unconfined)						
Pumping Well KM-1	28.24	NA	18.4	NA	NA	NA
TH-3A	28.24	7872.56	16	492.0	0.11	NA
TH-8	28.24	9820.1	19.3	508.8	0.05	NA
Cooper & Jacob (straight line)						
Pumping Well KM-1	28.24	4495.17	18.4	244.3	NA	NA
TH-3A	28.24	8116.81	16	507.3	0.1	NA
TH-8	28.24	9552.45	19.3	494.9	0.07	NA

Recovery Test No. 2 8/25/00 (1447)- 8/25/00 (1520)	Pumping Rate (gpm)	Transmissivity (sq. ft/day)	Saturated Thickness (ft)	Hydraulic Conductivity (ft/day)	Storativity	Storage Coefficient Ratio
Theis (recovery)						
Pumping Well KM-1	28.24	4573.1	18.4	248.5	NA	NA
TH-3A	28.24	20034.5	16	1252.2	NA	2.40E-05
TH-8	28.24	22277.2	19.3	1154.3	NA	7.70E-05
Cooper & Jacob (straight line)						
Pumping Well KM-1	28.24	4313.32	18.4	234.4	NA	NA
TH-3A	28.24	8449.92	16	528.1	0.1	NA
TH-8	28.24	10647	19.3	551.7	0.05	NA

TABLE A-3
Injection Test Data Analysis
Kaiser Aluminum, Mead Washington

Pumping Well	Distance from KM-1 (ft)	Hydrostratigraphic Zone	Screen Length (ft)
KM-1	0	A	18.4
OB-1	9.7	B	9.0
TH-3A	16.4	A	16.0
TH-8	25.3	A	5.0

Injection Test 8/25/00 (1625)- 8/26/00 (1211)	Pumping Rate (gpm)	Transmissivity (sq. ft/day)	Saturated Thickness (ft)	Hydraulic Conductivity (ft/day)	Storativity	Storage Coefficient Ratio
Theis (unconfined)						
Pumping Well KM-1	20.5	NA	18.4	NA	NA	NA
TH-3A	20.5	3881.55	16	242.6	NA	0.28
TH-8	20.5	4217.01	19.3	218.5	NA	0.17
Cooper & Jacob (straight line)						
Pumping Well KM-1	20.5	NA	18.4	NA	NA	NA
TH-3A	20.5	4093.3	16	255.8	0.003	NA
TH-8	20.5	4275.47	19.3	221.5	0.002	NA

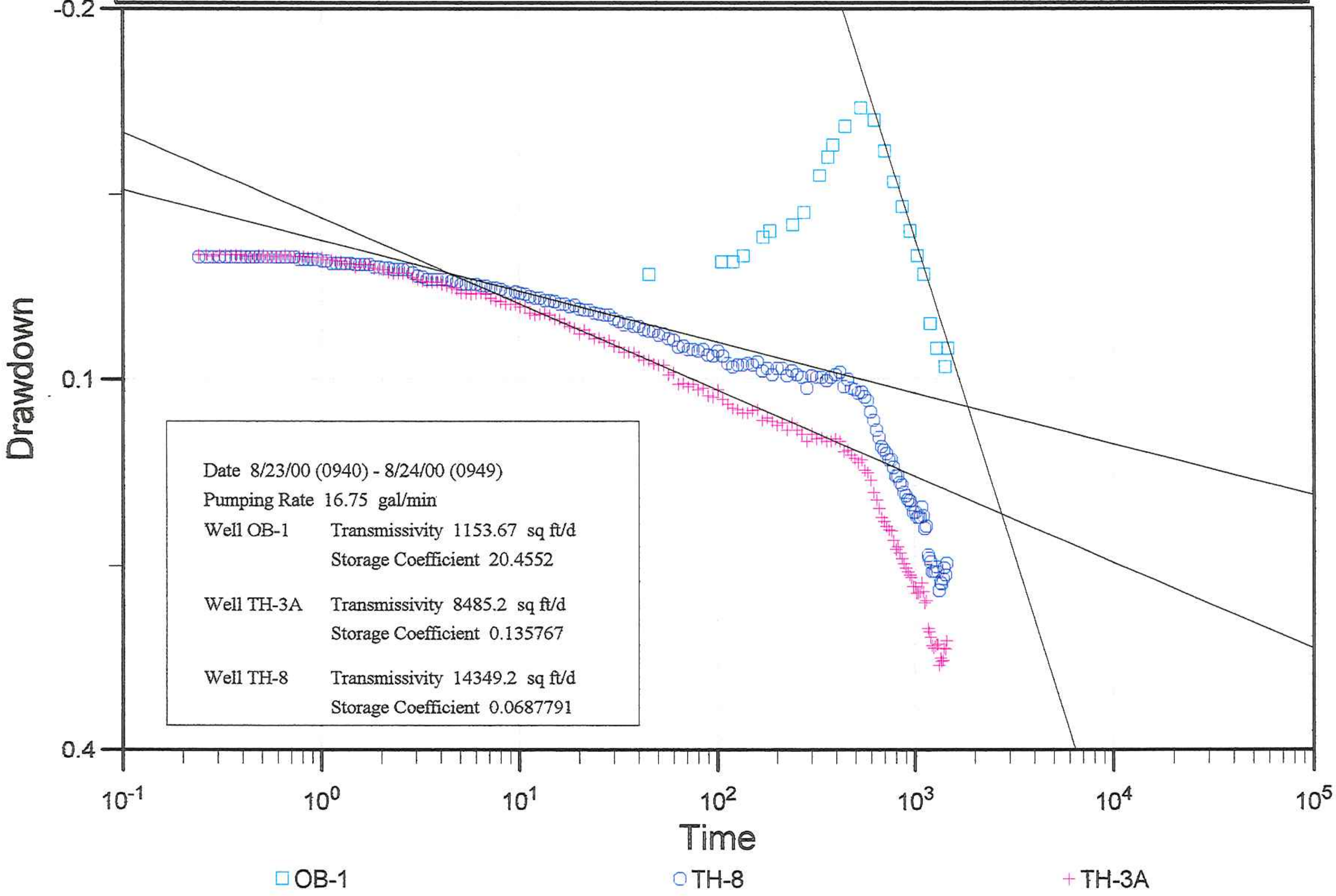
TABLE A-4
Summary of Aquifer Test Results
Kaiser Aluminum, Mead Washington

	Transmissivity (sq. ft/day)	Hydraulic Conductivity (ft/day)	Storativity
Pump Test No. 1			
KM-1	NA	NA	NA
TH-3A	8530	533	0.14
TH-8	14225	737	0.07
Recovery Test No. 1			
KM-1	5123	278	NA
TH-3A	14346	897	0.11
TH-8	15429	799	0.06
Pump Test No. 2			
KM-1	NA	NA	NA
TH-3A	7995	500	0.11
TH-8	9686	502	0.06
Recovery Test No. 2			
KM-1	4443	241	NA
TH-3A	14242	890	0.10
TH-8	16462	853	0.06
Injection Test			
KM-1	NA	NA	NA
TH-3A	3987	249	0.003
TH-8	4246	220	0.002

ATTACHMENT A-3

Graphs

Cooper and Jacob Analysis (Pump Test No. 1)



Date 8/23/00 (0940) - 8/24/00 (0949)
Pumping Rate 16.75 gal/min
Well OB-1 Transmissivity 1153.67 sq ft/d
Storage Coefficient 20.4552

Well TH-3A Transmissivity 8485.2 sq ft/d
Storage Coefficient 0.135767

Well TH-8 Transmissivity 14349.2 sq ft/d
Storage Coefficient 0.0687791

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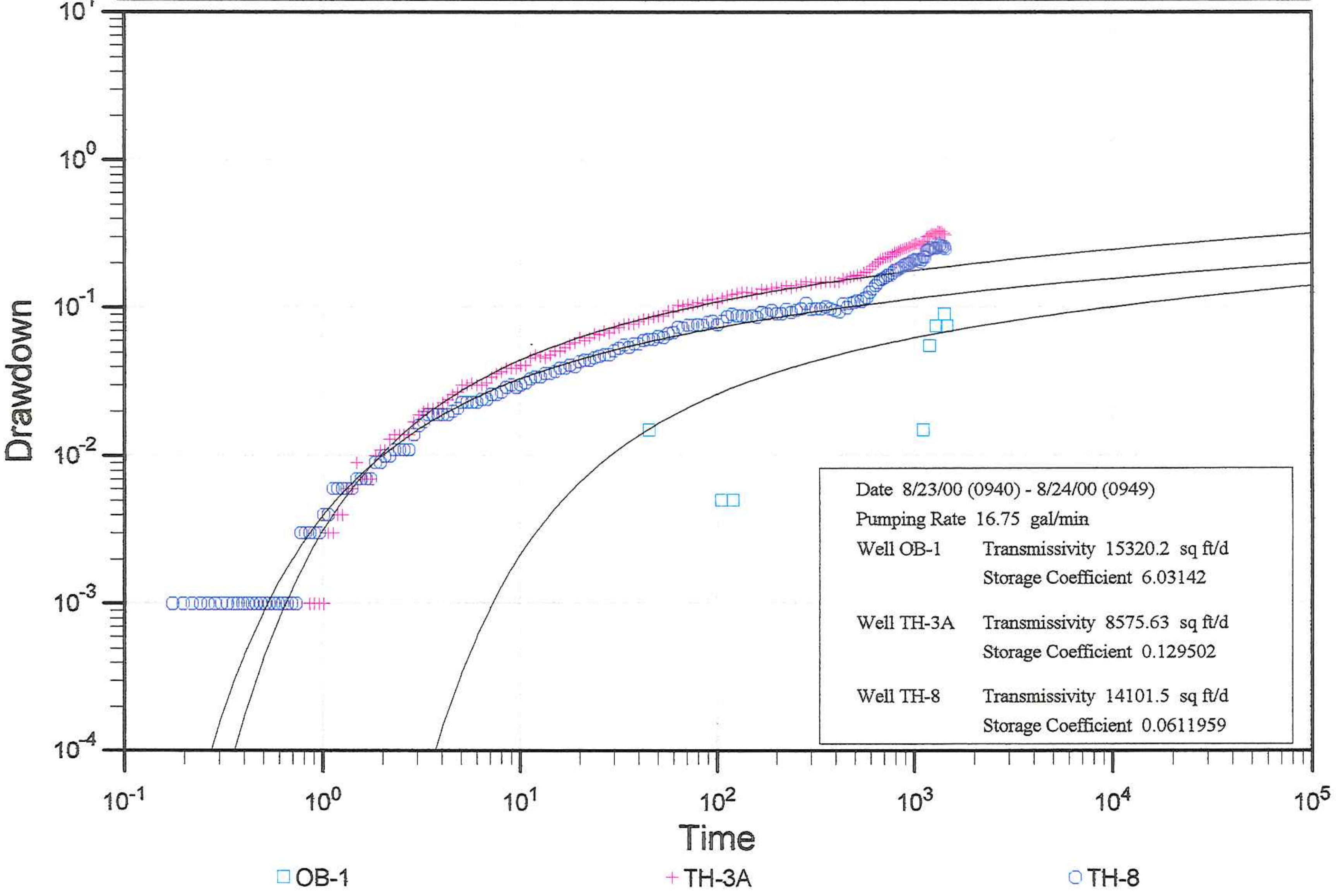
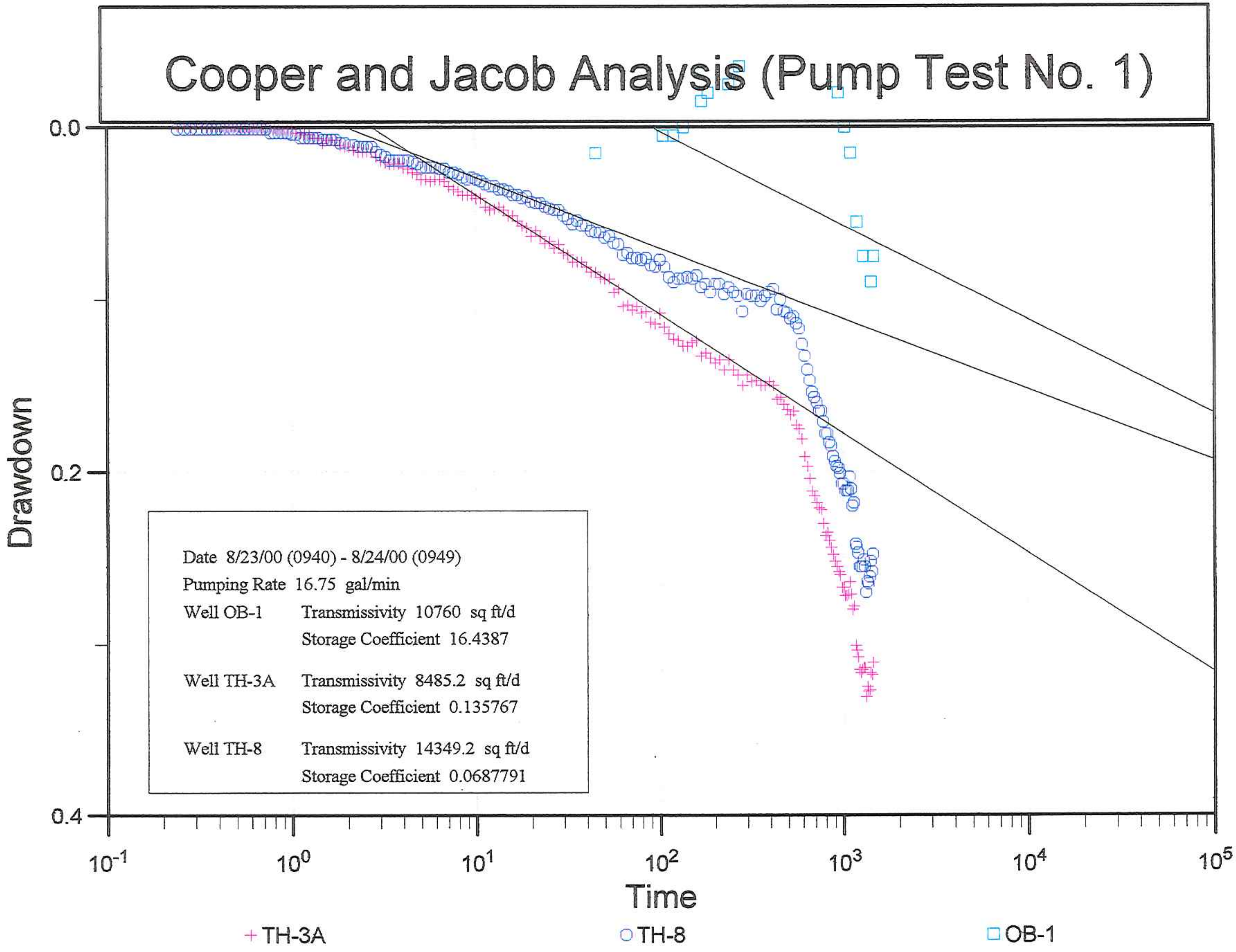
Theis Analysis (Pump Test No. 1)

Kaiser Aluminum
Mead Works
Mead, Washington



Date 8/23/00 (0940) - 8/24/00 (0949)
Pumping Rate 16.75 gal/min

Well OB-1	Transmissivity	15320.2 sq ft/d
	Storage Coefficient	6.03142
Well TH-3A	Transmissivity	8575.63 sq ft/d
	Storage Coefficient	0.129502
Well TH-8	Transmissivity	14101.5 sq ft/d
	Storage Coefficient	0.0611959



Cooper and Jacob Analysis (Pump Test No. 1)

Date 8/23/00 (0940) - 8/24/00 (0949)
Pumping Rate 16.75 gal/min

Well OB-1	Transmissivity	10760 sq ft/d
	Storage Coefficient	16.4387
Well TH-3A	Transmissivity	8485.2 sq ft/d
	Storage Coefficient	0.135767
Well TH-8	Transmissivity	14349.2 sq ft/d
	Storage Coefficient	0.0687791

