APPENDIX K

Brown and Caldwell, Municipality of Metropolitan Seattle, and TCW Associates, Inc. (1989)

CH2M Hill and Hong West & Associates (1991)

Leon M

Geohydrology Studies of the Metro Section 16 Silvigrow Project

Prepared by

Brown & Caldwell
Municipality of Metropolitan Seattle
TCW Associates, Inc.

March 1989

METRO
Municipality of Metropolitan Seattle
Exchange Building • 821 Second Ave. • Seattle, WA 98104-1598

March 13, 1989

The Honorable Mayor Howard Botts
City of Black Diamond
P.O. Box 599
Black Diamond, WA 98010

Black Diamond Summary Report

Dear Mayor Botts:

Metro and the City of Black Diamond recently agreed that it was in their mutual best interests to work together to develop a Silvigrow project on Metro's recently acquired Section 16 property. Joint studies were to be conducted to determine what effect, if any, the Silvigrow project may have on the City's water supply, the Black Diamond Springs, and to use that information to prepare an effective Silvigrow project plan. Those studies have recently been completed and I am pleased to transmit that report to you with this letter.

The study group also included a representative of the Seattle-King County Department of Public Health (Mr. Dan Moran), the local agency that is responsible for permitting Silvigrow projects. In addition, the Washington State Department of Social and Health Services was kept apprised of study progress and conclusions.

The enclosed reports are the results of this joint study process. The technical analysis was extensive and the hydrogeologists have a high degree of confidence in the study's results and conclusions.

The report conclusions are summarized below.

- The source of the Black Diamond springs has been identified.
- The Black Diamond springs are groundwater.
- There will be no impact on the water quality of the springs from the Silvigrow project.

Attached with this letter is an Executive Summary which goes into slightly more detail and serves as a preface to the detailed reports.

With the successful completion of these studies, Metro will be completing the permit application form to request a permit from the Seattle-King County

Health Department and will be conducting appropriate public and environmental review processes in the next month or so, with the intent of beginning its first Silvigrow application to the Section 16 site in May of this year.

I want to thank you for your patience as these studies were developed. I believe the end result is a very thorough analysis of the waters in the vicinity of the Silvigrow project. This in turn should give everyone a high degree of confidence in the Silvigrow project safety.

I would also like to thank your Director of Public Works, Mr. Keith Olson, for his assistance to the project team. We realize that he is a very busy man on the City's behalf; we appreciate the extra effort it must have taken for him to assist the study team. He was frequently able to provide data and observations that helped the study team analyze this complicated subject.

In addition, Bill Lee was another contributor that we would like to gratefully acknowledge. Bill was frequently able to help the study team cut to the essence of the discussion, thus helping to keep the studies focused and efficient.

The Brown and Caldwell experts, Glen Wyatt, George Mason and Peter Barry, were real team players, willing to tackle the issues with an open, questioning attitude. Their contribution to the study was warmly welcomed.

And lastly, I'd like to recognize the Metro "team" that pulled all this excellent work together. Metro's Silvigrow project planning staff and the consulting firm of TCW Associates, Chen Wang and Dick Bain, took the lead with the study team and provided the continuity necessary to put together such a fine analysis and report.

We look forward to a long and continued good working relationship with the City over the years, now that Metro is a property owner in the neighborhood. Please be sure and let me know when I can be of service.

Sincerely,

John F Spencer

John F. Spencer
Director of Water Pollution Control

JFS/pcl

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Executive Summary

EXECUTIVE SUMMARY

Source of Black Diamond Springs

- The source of the Black Diamond springs has been defined as groundwater fed by an extensive recharge area that covers many square miles east of the springs.
- This groundwater originates as precipitation which enters the aquifer via lakes or infiltration.
- The main recharge source for the Black Diamond Springs appears to be water infiltrating from Hyde and Deep Lakes. Recharge may also be occurring from Fish Lake.
- The Metro Silvigrow projects would occur on little more than one square mile, little of which overlaps the Black Diamond Springs recharge area.