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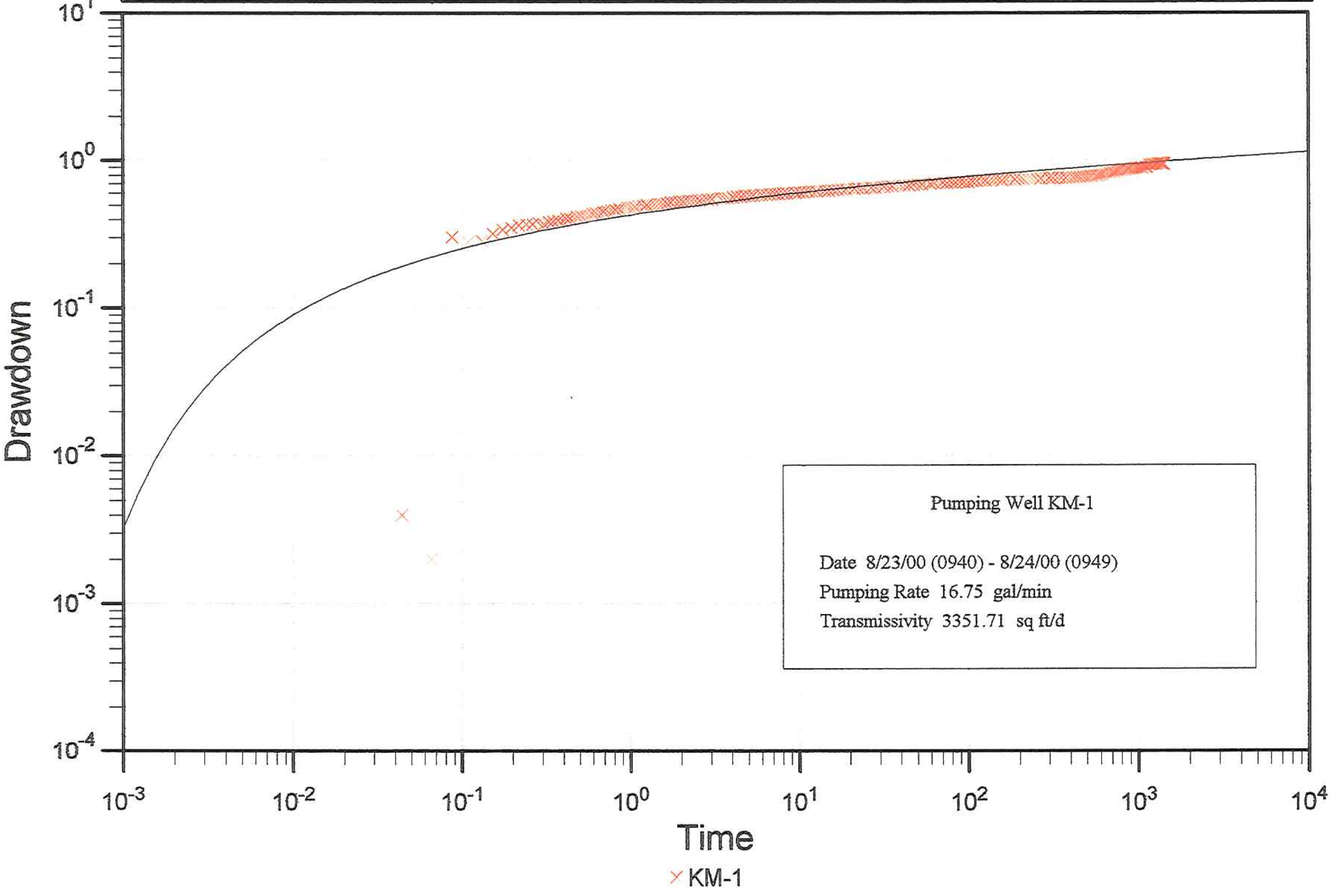
Theis Analysis (Pump Test No. 1)

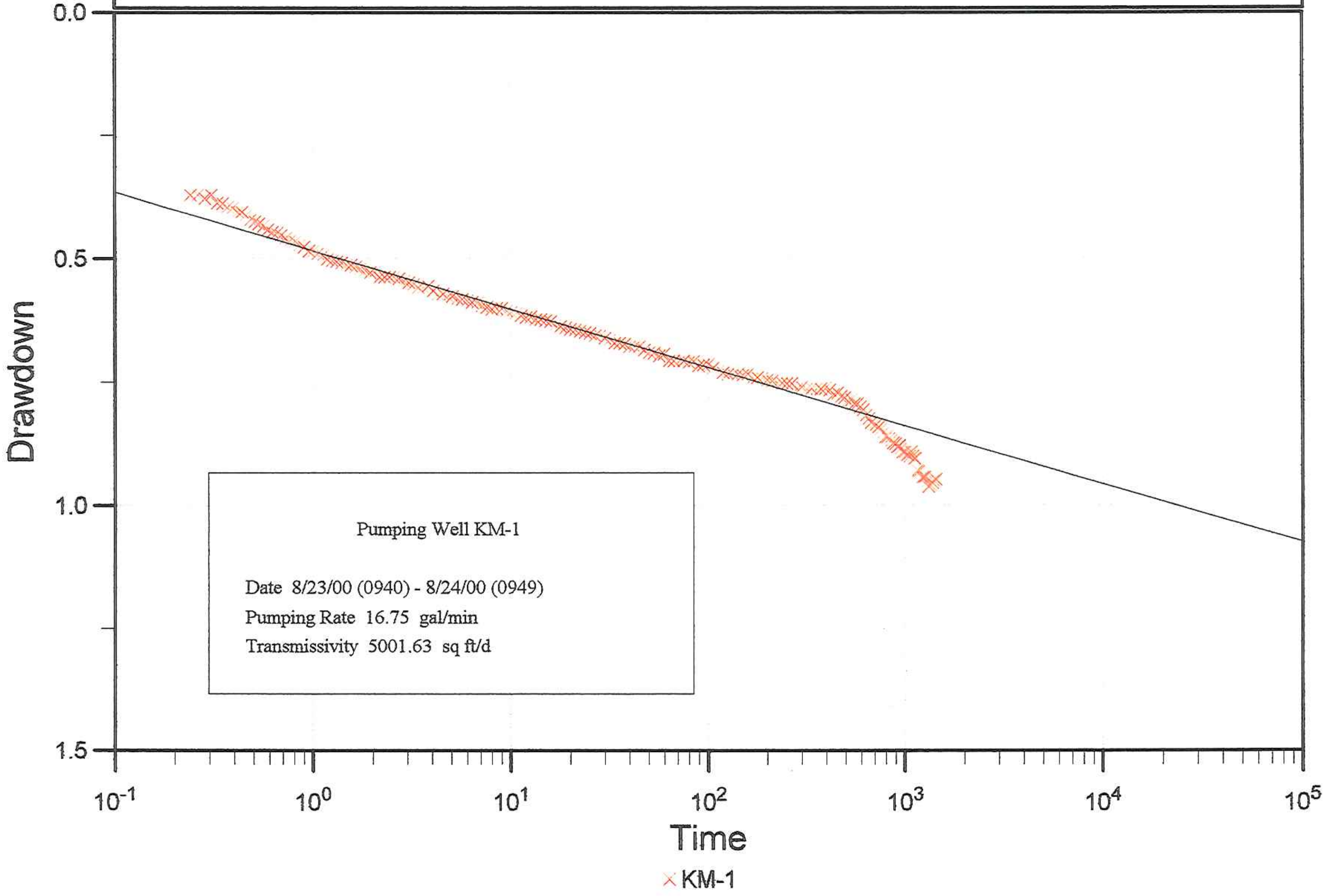
Kaiser Aluminum
Mead Works
Mead, Washington



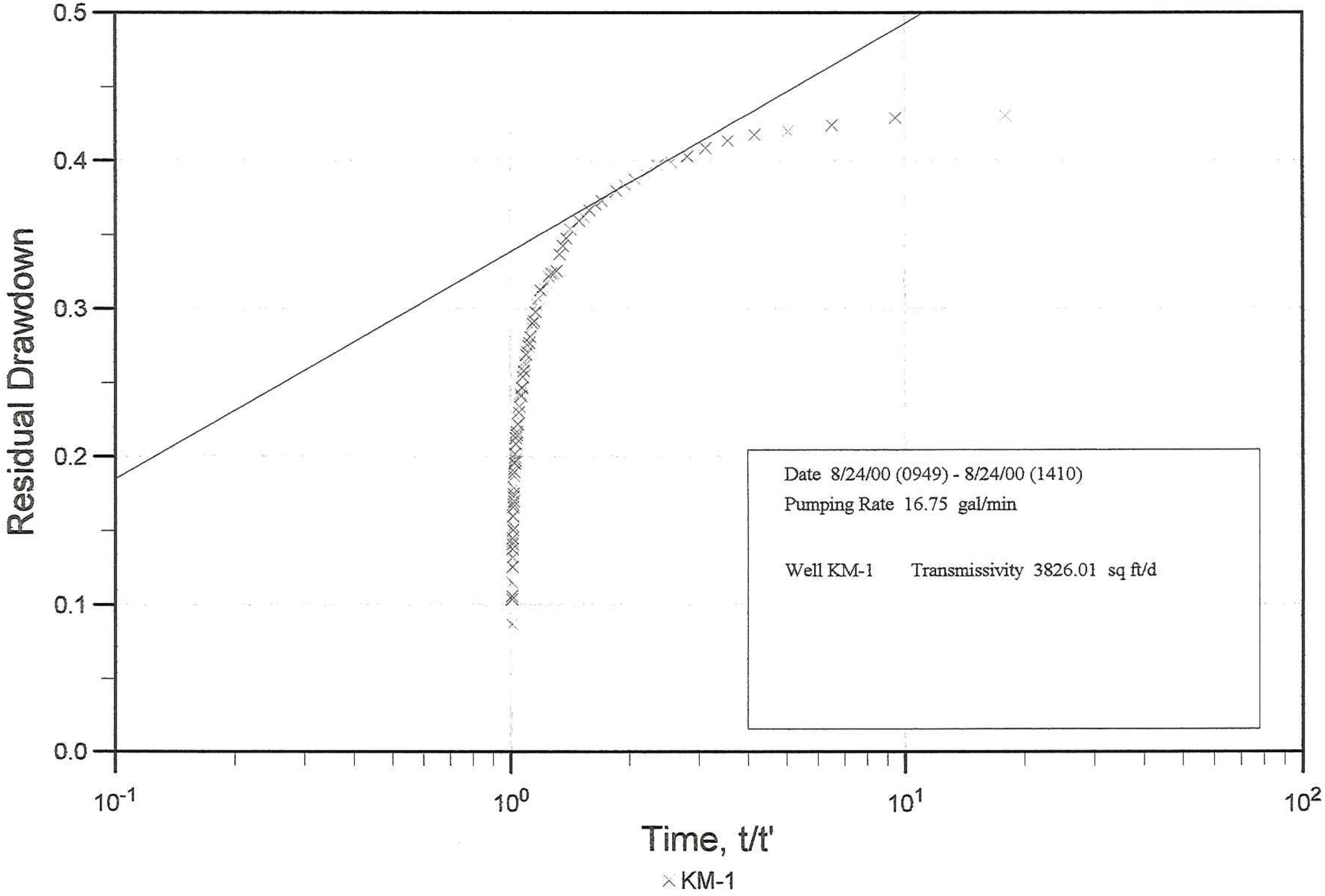
Pumping Well KM-1

Date 8/23/00 (0940) - 8/24/00 (0949)
Pumping Rate 16.75 gal/min
Transmissivity 3351.71 sq ft/d

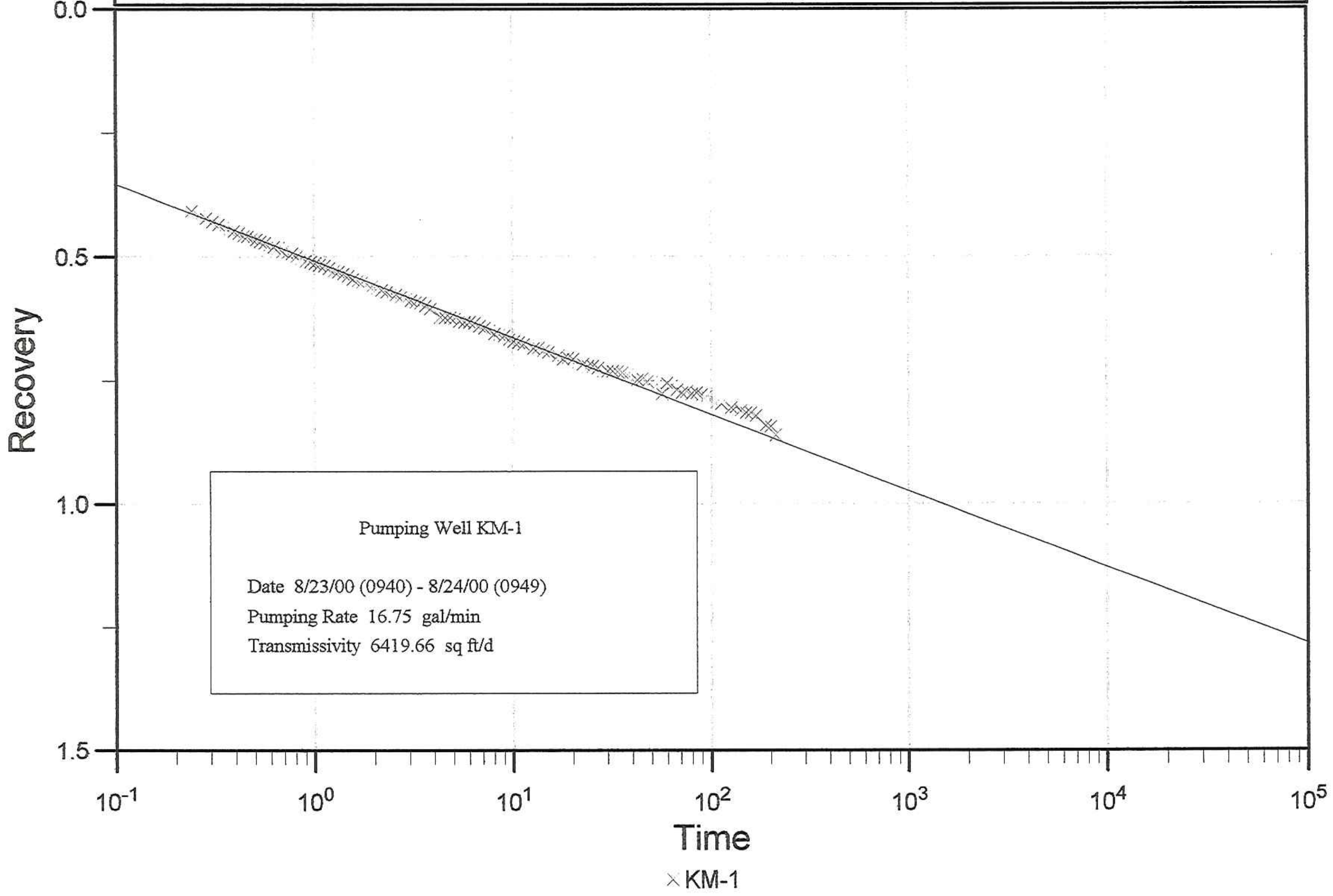
Cooper and Jacob Analysis (Pump Test No.1)



Theis Recovery Analysis KM-1 (Recovery Test No.1)



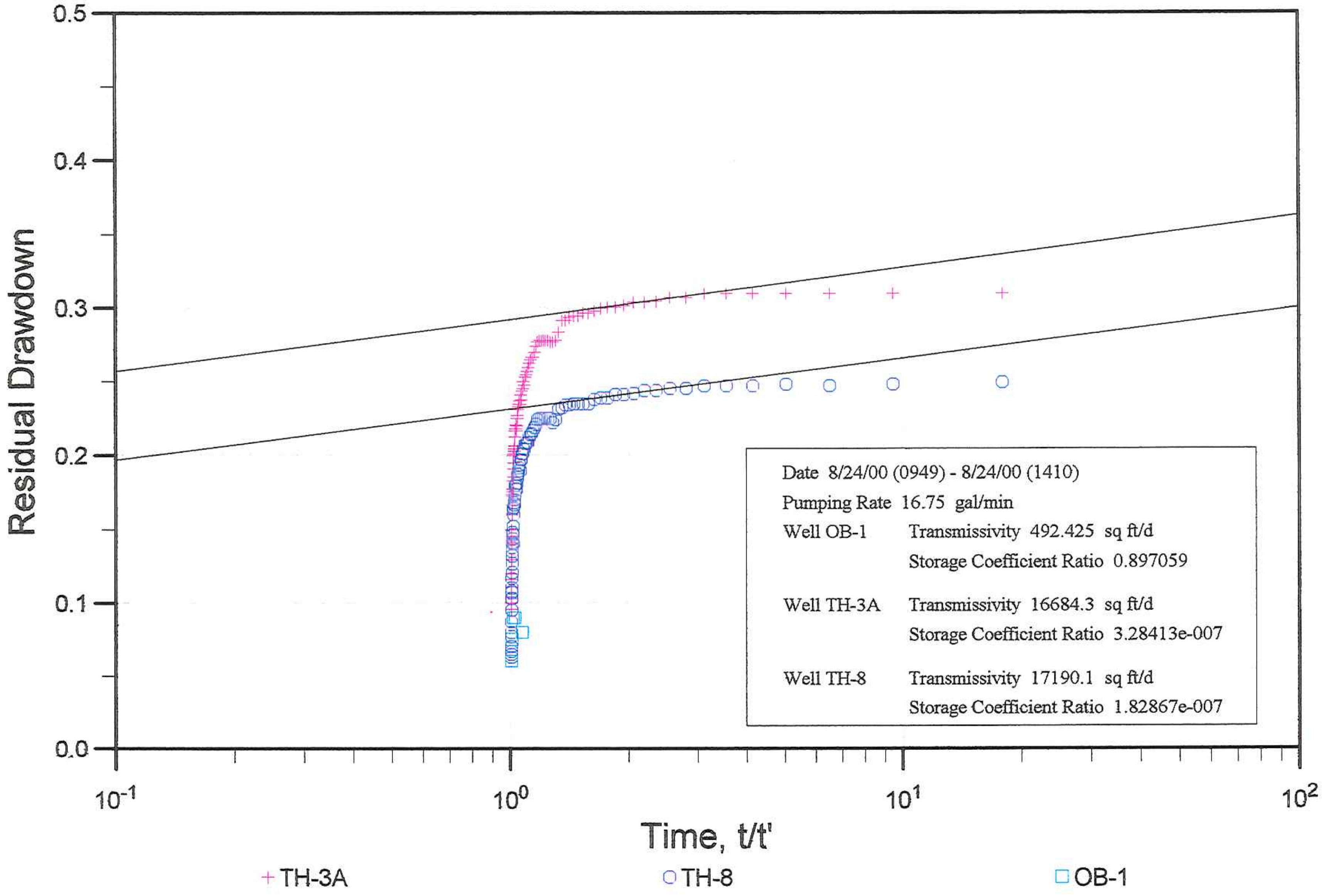
Cooper and Jacob Analysis (RecoveryTest No.1)



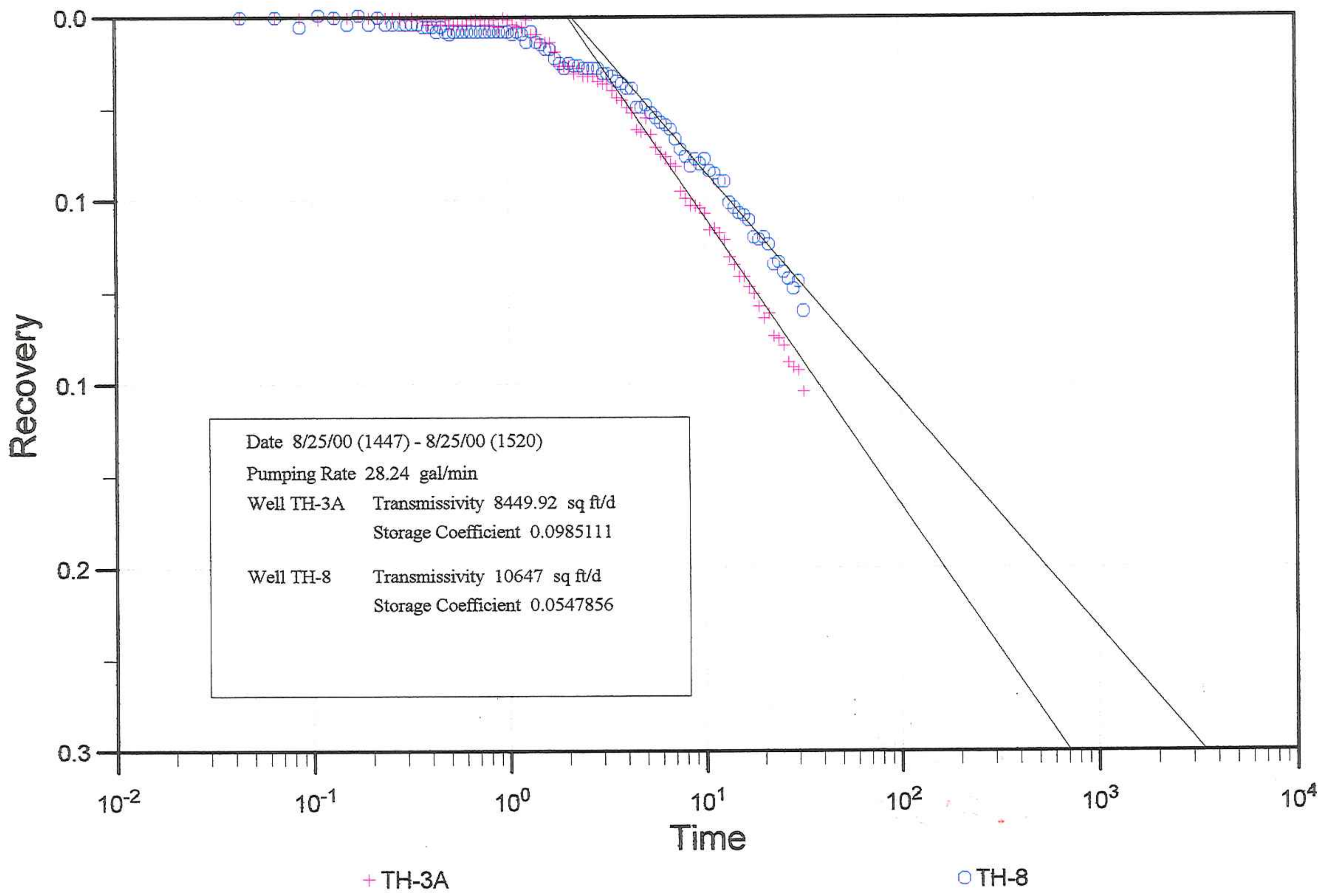
Pumping Well KM-1

Date 8/23/00 (0940) - 8/24/00 (0949)
Pumping Rate 16.75 gal/min
Transmissivity 6419.66 sq ft/d

Theis Recovery Analysis (Recovery Test No. 1)

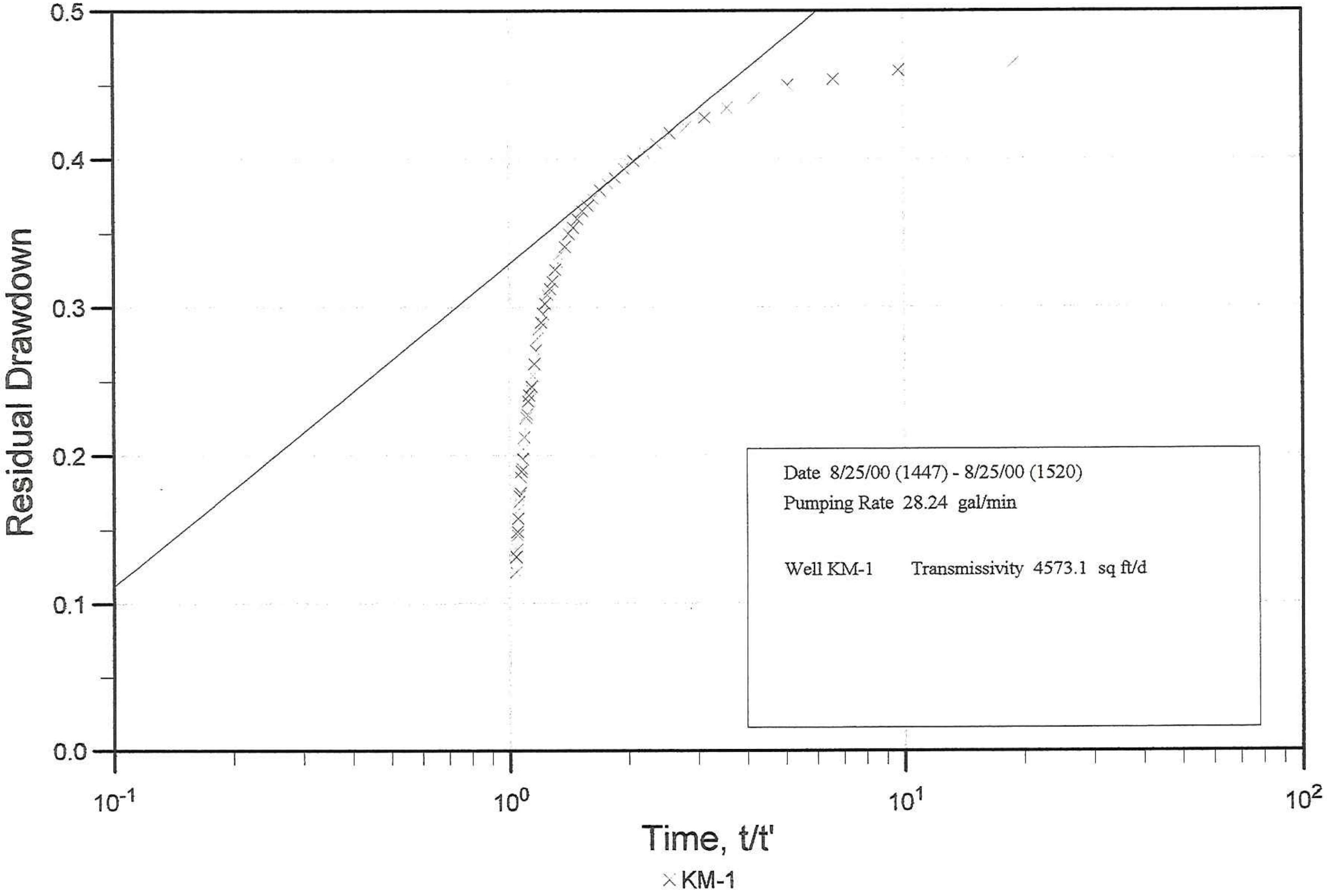


Cooper and Jacob Analysis (Recovery Test No. 2)



Date 8/25/00 (1447) - 8/25/00 (1520)
Pumping Rate 28.24 gal/min
Well TH-3A Transmissivity 8449.92 sq ft/d
Storage Coefficient 0.0985111
Well TH-8 Transmissivity 10647 sq ft/d
Storage Coefficient 0.0547856

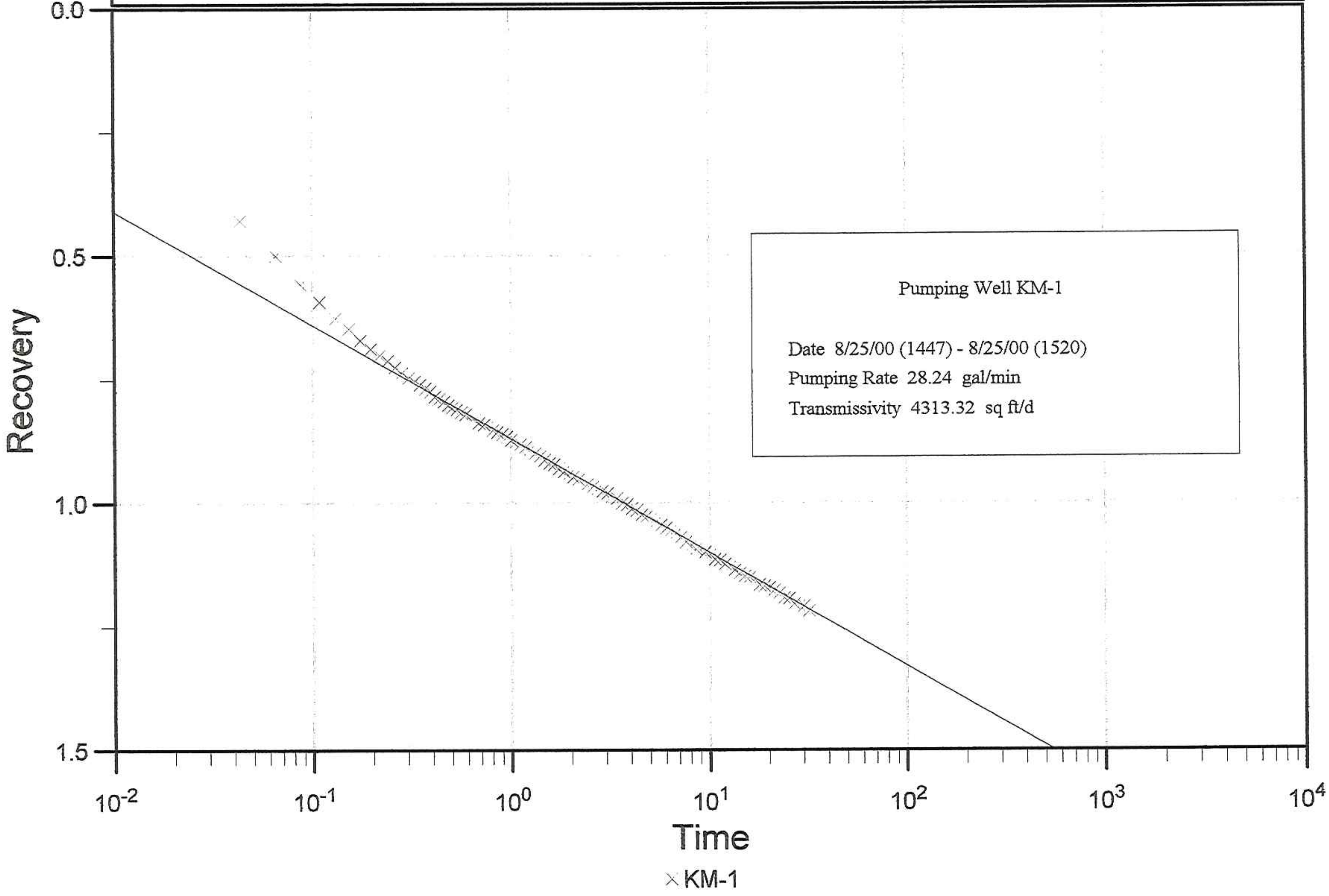
Theis Recovery Analysis KM-1 (Recovery Test No.2)



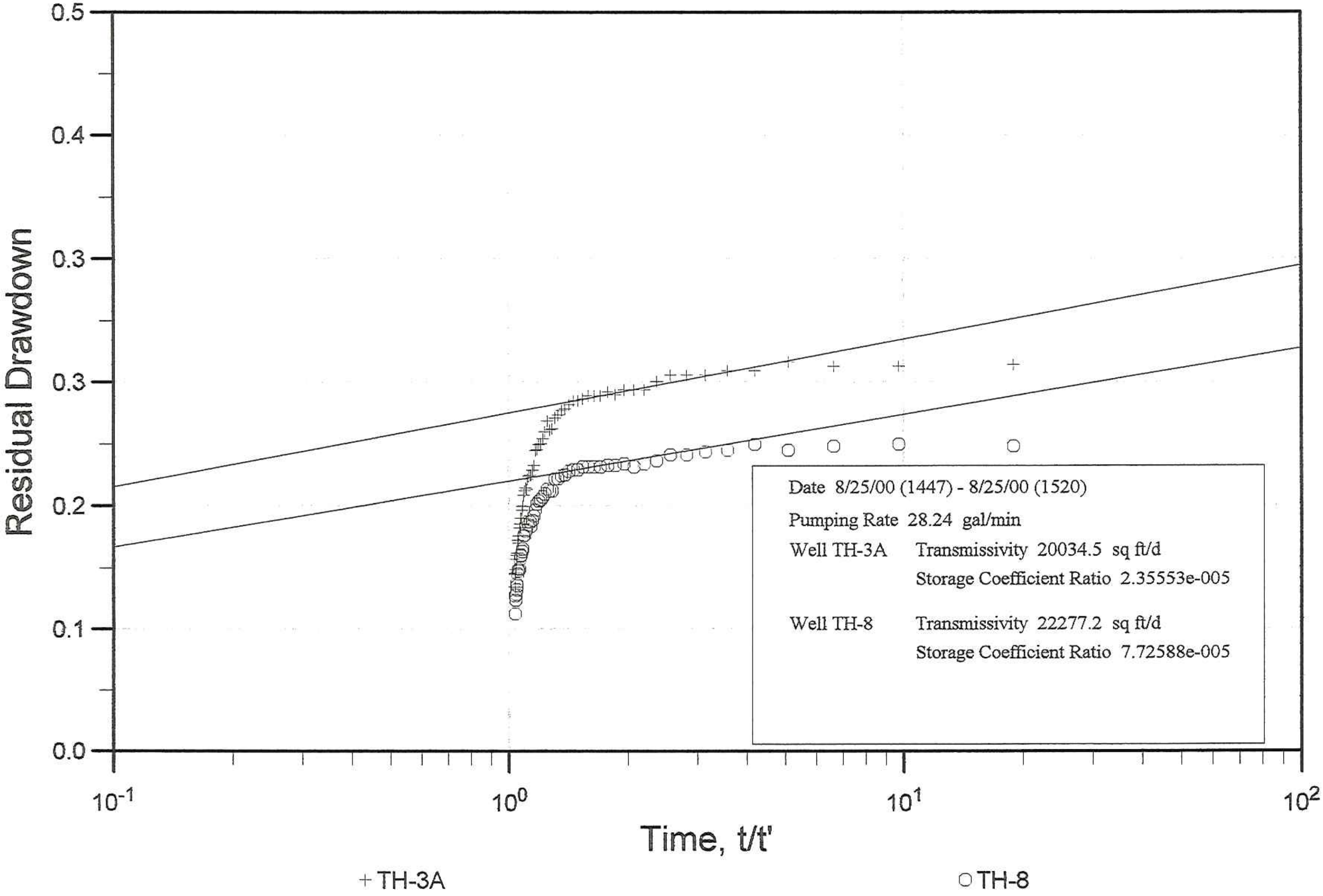
Date 8/25/00 (1447) - 8/25/00 (1520)
Pumping Rate 28.24 gal/min