Water Quality

- Water quality of the Springs is very good and has remained unchanged for 25 years.
- This study also included analysis of surface and groundwaters in the area and found them to be of good quality.

No Significant Effects of Silvigrow

- To illustrate the relative risk/safety of the Silvigrow project, the study team developed a "worst case" scenario that was actually beyond the realm of possibilities.
- In this scenario, the team consulted with University of Washington researchers and concluded that nitrogen, which transforms over time to nitrate, was the Silvigrow constituent that could most easily leave the project area and enter groundwater.
- The study team therefore said "what if all the nitrogen in Silvigrow directly entered the aquifer as nitrate?" They concluded that even in such an unrealistic situation, the impact of Silvigrow would be insignificant.
- This drop in the ocean analogy gave the study team the confidence to recommend that the Silvigrow project is safely designed and will not impact water quality.
- In addition, this study showed that the Silvigrow application area is underlain by a layer of glacial till.
- This relatively non-porous material may function as a restrictive layer under the Silvigrow project. It is impossible to prove that the till is continuous, but the till can be thought of as providing an extra margin of safety.

Follow Up Water Quality Monitoring

- A water quality monitoring plan was also designed to sample a number of wells, springs, and the Green River.
- The plan includes sampling points proposed for technical reasons as well as those which will ensure community peace of mind.

The conclusions of the study are that the Silvigrow project is safe and that the corresponding water quality monitoring program has been designed to watch for any unexpected changes as early as possible. Black Diamond water quality will not be affected by Metro's Silvigrow program.

TCW Analysis

TCW CONSULTING ENGINEERS

426 Second Avenue West, Seattle, Washington 98119 (206) 284-4343

SUMMARY AND CONCLUSIONS
SECTION 16 COOPERATIVE GEOHYDROLOGY MEETINGS

The following paragraphs summarize and offer conclusions relative to information gathered on planned Silvigrow applications on 785 acres in Sections 16 and 20 (T21N R7E) north and west of the town of Cumberland. Meetings were held on December 1, 1988 and January 17, February 3 and February 17, 1989 which served as a forum for information exchange and for formulation of technically based explanations of the source of major springs along the Green River Gorge, including springs used for public water supply by the City of Black Diamond.

Persons attending the referenced meetings are identified below:

Pete Machno, Suzanne Schweitzer, Peggy Leonard, Roberta King, Mollie Bigger (Metro Sludge Program Staff)

Keith Olson (City of Black Diamond)

Bill Lee, W.H. Lee Associates, Inc. (consultant to the City of Black Diamond)

Chen Wang and Dick Bain (TCW Associates, consultants to Metro)

Glen Wyatt, George Mason, Peter Barry (Brown and Caldwell, consultants to City of Black Diamond)

Dan Moran, King County Department of Public Health

Most of these individuals were present at all meetings. Minutes of the December meeting and various handouts (such as maps, well logs, geological cross sections and water quality data) provided to the group are attached for reference. The attachments also include a write-up on hydrogeology of the Black Diamond Springs prepared by Brown and Caldwell which synthesizes technical information gathered for this study.

SUMMARY

Metro sponsored a drilling program to discover whether a glacial till layer existed under the proposed application site. See Figure 1, Vicinity Map, attached. Nine borings were successfully completed. Evaluation of subsurface materials brought up by the driller were evaluated by Chen Wang of TCW. Till was encountered in eight of the nine holes all of which were in Section 16 or 20. See boring logs attached. Test hole B3 in the southwestern quadrant of Section 17 was drilled to a depth of 44 feet; this boring revealed no till whereas the other borings encountered till at depths of 12 to 38 feet. Boring B3 is located near the Green River west of the proposed application area. Boring B1 was extended through the till layer to bedrock; the till layer encountered was about five feet thick. Test hole B1 was cased and set up as a monitoring well. Water samples were subsequently obtained by Brown and Caldwell. All of the borings except B1 were backfilled and sealed after drilling was completed.