Well KM-1 Transmissivity 4573.1 sq ft/d

Cooper and Jacob Analysis (RecoveryTest No.2)



Theis Recovery Analysis (Recovery Test No. 2)



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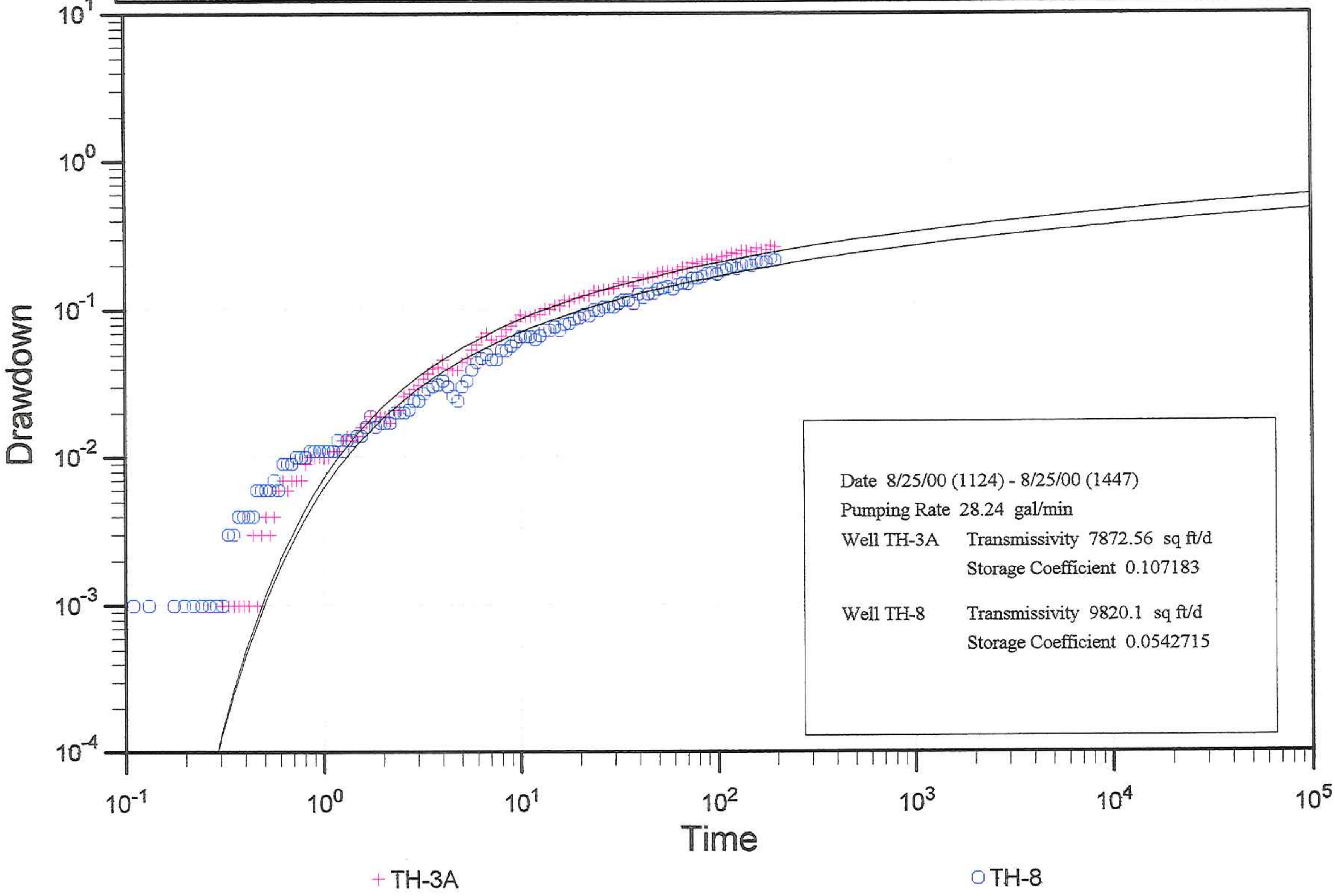
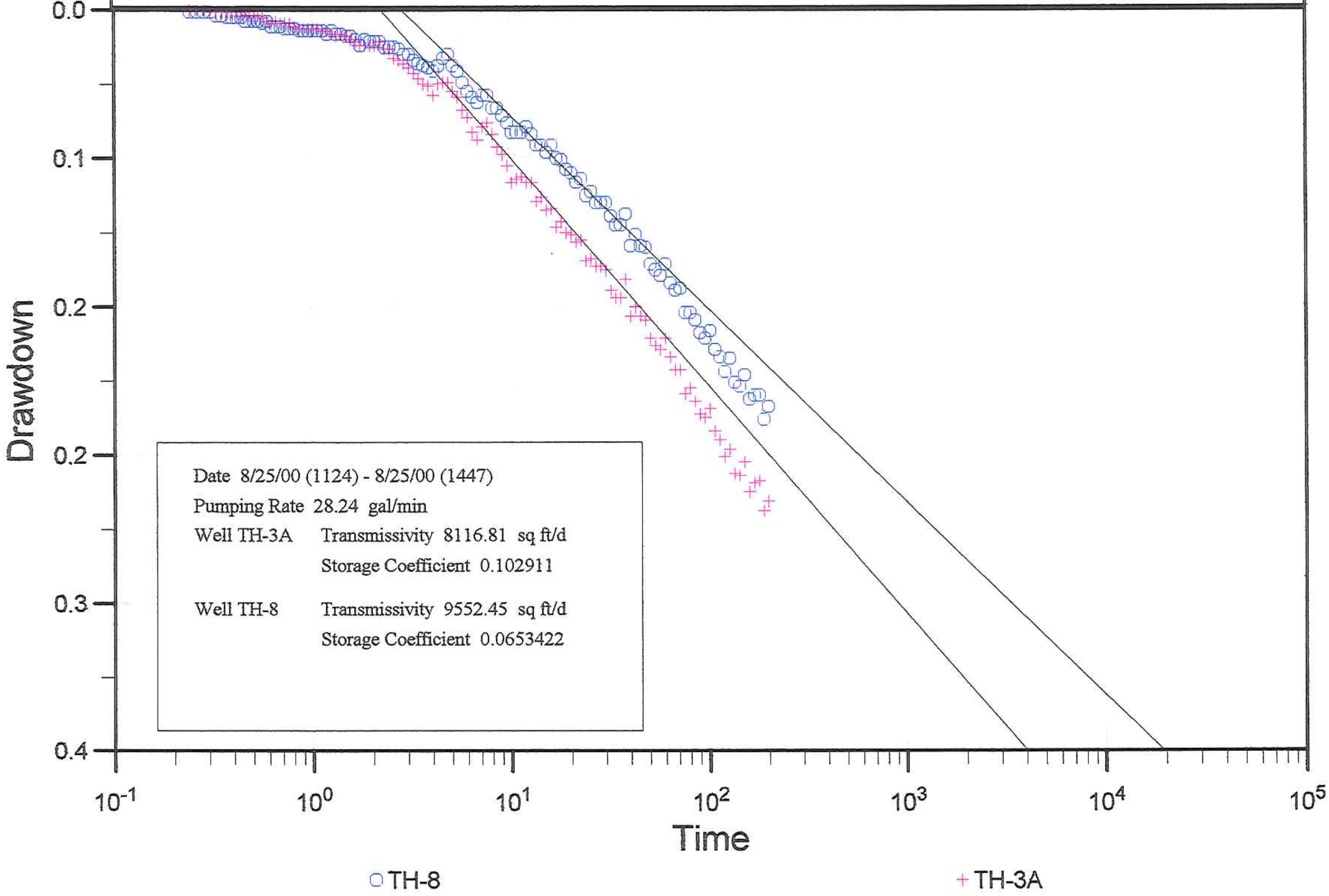
Theis Analysis (Pump Test No. 2)

Kaiser Aluminum
Mead Works
Mead, Washington



Date 8/25/00 (1124) - 8/25/00 (1447)
Pumping Rate 28.24 gal/min
Well TH-3A Transmissivity 7872.56 sq ft/d
Storage Coefficient 0.107183
Well TH-8 Transmissivity 9820.1 sq ft/d
Storage Coefficient 0.0542715

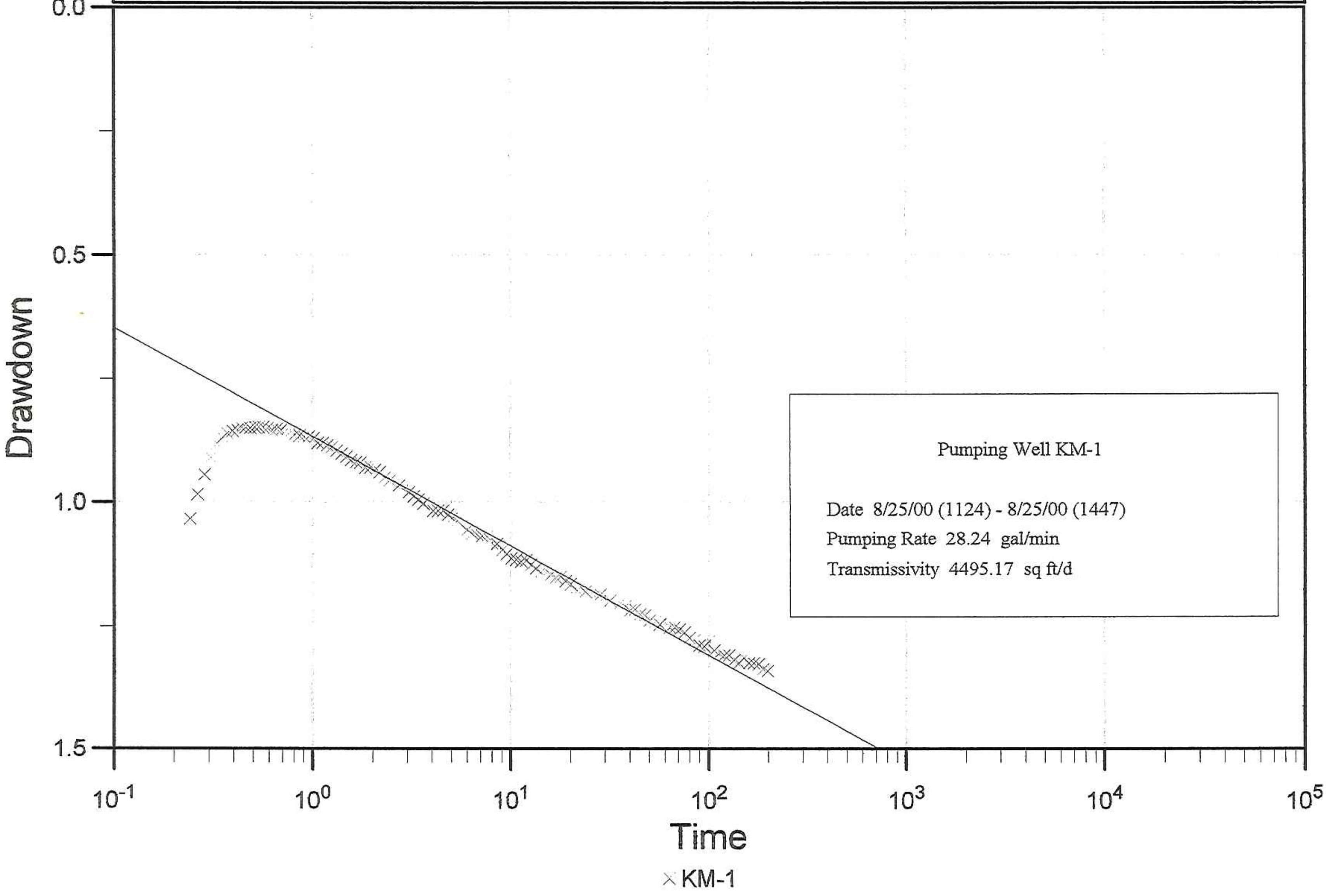
Cooper and Jacob Analysis (Pump Test No.2)



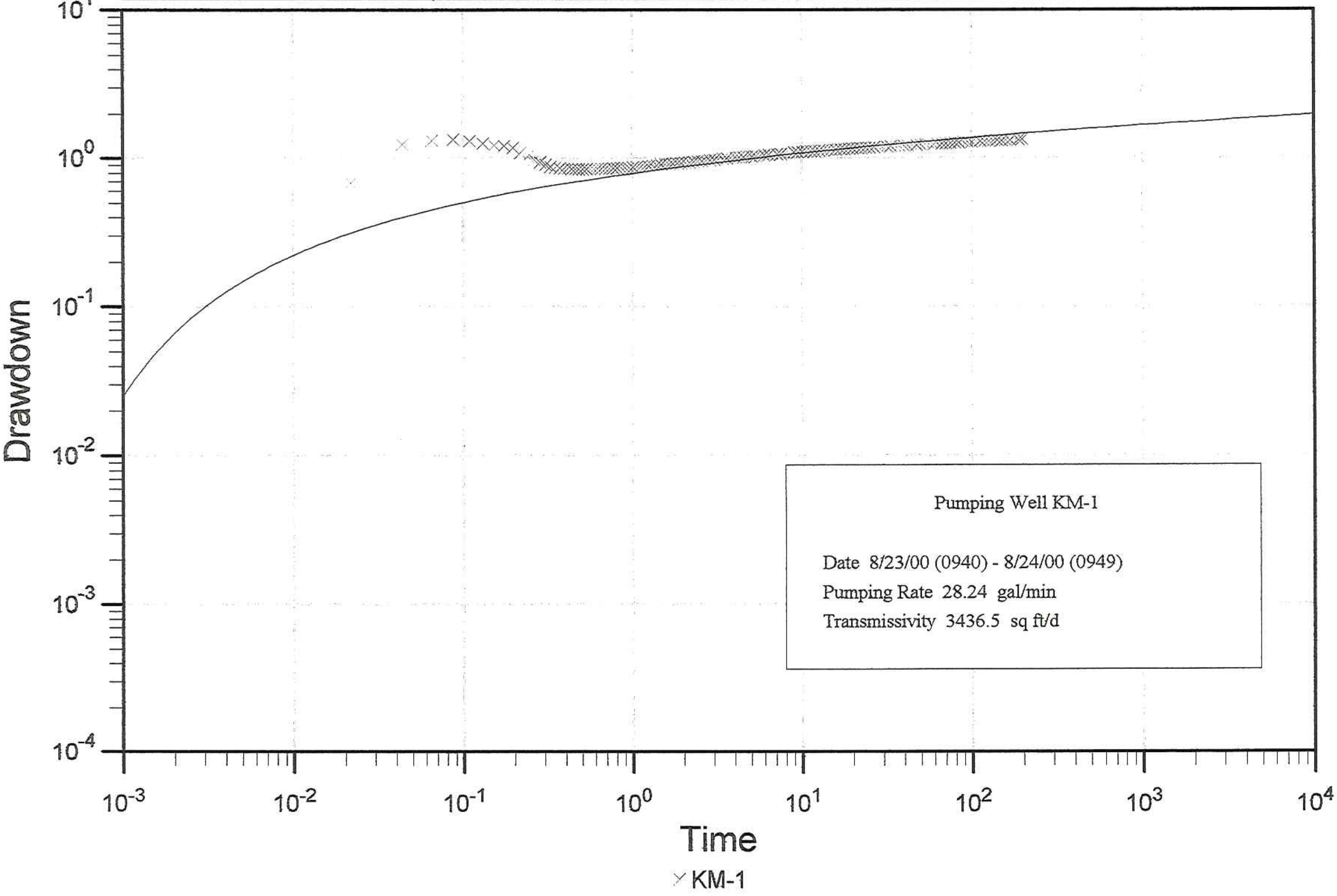
Date 8/25/00 (1124) - 8/25/00 (1447)
Pumping Rate 28.24 gal/min
Well TH-3A Transmissivity 8116.81 sq ft/d
Storage Coefficient 0.102911

Well TH-8 Transmissivity 9552.45 sq ft/d
Storage Coefficient 0.0653422

Cooper and Jacob Analysis (Pump Test No.2)



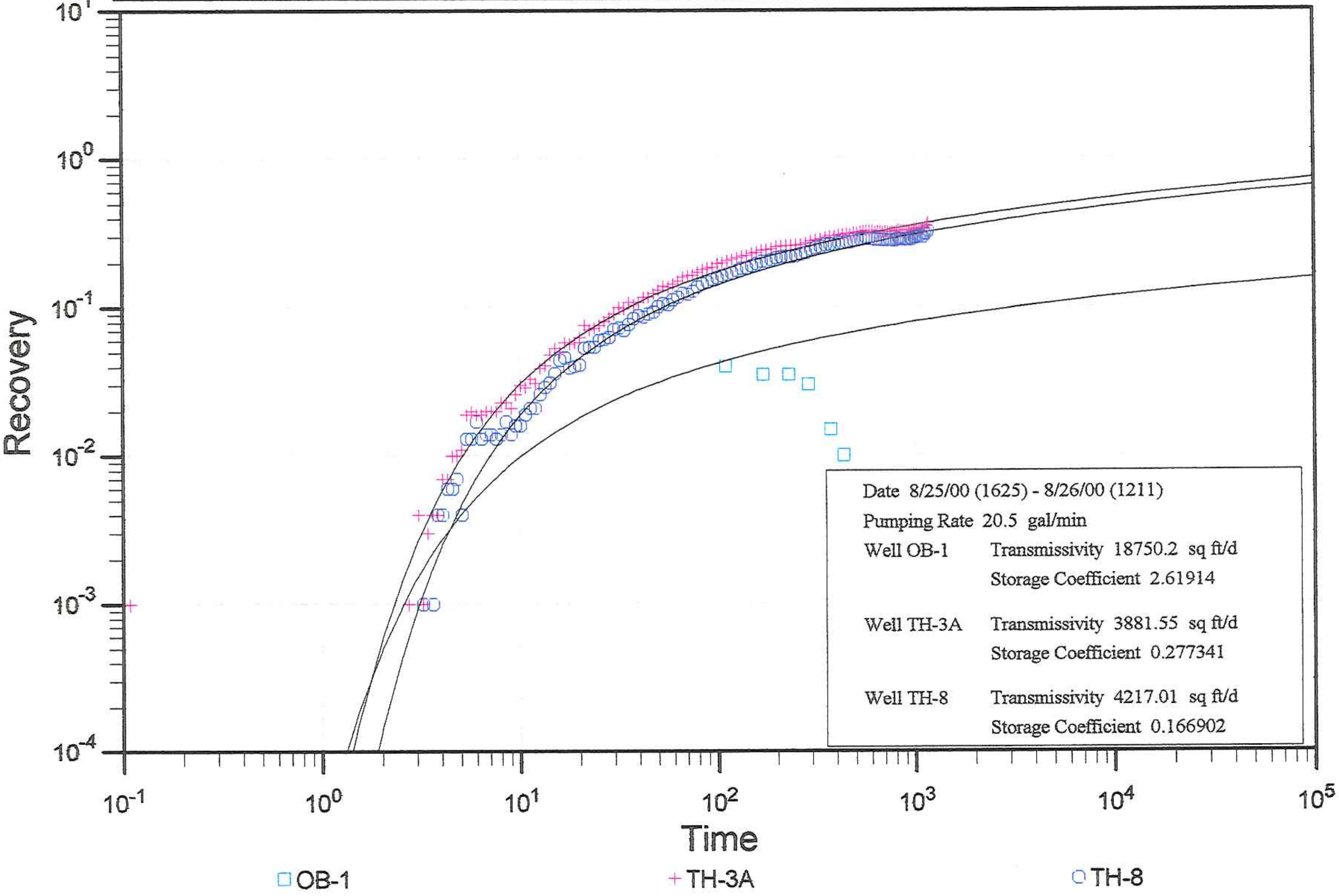
consulting scientists and engineers	Theis Analysis (Pump Test No.2)	Kaiser Aluminum Mead Works Mead, Washington



Pumping Well KM-1

Date 8/23/00 (0940) - 8/24/00 (0949)
Pumping Rate 28.24 gal/min
Transmissivity 3436.5 sq ft/d

consulting scientists and engineers	Theis Analysis (Injection Test)	Kaiser Aluminum Mead Works Mead, Washington



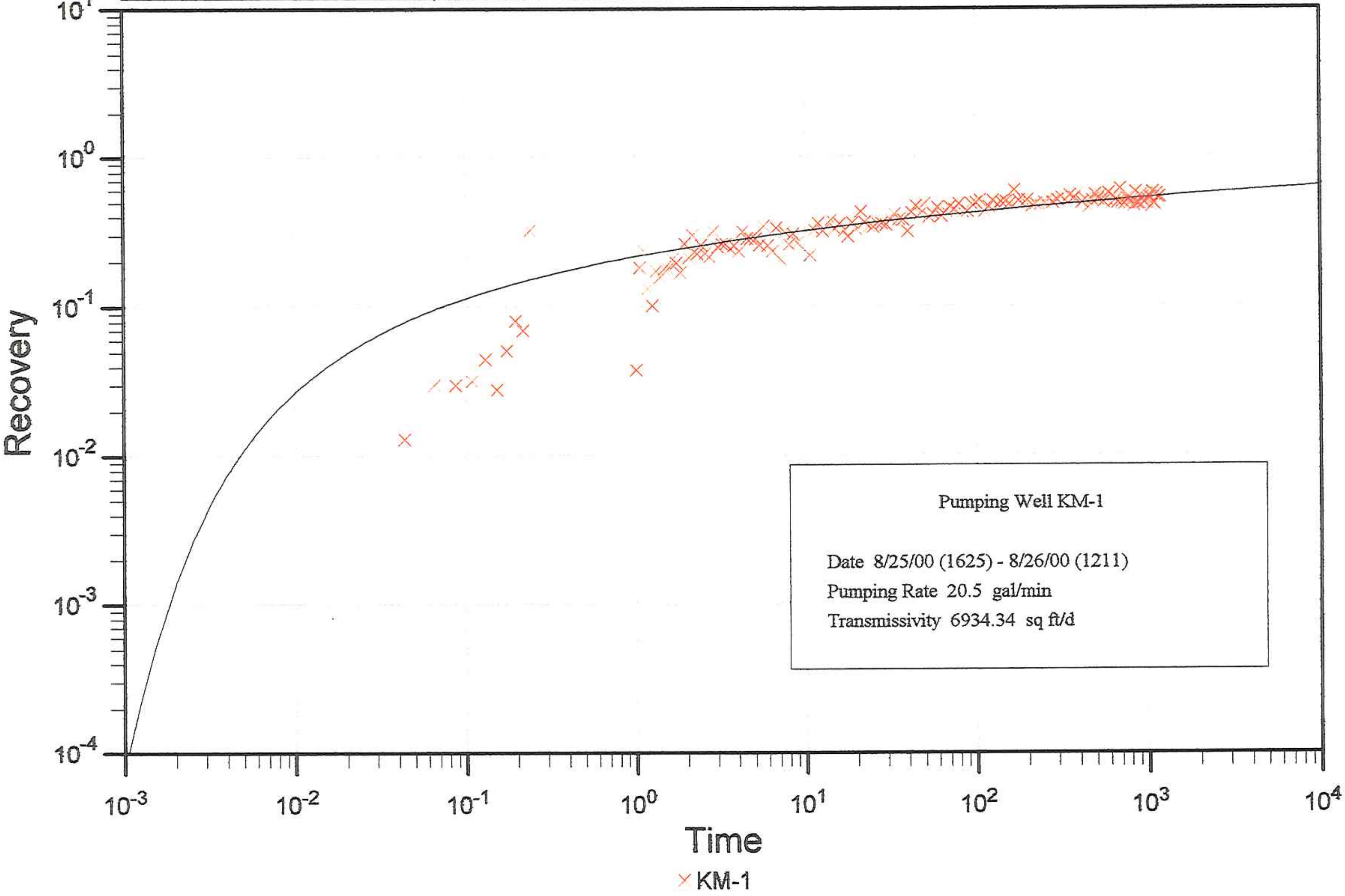
Date 8/25/00 (1625) - 8/26/00 (1211)
Pumping Rate 20.5 gal/min

Well OB-1	Transmissivity	18750.2 sq ft/d
	Storage Coefficient	2.61914
Well TH-3A	Transmissivity	3881.55 sq ft/d
	Storage Coefficient	0.277341
Well TH-8	Transmissivity	4217.01 sq ft/d
	Storage Coefficient	0.166902

consulting
scientists and
engineers

Theis Analysis (Injection Test)

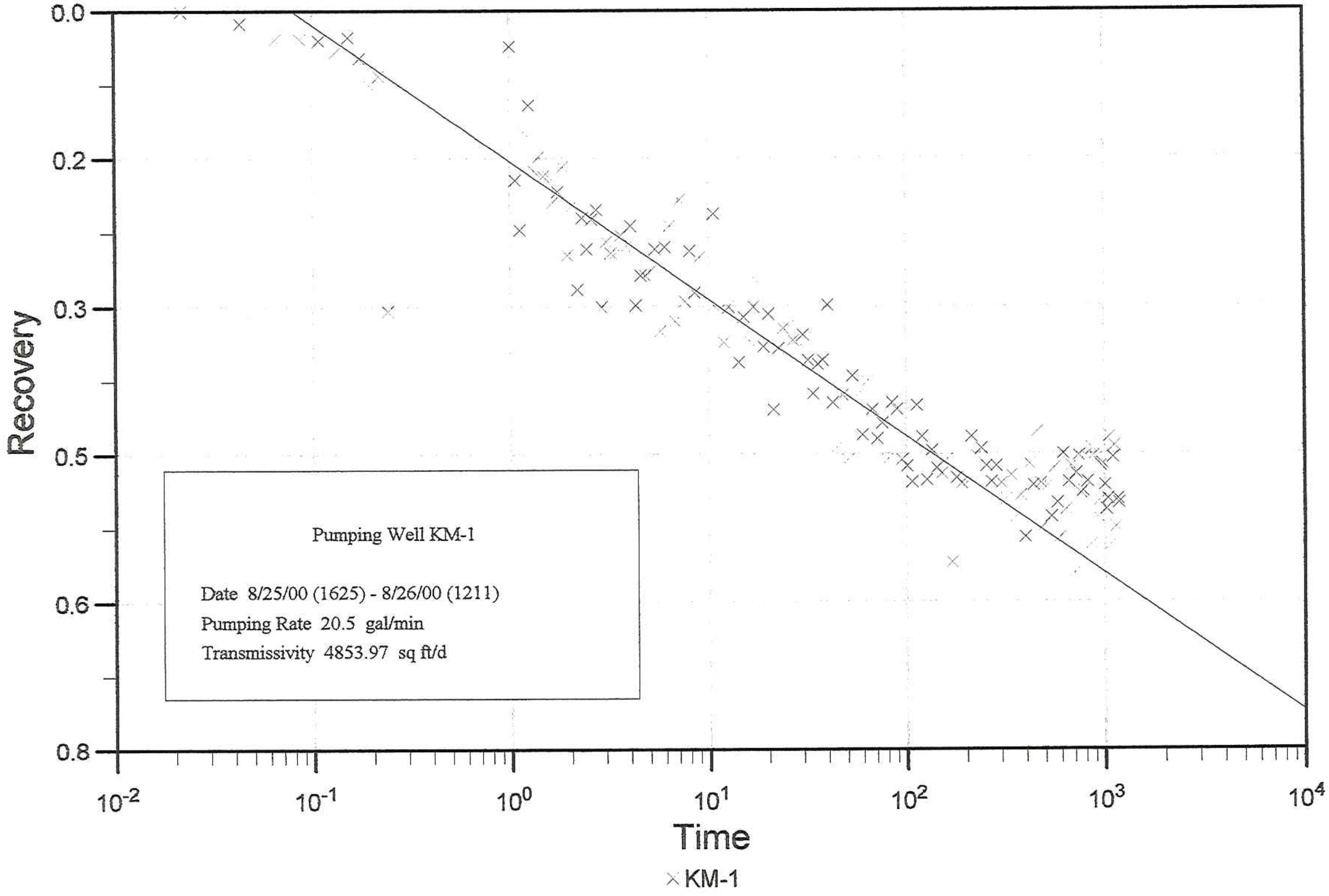
Kaiser Aluminum
Mead Works
Mead, Washington



Pumping Well KM-1

Date 8/25/00 (1625) - 8/26/00 (1211)
Pumping Rate 20.5 gal/min
Transmissivity 6934.34 sq ft/d

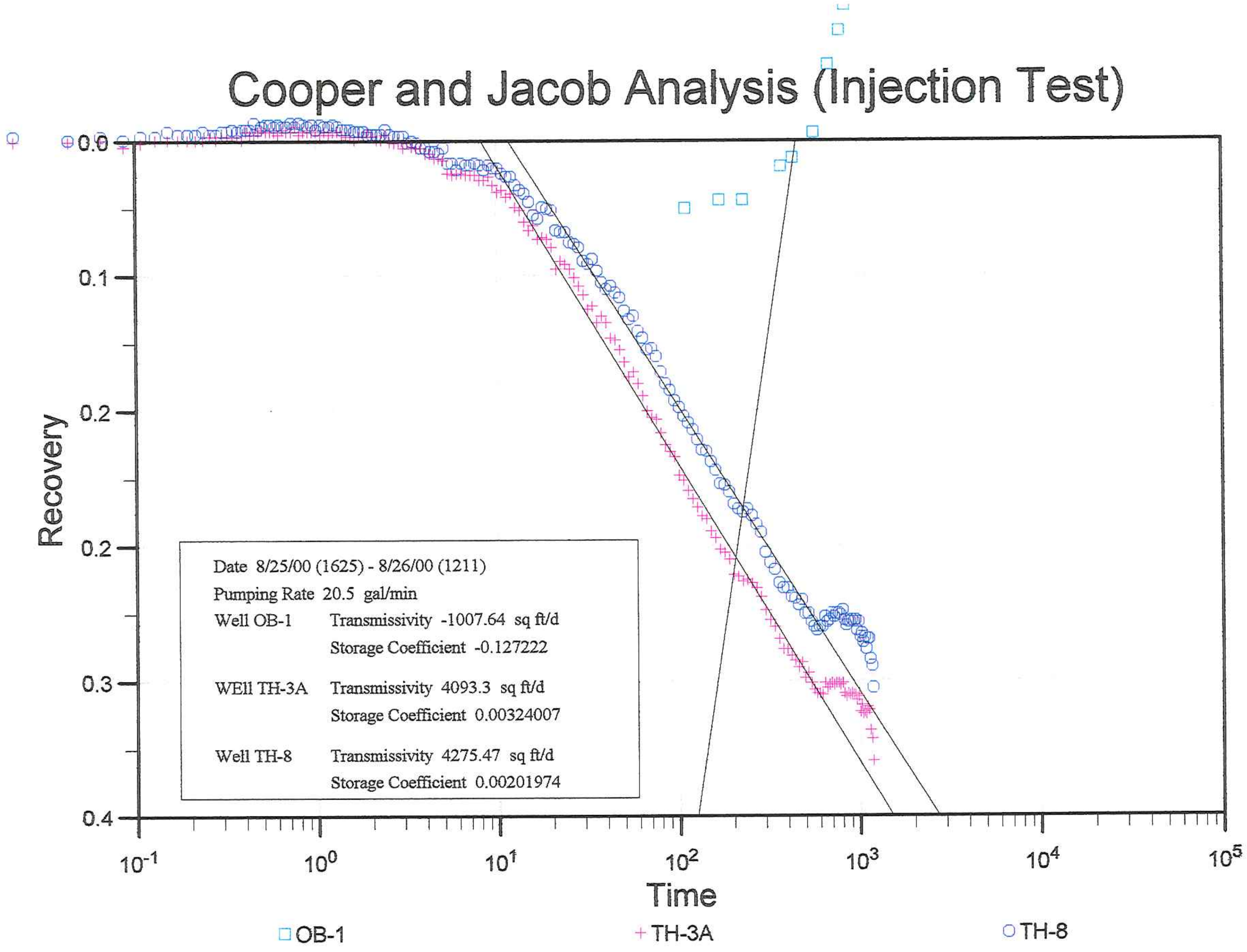
Cooper and Jacob Analysis (Injection Test)



Pumping Well KM-1

Date 8/25/00 (1625) - 8/26/00 (1211)
Pumping Rate 20.5 gal/min
Transmissivity 4853.97 sq ft/d

Cooper and Jacob Analysis (Injection Test)



Date 8/25/00 (1625) - 8/26/00 (1211)
Pumping Rate 20.5 gal/min

Well OB-1	Transmissivity	-1007.64 sq ft/d
	Storage Coefficient	-0.127222
WEll TH-3A	Transmissivity	4093.3 sq ft/d
	Storage Coefficient	0.00324007
Well TH-8	Transmissivity	4275.47 sq ft/d
	Storage Coefficient	0.00201974

ATTACHMENT A-4

Water Quality Data

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503.906.9200 fax 503.906.9210
Bend 20332 Empire Avenue, Suite F-1, Bend, OR 97701-5711
541.383.9310 fax 541.382.7588

McCulley, Frick & Gilman, Inc., Seattle
19203 36th Ave. W 101
Lynnwood, WA 98036

Project: Kaiser Pump Test
Project Number: 020055-6
Project Manager: Doug Frick

Sampled: 11/1/00
Received: 11/1/00
Reported: 11/10/00 16:35

ANALYTICAL REPORT FOR SAMPLES:

Sample Description	Laboratory Sample Number	Sample Matrix	Date Sampled
OB-1	S011008-01	Water	11/1/00

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report must be reproduced in its entirety.