Water quality testing was performed on the sample taken from Test Hole B1 and 23 other samples collected by Brown and Caldwell. These included samples from numerous wells and springs in the area as well as for Deep Lake, Fish Lake and the Green River. See attached map and water quality data summaries. Samples were for four anions (Cl, S04, HC03, NO3) four cations (Ca, Mg, Na, K), total dissolved solids (TDS), specific conductance (Sc) and pH. Total cations and total anions were computed (millequivalents/liter) and the percentage error in the cation-anion balance was determined. Characteristics of each sample were determined as percentages of individual cations or anions or combinations (e.g., Na+K, Cl+NO3). This evaluation effort indicated that the waters sampled were generally dominated by calcium bicarbonate with the exception of a sample taken from a stream at Palmer Coking Coal that was notably high in sodium and higher in chloride than the other samples. Similar findings were reported from an analysis of nine well, spring and river samples gathered in June, 1988.

Previous evaluations of the aquifer in this area (Cumberland Aquifer) by Robinson and Noble (1972) have concluded that all of the runoff from the mountains east of the aquifer passes through it as groundwater under flow. Deep Creek and Coal Creek were identified as major contributors to the aquifer. It should be noted that Deep Creek flows into Deep Lake and Coal Creek flows into Fish Lake; neither lake has a surface outlet. Groundwater from the Cumberland Aquifer discharges into the Green River gorge through extensive springs. Robinson and Noble estimated aquifer production at 15,000 gpm (33 cfs).

Hydrology of the area was evaluated by Brown and Caldwell and TCW considering precipitation, stream flows, spring flows and Deep Lake/Fish Lake percolation. Precipitation in the area is highly variable with highest levels in the upper elevations. Average precipitation at Black Diamond is approximately 55 inches per year. Storm isopluvials prepared for King County show precipitation rates are generally 50 percent higher at higher elevations in the watershed east of Deep Lake. NOAA data from a gauge at Palmer east of Black Diamond showed a 30 year average of 92 inches. Evaporation losses in the area are estimated to be 25 inches per year, mainly May through October.

Stream flow records were obtained from the U.S. Geological Survey including available local data from the Green River near Palmer, Deep Creek and Icy Creek. Deep Creek has a watershed area of approximately 4.7 square miles upstream of Deep Lake. Although stream flow records (other than peak flows) are not available for this creek there are USGS stream flow records for other creeks and rivers in the vicinity. Using straight line proportioning and a typical unit flow factor of 6.65 cfs per square mile the average annual flow in Deep Creek is estimated to be 26.6 cfs.1 Coal Creek which discharges to Fish Lake from a larger watershed (13.7) square miles) would be expected to have a proportionately higher flow (77.4 cfs) on the same basis. Actual measurements of these creeks on February 17, 1989 could account for lower than average flows. Water levels are known to fluctuate in Fish Lake reflecting seasonal differences in Coal Creek flows and evaporation.

Brown and Caldwell estimates that approximately 60 percent of the watershed area of these creeks is not underlain by glacial till whereas the lower lying plateau has a till layer which is apparently penetrated by Deep and Fish Lakes. Deep Lake (area 37 acres, volume 1,200 acre/feet) averages 33 feet deep with a maximum of 74 feet; Fish Lake (area 18 acres, volume 240 acre/feet) is shallower averaging 13 feet with a maximum depth of 24 feet. Clearly both Deep Lake and Fish Lake discharge through percolation into the coarse gravelly material below the till layer. There may also be some contribution from Hyde Lake.

Precipitation over area considered tributary to the Cumberland Aquifer by Brown and Caldwell geologists would account for flows significantly greater than the 33 cfs reported by Robinson and Noble. Based on precipitation and stream flow records and watershed characteristics, Brown and Caldwell estimates Deep Creek/Coal Creek could generate a median annual flow of about 100 cfs. However, recognizing that a somewhat larger watershed may be contributing to the aquifer (Brown and Caldwell estimates the contributing area may encompass 25 square miles) the precipitation/watershed runoff based flow estimate cited above may be increased to 140 cfs. This stream

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1 Annual flows and watershed areas for gaging stations on the Upper Puyallup River, South Prairie Creek, Carbon River, Rex River and Taylor Creek were used to obtain the 5.65 cfs/square mile factor.

flow-based estimate of overage conditions was modified downward to 120 cfs to account for evaporative losses from the lakes, transpiration losses from riparian areas, etc.