Dennis D Wells, Laboratory Director

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541.383.9310 fax 541.382.7588

McCulley, Frick & Gilman, Inc., Seattle
19203 36th Ave. W 101
Lynnwood, WA 98036

Project: Kaiser Pump Test
Project Number: 020055-6
Project Manager: Doug Frick

Sampled: 11/1/00
Received: 11/1/00
Reported: 11/10/00 16:35

Conventional Chemistry Parameters by APHA/EPA Methods
North Creek Analytical - Spokane

Analyte	Batch Number	Date Prepared	Date Analyzed	Specific Method	Reporting Limit	Result	Units	Notes*
OB-1			**S011008-01**				**Water**	
pH	1100009	11/3/00	11/3/00	EPA 150.1		7.86	pH Units	

North Creek Analytical - Spokane

Refer to end of report for text of notes and definitions.

Dennis D Wells, Laboratory Director

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Bend 20332 Empire Avenue, Suite F-1, Bend, OR 97701-5711
541.383.9310 fax 541.382.7508

McCulley, Frick & Gilman, Inc., Seattle 19203 36th Ave. W 101 Lynnwood, WA 98036	Project: Kaiser Pump Test Project Number: 020055-6 Project Manager: Doug Frick	Sampled: 11/1/00 Received: 11/1/00 Reported: 11/10/00 16:35

Physical Parameters by APHA/ASTM/EPA Methods
North Creek Analytical - Spokane

Analyte	Batch Number	Date Prepared	Date Analyzed	Specific Method	Reporting Limit	Result	Units	Notes*
OB-1			**S011008-01**				**Water**	
Specific Conductivity	1100027	11/7/00	11/7/00	EPA 120.1	1.00	**1030**	uS/cm	

North Creek Analytical - Spokane

**Refer to end of report for text of notes and definitions.*

Dennis D Wells, Laboratory Director

McCulley, Frick & Gilman, Inc., Seattle 19203 36th Ave. W 101 Lynnwood, WA 98036	Project: Kaiser Pump Test Project Number: 020055-6 Project Manager: Doug Frick	Sampled: 11/1/00 Received: 11/1/00 Reported: 11/10/00 16:35

Conventional Chemistry Parameters by APHA/EPA Methods
North Creek Analytical - Bothell

Analyte	Batch Number	Date Prepared	Date Analyzed	Specific Method	Reporting Limit	Result	Units	Notes*
OB-1			**S011008-01**				**Water**	
Total Dissolved Solids	0K10020	11/8/00	11/10/00	EPA 160.1	10	**680**	mg/l	
Cyanide (total)	0K03026	11/6/00	11/6/00	EPA 335.2	0.200	**6.02**	"	
Fluoride	0K08023	11/8/00	11/8/00	EPA 340.2	0.100	**7.05**	"	

North Creek Analytical - Spokane

Refer to end of report for text of notes and definitions.

Dennis D Wells, Laboratory Director

McCulley, Frick & Gilman, Inc., Seattle
19203 36th Ave. W 101
Lynnwood, WA 98036

Project: Kaiser Pump Test
Project Number: 020055-6
Project Manager: Doug Frick

Sampled: 11/1/00
Received: 11/1/00
Reported: 11/10/00 16:35

Conventional Chemistry Parameters by APHA/EPA Methods/Quality Control
North Creek Analytical - Spokane

Analyte	Date Analyzed	Spike Level	Sample Result	QC Result	Units	Reporting Limit Recov. Limits	Recov. %	RPD Limit	RPD %	Notes*
Batch: 1100009	**Date Prepared: 11/3/00**				**Extraction Method: Wet Chem**					
Duplicate	**1100009-DUP1**		**S010092-03**							
pH	11/3/00		7.22	7.26	pH Units			20.0	0.552	

*Refer to end of report for text of notes and definitions.

North Creek Analytical - Spokane

Dennis D Wells, Laboratory Director

McCulley, Frick & Gilman, Inc., Seattle
19203 36th Ave. W 101
Lynnwood, WA 98036

Project: Kaiser Pump Test
Project Number: 020055-6
Project Manager: Doug Frick

Sampled: 11/1/00
Received: 11/1/00
Reported: 11/10/00 16:35

Physical Parameters by APHA/ASTM/EPA Methods/Quality Control
North Creek Analytical - Spokane

Analyte	Date Analyzed	Spike Level	Sample Result	QC Result	Units	Reporting Limit Recov. Limits	Recov. %	RPD Limit	RPD %	Notes*
Batch: 1100027	**Date Prepared: 11/7/00**				**Extraction Method: Wet Chem**					
Blank	**1100027-BLK1**									
Specific Conductivity	11/7/00			ND	uS/cm	1.00				
Duplicate	**1100027-DUP1**		**S010090-05**							
Specific Conductivity	11/7/00		575	570	uS/cm			4.00	0.873	

Refer to end of report for text of notes and definitions.

North Creek Analytical - Spokane

Dennis D Wells, Laboratory Director

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541.383.9310 fax 541.382.7588

McCulley, Frick & Gilman, Inc., Seattle
19203 36th Ave. W 101
Lynnwood, WA 98036

Project: Kaiser Pump Test
Project Number: 020055-6
Project Manager: - Doug Frick

Sampled: 11/1/00
Received: 11/1/00
Reported: 11/10/00 16:35

Conventional Chemistry Parameters by APHA/EPA Methods/Quality Control
North Creek Analytical - Bothell

Analyte	Date Analyzed	Spike Level	Sample Result	QC Result	Units	Reporting Limit Recov. Limits	Recov. %	RPD Limit	RPD %	Notes*
Batch: 0K03026	**Date Prepared: 11/2/00**				**Extraction Method: General Preparation**					
Blank	**0K03026-BLK1**									
Cyanide (total)	11/2/00			ND	mg/l	0.0100				
Blank	**0K03026-BLK3**									
Cyanide (total)	11/6/00			ND	mg/l	0.0100				
LCS	**0K03026-BS1**									
Cyanide (total)	11/2/00	0.0500		0.0502	mg/l	75-125	100			
LCS	**0K03026-BS3**									
Cyanide (total)	11/6/00	0.0500		0.0398	mg/l	75-125	79.6			
Duplicate	**0K03026-DUP1**		**B0J0752-05**							
Cyanide (total)	11/2/00		ND	ND	mg/l			21		
Matrix Spike	**0K03026-MS1**		**B0J0752-05**							
Cyanide (total)	11/2/00	0.0500	ND	0.0513	mg/l	75-125	103			
Batch: 0K08023	**Date Prepared: 11/8/00**				**Extraction Method: General Preparation**					
Blank	**0K08023-BLK1**									
Fluoride	11/8/00			ND	mg/l	0.100				
LCS	**0K08023-BS1**									
Fluoride	11/8/00	2.00		1.88	mg/l	78-113	94.0			
Duplicate	**0K08023-DUP1**		**S011008-01**							
Fluoride	11/8/00		7.05	7.13	mg/l			25	1.13	
Matrix Spike	**0K08023-MS1**		**S011008-01**							
Fluoride	11/8/00	2.00	7.05	8.61	mg/l	75-125	78.0			
Batch: 0K10020	**Date Prepared: 11/8/00**				**Extraction Method: General Preparation**					
Blank	**0K10020-BLK1**									
Total Dissolved Solids	11/10/00			ND	mg/l	10				
Duplicate	**0K10020-DUP1**		**B0K0009-01**							
Total Dissolved Solids	11/10/00		150	150	mg/l			17	0	

Refer to end of report for text of notes and definitions.

North Creek Analytical - Spokane

Dennis D Wells, Laboratory Director

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McCulley, Frick & Gilman, Inc., Seattle 19203 36th Ave. W 101 Lynnwood, WA 98036	Project: Kaiser Pump Test Project Number: 020055-6 Project Manager: - Doug Frick	Sampled: 11/1/00 Received: 11/1/00 Reported: 11/10/00 16:35

Notes and Definitions

#	Note
DET	Analyte DETECTED
ND	Analyte NOT DETECTED at or above the reporting limit
NR	Not Reported
dry	Sample results reported on a dry weight basis
Recov.	Recovery
RPD	Relative Percent Difference

North Creek Analytical - Spokane

Dennis D Wells, Laboratory Director

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20332 Empire Avenue, Suite F-1, Bend, OR 97701-5711 (541) 383-9310 FAX 382-7588

CHAIN OF CUSTODY REPORT

Work Order #: S011008-

CLIENT: MFG
REPORT TO: Doug. Frick
ADDRESS:
PHONE: 425-921-4000
FAX: 425-921-4040
INVOICE TO:
P.O. NUMBER:
PROJECT NAME:
PROJECT NUMBER: 020055-6
SAMPLED BY: SBW

TURNAROUND REQUEST in Business Days*

Organic & Inorganic Analyses: [✓ 10] 7 5 4 3 2 1 <1
STD.

Petroleum Hydrocarbon Analyses: 5 4 3 2 1 <1
STD.

OTHER Please Specify

*Turnaround Requests less than standard may incur Rush Charges.

		REQUESTED ANALYSES															
CLIENT SAMPLE IDENTIFICATION	SAMPLING DATE/TIME	Total cyanide	total fluoride	TDS	pH	conductivity									MATRIX (W, S, O)	# OF CONT.	COMMENTS	NCA WO ID
1. OB-1	11-1-00 1535		X												W	1	unpreserved	1
2. OB-1	1535			X	X	X									W	1	unpreserved	1
3. OB-1	1537	X													W	1	NaOH preserved	1
4.																		
5.																		
6.																		
7.																		
8.																		
9.																		
10.																		
11.																		
12.																		
13.																		
14.																		
15.																		

RELINQUISHED BY: Sean Willi
PRINT NAME: Sean Williams FIRM: MFG DATE: 11-1-00 TIME: 1645
RECEIVED BY:
PRINT NAME: Dennis Dwells FIRM: NCA DATE: 11/1/00 TIME: 16:45

RELINQUISHED BY:
PRINT NAME: FIRM: DATE: TIME:
RECEIVED BY:
PRINT NAME: FIRM: DATE: TIME:

ADDITIONAL REMARKS:

TEMP:

PAGE OF

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503.906.9200 fax 503.906.9210
Bend 20332 Empire Avenue, Suite F-1, Bend, OR 97701-5711
541.383.9310 fax 541.382.7588

McCulley, Frick & Gilman, Inc., Seattle	Project: Kaiser Pump Test	Sampled:	8/23/00 to 8/24/00
19203 36th Ave. W 101	Project Number: 020055-6	Received:	8/24/00
Lynnwood, WA 98036	Project Manager: Deborah Lambert	Reported:	9/7/00 10:22

ANALYTICAL REPORT FOR SAMPLES:

Sample Description	Laboratory Sample Number	Sample Matrix	Date Sampled
KM-1-1	S008090-01	Water	8/23/00
KM-1-2	S008090-02	Water	8/24/00
KM-1-3	S008090-03	Water	8/24/00

North Creek Analytical - Spokane

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report must be reproduced in its entirety.

D. Wells

Dennis D Wells, Laboratory Director

North Creek Analytical, Inc.
Environmental Laboratory Network

McCulley, Frick & Gilman, Inc., Seattle	Project:	Kaiser Pump Test	Sampled:	8/23/00 to 8/24/00
19203 36th Ave. W 101	Project Number:	020055-6	Received:	8/24/00
Lynnwood, WA 98036	Project Manager:	Deborah Lambert	Reported:	9/7/00 10:22

Conventional Chemistry Parameters by APHA/EPA Methods
North Creek Analytical - Bothell

Analyte	Batch Number	Date Prepared	Date Analyzed	Specific Method	Reporting Limit	Result	Units	Notes*
KM-1-1			**S008090-01**				**Water**	
Cyanide (total)	0H28042	8/30/00	8/30/00	EPA 335.2	2.00	**56.4**	mg/l	
Fluoride	0H31019	8/31/00	8/31/00	EPA 340.2	1.00	**57.1**	"	
KM-1-2			**S008090-02**				**Water**	
Cyanide (total)	0H28042	8/30/00	8/30/00	EPA 335.2	2.00	**55.2**	mg/l	
Fluoride	0H31019	8/31/00	8/31/00	EPA 340.2	1.00	**56.7**	"	
KM-1-3			**S008090-03**				**Water**	
Cyanide (total)	0H28042	8/30/00	8/30/00	EPA 335.2	2.00	**57.4**	mg/l	
Fluoride	0H31019	8/31/00	8/31/00	EPA 340.2	1.00	**59.1**	"	

North Creek Analytical - Spokane

**Refer to end of report for text of notes and definitions.*

D Wells

Dennis D Wells, Laboratory Director

McCulley, Frick & Gilman, Inc., Seattle 19203 36th Ave. W 101 Lynnwood, WA 98036	Project: Kaiser Pump Test Project Number: 020055-6 Project Manager: Deborah Lambert	Sampled: 8/23/00 to 8/24/00 Received: 8/24/00 Reported: 9/7/00 10:22

Conventional Chemistry Parameters by APHA/EPA Methods/Quality Control
North Creek Analytical - Bothell

Analyte	Date Analyzed	Spike Level	Sample Result	QC Result	Units	**Reporting Limit** Recov. Limits	Recov. %	RPD Limit	RPD %	Notes*
Batch: 0H28042	**Date Prepared: 8/28/00**				**Extraction Method: General Preparation**					
Blank	**0H28042-BLK1**									
Cyanide (total)	8/28/00			**ND**	mg/l	**0.0100**				
Blank	**0H28042-BLK2**									
Cyanide (total)	8/28/00			**ND**	mg/l	**0.0100**				
Blank	**0H28042-BLK3**									
Cyanide (total)	8/30/00			**ND**	mg/l	**0.0100**				
LCS	**0H28042-BS1**									
Cyanide (total)	8/28/00	0.0500		0.0414	mg/l	75-125	82.8			
LCS	**0H28042-BS2**									
Cyanide (total)	8/28/00	0.0500		0.0388	mg/l	75-125	77.6			
LCS	**0H28042-BS3**									
Cyanide (total)	8/30/00	0.0500		0.0539	mg/l	75-125	108			
Duplicate	**0H28042-DUP1**		**B0H0391-03**							
Cyanide (total)	8/28/00		ND	ND	mg/l			21		
Matrix Spike	**0H28042-MS1**		**B0H0391-03**							
Cyanide (total)	8/28/00	0.0500	ND	0.0497	mg/l	75-125	**99.4**			
Batch: 0H31019	**Date Prepared: 8/31/00**				**Extraction Method: General Preparation**					
Blank	**0H31019-BLK1**									
Fluoride	8/31/00			**ND**	mg/l	**0.100**				
LCS	**0H31019-BS1**									
Fluoride	8/31/00	1.00		0.988	mg/l	78-113	98.8			
Duplicate	**0H31019-DUP1**		**B0H0483-01**							
Fluoride	8/31/00		0.208	0.190	mg/l			25	**9.05**	
Matrix Spike	**0H31019-MS1**		**B0H0483-01**							
Fluoride	8/31/00	1.00	0.208	1.15	mg/l	75-125	**94.2**			

Notes and Definitions

#	Note
DET	Analyte DETECTED
ND	Analyte NOT DETECTED at or above the reporting limit
NR	Not Reported
dry	Sample results reported on a dry weight basis
Recov.	Recovery
RPD	Relative Percent Difference

North Creek Analytical - Spokane

Dennis D Wells, Laboratory Director

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20332 Empire Avenue, Suite F-1, Bend, OR 97701-5711 (541) 383-9310 FAX 382-7588

CHAIN OF CUSTODY REPORT

Work Order #: S008090

CLIENT: KAISER
REPORT TO: Deborah Lambert - MFG, Inc.
ADDRESS: ~~140~~ 19203 36th Ave West Suite 101
Lynwood, WA ~~98103~~ 98036
PHONE: (425) 421-4000 FAX: 425-921-4040

INVOICE TO: MFG
LYNWOOD WA ATTN: DEB LAMBERT
P.O. NUMBER: 020055-6

PROJECT NAME: KAISER PUMP TEST
PROJECT NUMBER: 020055-6
SAMPLED BY: BOB TROUTMAN/STEVE SMITH

TURNAROUND REQUEST in Business Days*
Organic & Inorganic Analyses
~~10~~ 7 5 4 3 2 1 <1
STD.
Petroleum Hydrocarbon Analyses
5 4 3 2 1 <1
STD.
OTHER Please Specify
*Turnaround Requests less than standard may incur Rush Charges.

		REQUESTED ANALYSES																
CLIENT SAMPLE IDENTIFICATION	SAMPLING DATE/TIME	Total Cyanide	Flouride												MATRIX (W, S, O)	# OF CONT.	COMMENTS	NCA WO ID
1. KM-1-1	8/23/00 1640	x	x												W	2		1
2. Km-1-2	8/24/00 00:01	x	x												W	2		2
3. Km-1-3	8/24/00 9:30	x	x												W	2	CALL B. TROUTMAN	3
4. PIPE SMEGMA	8/24/00 1500																IN MISSOULA	4
5.																	IDENTIFY?	
6.																	$CaCO_3$?	
7.																		
8.																		
9.																		
10.																		
11.																		
12.																		
13.																		
14.																		
15.																		

RELINQUISHED BY:
PRINT NAME: BOB TROUTMAN FIRM: MFG DATE: 8/24/00 TIME: 1537
RECEIVED BY: Teresa L. Aramboury
PRINT NAME: Teresa L. Aramboury FIRM: NCA-S DATE: 8-24-0 TIME: 15:3

RELINQUISHED BY:
PRINT NAME: FIRM: DATE: TIME:
RECEIVED BY:
PRINT NAME: FIRM: DATE: TIME:

ADDITIONAL REMARKS: TEMP: PAGE OF

COC REV 3/99

www.ncalabs.com

Seattle 11720 North Creek Pkwy N, Suite 400, Bothell, WA 98011-8223
425.420.9200 fax 425.420.9210
Spokane East 11115 Montgomery, Suite B, Spokane, WA 99206-4776
509.924.9200 fax 509.924.9290
Portland 9405 SW Nimbus Avenue, Beaverton, OR 97008-7132
503.906.9200 fax 503.906.9210
Bend 20332 Empire Avenue, Suite F-1, Bend, OR 97701-5711
541.383.9310 fax 541.382.7588

McCulley, Frick & Gilman, Inc., Seattle
19203 36th Ave. W 101
Lynnwood, WA 98036

Project: Kaiser Pump Test
Project Number: 020055-6
Project Manager: Deborah Lambert

Sampled: 8/25/00
Received: 8/25/00
Reported: 9/12/00 09:42

ANALYTICAL REPORT FOR SAMPLES:

Sample Description	Laboratory Sample Number	Sample Matrix	Date Sampled
KM-1-4	S008096-01	Water	8/25/00
KM-1-5	S008096-02	Water	8/25/00

North Creek Analytical - Spokane

The results in this report apply to the samples analyzed in accordance with the chain of custody document. This analytical report must be reproduced in its entirety.

Dennis D Wells, Laboratory Director

McCulley, Frick & Gilman, Inc., Seattle 19203 36th Ave. W 101 Lynnwood, WA 98036	Project: Kaiser Pump Test Project Number: 020055-6 Project Manager: Deborah Lambert	Sampled: 8/25/00 Received: 8/25/00 Reported: 9/12/00 09:42

Conventional Chemistry Parameters by APHA/EPA Methods
North Creek Analytical - Bothell

Analyte	Batch Number	Date Prepared	Date Analyzed	Specific Method	Reporting Limit	Result	Units	Notes*
KM-1-4			**S008096-01**				**Water**	
Cyanide (total)	0H31040	8/31/00	8/31/00	EPA 335.2	2.00	**58.8**	mg/l	
Fluoride	0H31019	"	"	EPA 340.2	1.00	**61.3**	"	
KM-1-5			**S008096-02**				**Water**	
Cyanide (total)	0H31040	8/31/00	8/31/00	EPA 335.2	2.00	**56.8**	mg/l	
Fluoride	0H31019	"	"	EPA 340.2	1.00	**60.3**	"	

North Creek Analytical - Spokane

Refer to end of report for text of notes and definitions.

Dennis D Wells, Laboratory Director

Conventional Chemistry Parameters by APHA/EPA Methods/Quality Control
North Creek Analytical - Bothell

Analyte	Date Analyzed	Spike Level	Sample Result	QC Result	Units	Reporting Limit Recov. Limits	Recov. %	RPD Limit	RPD %	Notes*
Batch: 0H31019	**Date Prepared: 8/31/00**				**Extraction Method: General Preparation**					
Blank	**0H31019-BLK1**									
Fluoride	8/31/00			**ND**	mg/l	**0.100**				
LCS	**0H31019-BS1**									
Fluoride	8/31/00	1.00		0.988	mg/l	78-113	98.8			
Duplicate	**0H31019-DUP1**		**B0H0483-01**							
Fluoride	8/31/00		0.208	0.190	mg/l			25	**9.05**	
Matrix Spike	**0H31019-MS1**		**B0H0483-01**							
Fluoride	8/31/00	1.00	0.208	1.15	mg/l	75-125	**94.2**			
Batch: 0H31040	**Date Prepared: 8/31/00**				**Extraction Method: General Preparation**					
Blank	**0H31040-BLK1**									
Cyanide (total)	8/31/00			**ND**	mg/l	**0.0100**				
LCS	**0H31040-BS1**									
Cyanide (total)	8/31/00	0.0500		0.0440	mg/l	75-125	88.0			
Duplicate	**0H31040-DUP1**		**B0F0257-07**							
Cyanide (total)	8/31/00		0.800	0.815	mg/l			21	**1.86**	
Matrix Spike	**0H31040-MS1**		**B0F0257-07**							
Cyanide (total)	8/31/00	0.0500	0.800	0.880	mg/l	75-125	**160**			1

North Creek Analytical - Spokane

**Refer to end of report for text of notes and definitions.*

Dennis D Wells, Laboratory Director

McCulley, Frick & Gilman, Inc., Seattle
19203 36th Ave. W 101
Lynnwood, WA 98036

Project: Kaiser Pump Test
Project Number: 020055-6
Project Manager: Deborah Lambert

Sampled: 8/25/00
Received: 8/25/00
Reported: 9/12/00 09:42

Notes and Definitions

#	Note
1	Analyses are not controlled on matrix spike RPD and/or percent recoveries when the sample concentration is significantly higher than the spike level.
DET	Analyte DETECTED
ND	Analyte NOT DETECTED at or above the reporting limit
NR	Not Reported
dry	Sample results reported on a dry weight basis
Recov.	Recovery
RPD	Relative Percent Difference

North Creek Analytical - Spokane

Dennis D Wells, Laboratory Director

S0080916

CHAIN-OF-CUSTODY RECORD AND REQUEST FOR ANALYSIS

McCULLEY, FRICK & GILMAN, INC.

COC NO. 10313

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8900 Business Park Dr.
Austin, TX 78759
TEL: (512) 338-1667
FAX: (512) 338-1331

☐ Boston Office
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Woburn, MA 01801
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FAX: (617) 937-0578

☐ Boulder Office
4840 Pearl E. Circle, Suite 200W
Boulder, CO 80301
TEL: (303) 447-1823
FAX: (303) 447-1836

☐ Missoula Office
215 S. 3rd St. West
Missoula, MO 59801
TEL: (406) 728-4600
FAX: (406) 728-4698

☐ Osburn Office
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☐ ~~Seattle Office~~ ~~19203 S 36th Ave W~~
~~3400 188th St. SW, Ste. 400~~
~~Lynnwood, WA 98037~~ 98036
~~TEL: (206) 778-8252~~
~~FAX: (206) 771-8842~~

PROJECT NO.: 020055-6
PROJECT NAME: KAISER
PAGE: 1 OF: 1
SAMPLER (Signature):
PROJECT MANAGER: Deborah Lambert
DATE: 8/25/00
METHOD OF SHIPMENT: Lab Courier
CARRIER/WAYBILL NO. —
DESTINATION: North Creek Analytical

SAMPLES														ANALYSIS REQUEST										
Lab No.	Field Sample Identification	Sample Collection			Preservation					FILTRATION *	Containers *			Constituents/Methods							Handling			Remarks
		DATE	TIME	Matrix*	HCl	HNO_3	H_2SO_4	COLD	NAOH		VOLUME (ml/oz)	TYPE *	NO.	Flouride	Cyanide						HOLD	RUSH	STANDARD	Report to: Seattle Office
	KM-1-4'	8/25	1220	W				X		U	–	P	1	X									X	19203 36th Ave West Suite K
	KM-1-4	8/25	1220	W				X	X	U	–	P	1		X								X	Lynnwood, WA 98036
	KM-1-5	8/25	1645	W				X		U	–	P	1	X									X	(425) 921-4000 (T)
	KM-1-5	8/25	1645	W				X	X	U	–	P	1		X								X	(425) 921-4040 (F)

TOTAL NUMBER OF CONTAINERS ④

LABORATORY COMMENTS/CONDITION OF SAMPLES

Cooler Temp:

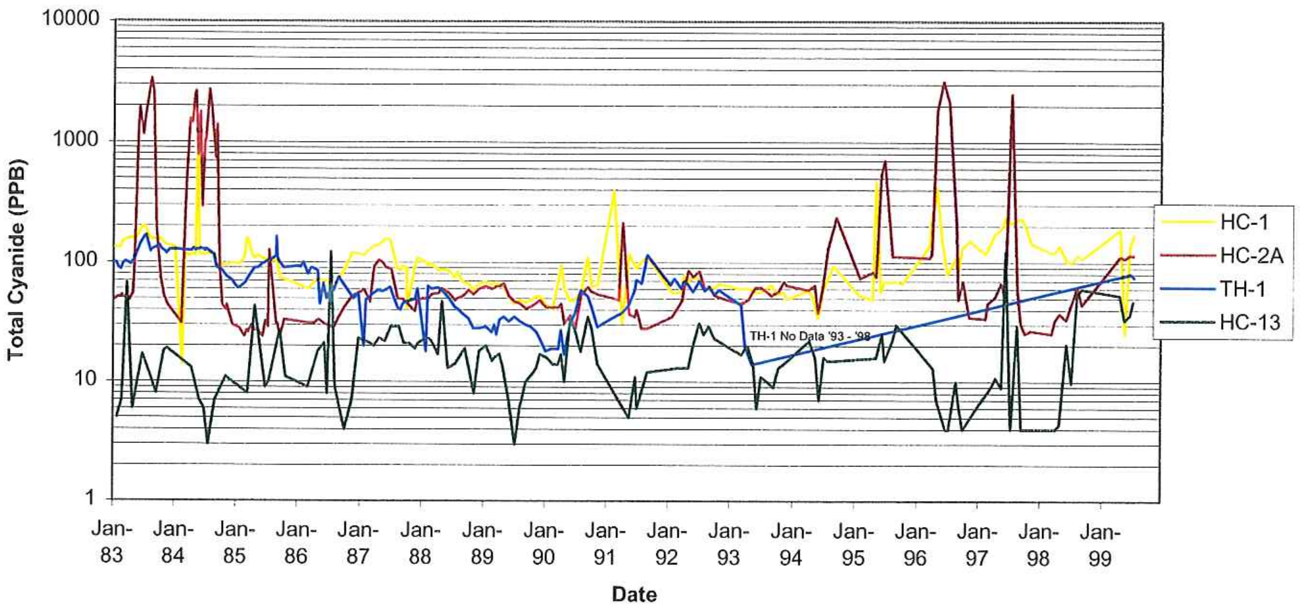
RELINQUISHED BY:			DATE	TIME	RECEIVED BY:		
SIGNATURE	PRINTED NAME	COMPANY			SIGNATURE	PRINTED NAME	COMPANY
	ROBERT TROUTMAN	MFG	8/25/00	5:00pm		Teresa Herambourg	NCA-S
							LABORATORY

* KEY: Matrix AQ-aquaous NA-nonaqueous SO-soil SL-sludge P-petroleum A-air
Containers: G-glass P-plastic T-teflon B-brass OT - other

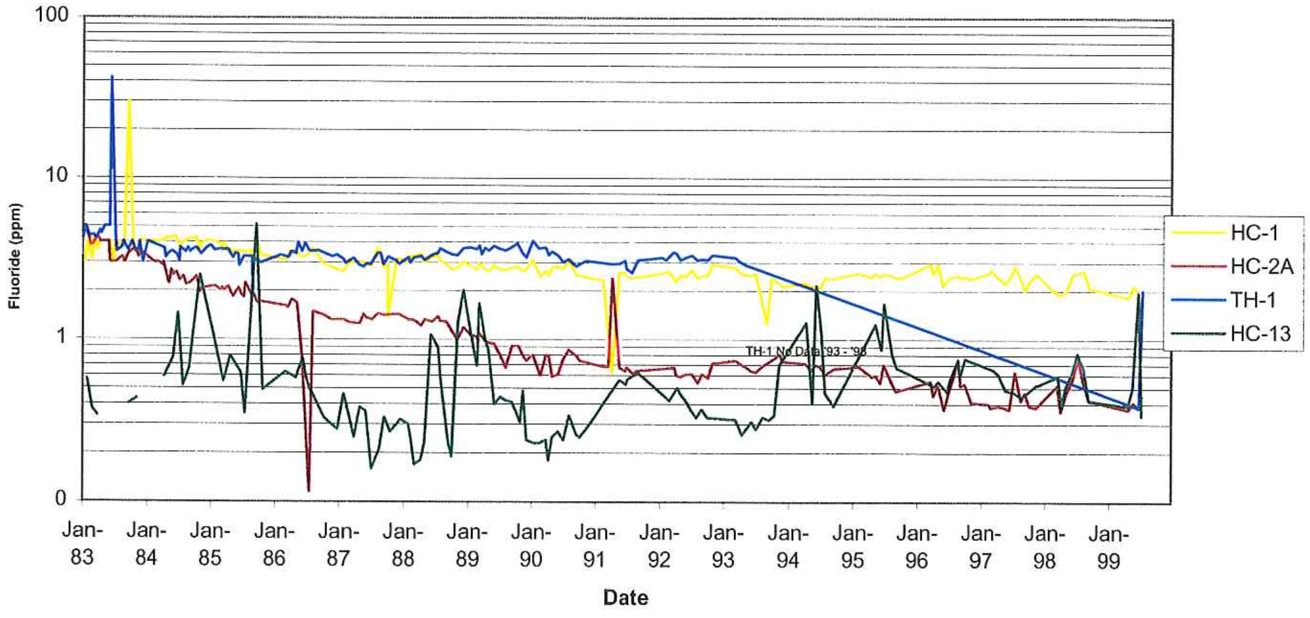
Filtration: F-filtered U-unfiltered

APPENDIX B

GROUNDWATER QUALITY

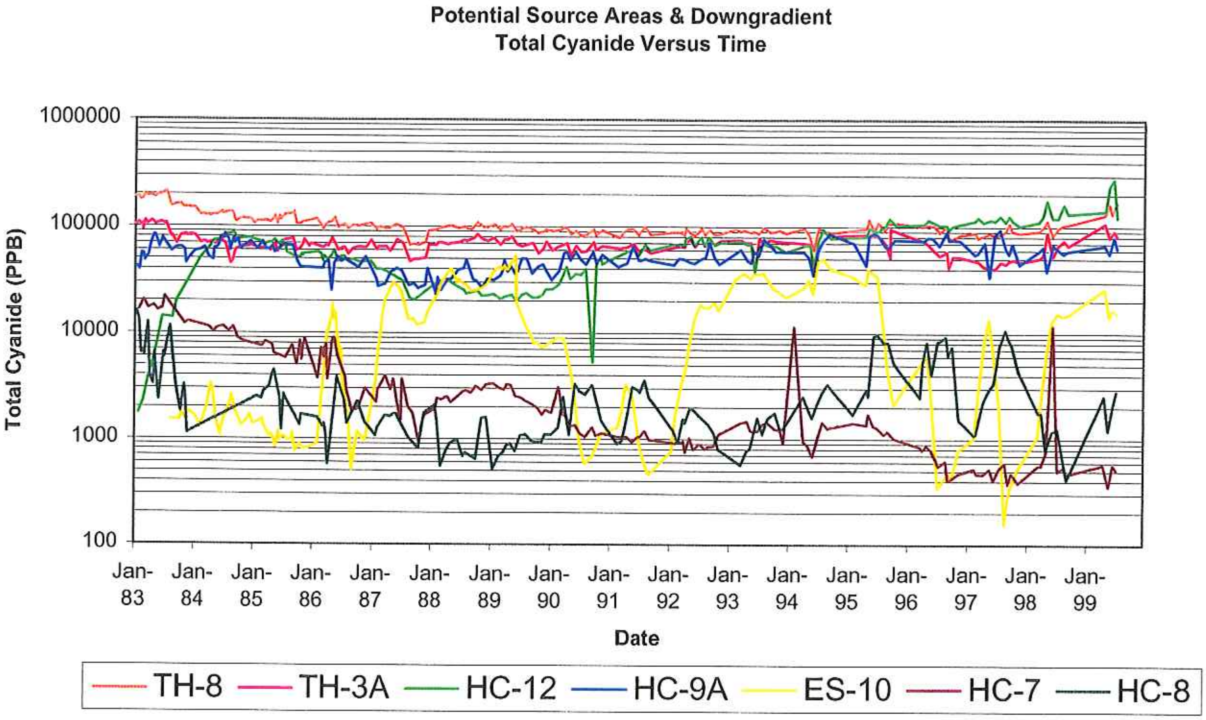


Up Gradient Well History
Total Cyanide Versus Time



Up Gradient Well History
Fluoride Versus Time

Figure B-1


Potential Source Areas & Downgradient
Total Cyanide Versus Time

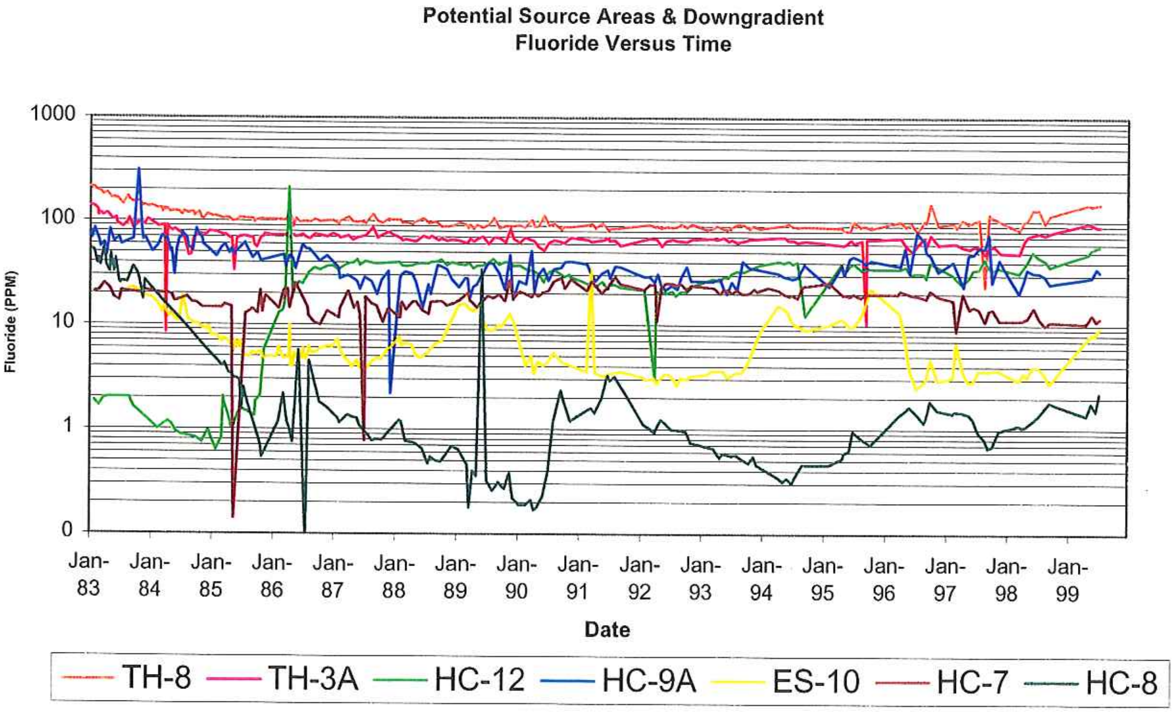
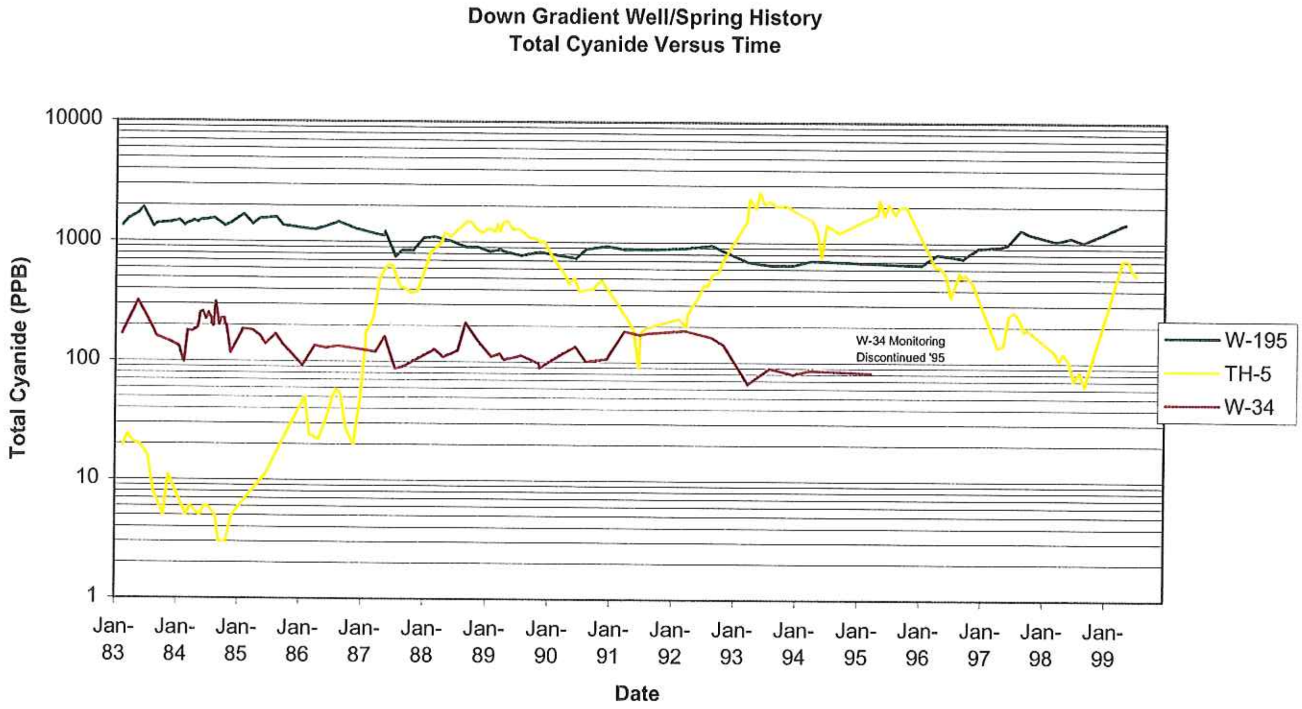

Potential Source Areas & Downgradient
Fluoride Versus Time

Figure B-2


Down Gradient Well/Spring History
Total Cyanide Versus Time
Total Cyanide (PPB)
10000
1000
100
10
1
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Date
W-34 Monitoring Discontinued '95
W-195
TH-5
W-34

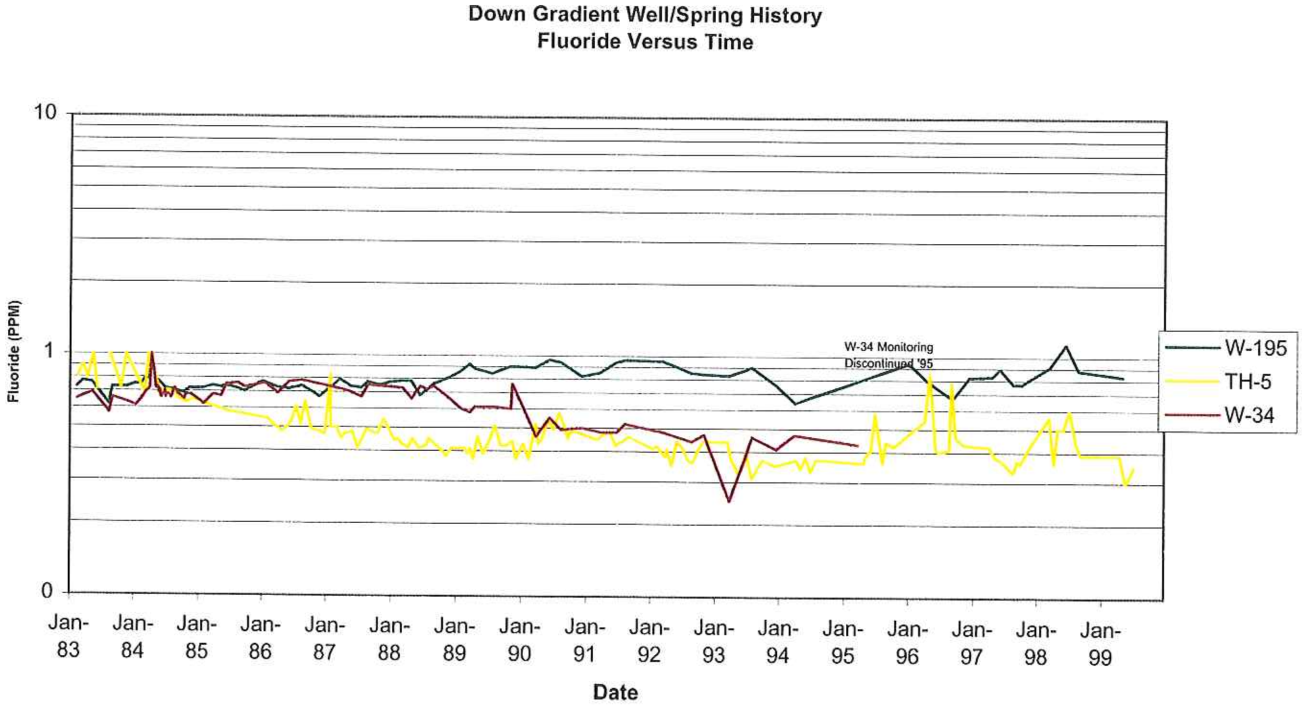
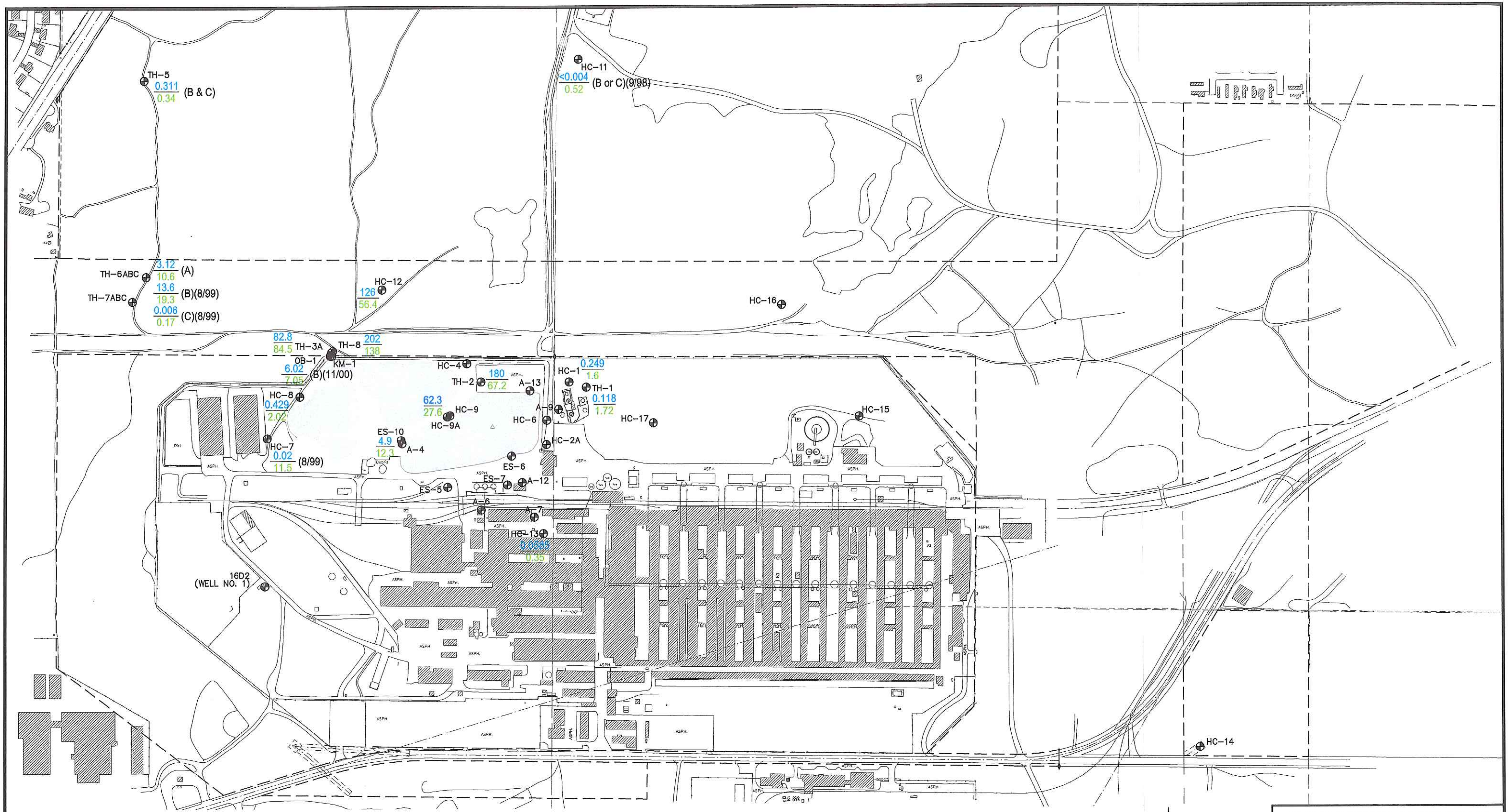

Down Gradient Well/Spring History
Fluoride Versus Time
Fluoride (PPM)
10
1
0
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Date
W-34 Monitoring Discontinued '95
W-195
TH-5
W-34

Figure B-3



EXPLANATION

HC-11⊕ Monitoring Well

▨ Locations of Butt Tailing, Rubble and SPL Piles

3.12 / Total Cyanide (mg/L)
10.6 \ Fluoride (mg/L)

Notes:
The date samples collected on other than September 1999 are provided in "( )". All wells are completed in the A Zone unless otherwise specified.

Source:
Base map taken from Adams & Clark, Inc. Surveyed Map, November 8, 2000.

N

Scale in Feet
0 250 500

KAISER ALUMINUM - MEAD FACILITY

Figure B-4

TOTAL CYANIDE AND FLUORIDE IN GROUNDWATER SAMPLES, SEPTEMBER 1999

PROJECT: 020055	BY: ZGK	REVISIONS
DATE: DEC., 2000	CHECKED: PGP	

MFG, INC.
ENVIRONMENTAL SCIENCES AND ENGINEERING SERVICES