Water quality implications of sludge applications to forest land are better understood because of research experiments and large scale demonstrations carried out by the University of Washington College of Forestry. Nitrate leaching is the major concern; however, nitrate can be controlled by vegetative uptake and immobilization of unmineralized nitrogen forms through management practices (e.g., application techniques, site design, loading rates and attention to seasonal factors). Research to date has shown metals do not leach downward in significant quantities from sludge applications because of strong interactions with soil and because they are slowly released from the sludge matrix. Decomposition and absorption reactions also lower the risk of organic compounds leaching to groundwater. Pathogens are controlled by the filtering action of soils; direct runoff from application areas is controlled through use of buffers and attention to best management practices.

CONCLUSIONS

Based on information summarized above and Silvigrow application plans, the following conclusions are offered:

1. The Cumberland Aquifer is recharged by precipitation in the upper portion of Deep Creek and Coal Creek watersheds and percolation of runoff reaching Deep Lake, Fish Lake and possibly Hyde Lake.

2. Aquifer production estimates made by Robinson and Noble (33 cfs) are probably conservative since this is an estimate of safe yield that must account for occasional drought years. Groundwater flows entering the Green River Gorge as spring flow probably exceed this production estimate most of the time. A median flow of 120 cfs was computed based on precipitation and local watershed runoff records.

3. Silvigrow operations are planned for 160-acre blocks beginning in Section 20 in areas which are underlain by glacial till based on available drilling and geologic records. Silvigrow applications are designed to meet vegetative uptake requirements of Douglas fir/hemlock forests growing on the site.

4. Precipitation over Silvigrow application areas which percolates into the soil may be utilized by trees or form perched water bodies for subsequent utilization or drain

over the till layer to emerge as seepage in the Green River Gorge.

5. Should any water percolate through the till layer under a Silvigrow application area into the Cumberland Aquifer, the diluting capability of groundwater flows would be expected to maintain water quality at present high quality without impairment of beneficial use. This conclusion takes into account the relative size of the contributing watershed flows, soil absorption characteristics and the Silvigrow application itself which is designed to match forest nutrient needs.

Recommended Water Quality Monitoring Plan

SECTION 16 WATER QUALITY MONITORING PLAN

The water quality monitoring plan for Section 16 and Section 20 near the town of Cumberland has been developed from an understanding of the surrounding area hydrogeology. The technical basis for the plan is contained in the Brown and Caldwell report on hydrogeology of the Black Diamond Springs which summarizes available information on the Cumberland Aquifer, the contributing watershed area and local streams and lakes which recharge the aquifer. This report provides the best available information on groundwater flow directions under the proposed Silvigrow application area.

A four-faceted monitoring program is proposed involving the following kinds of sampling areas:

1. Green River upstream and downstream of the site.

2. Major springs discharging to the Green River Gorge.

3. Deep (Cumberland Aquifer) groundwater below till.

4. Vadose zone (unsaturated soil) beneath Silvigrow sites.

Locations of sampling wells, springs, and river stations are shown on Figure 1 attached. Additional details are listed below:

1. The Green River will be sampled at three locations, including areas upstream and downstream of the project area. These locations include the Green River near Palmer, the river at the Gorge Resort, and the river at the City of Black Diamond footbridge.

2. Four major springs discharging to the Green River Gorge will be sampled including the City of Black Diamond Springs, a spring on Palmer Coking Coal property, a spring near the Green River Gorge Resort, and a spring north of Section 16 near the Kanaskat-Palmer State Park (assuming the park spring is accessible).

3. Seven monitoring wells will be sampled to gather water quality data on the aquifer. In addition to the existing well in Section 20, four more monitoring wells are to be drilled in Sections 16 and 20. Two existing wells will be sampled, one in the Hyde Lake area and a control well upgradient of the Silvigrow area. See Figure 1.

4. Up to 35 lysimeters will be placed within the Silvigrow application area to serve as an early warning system to detect if nitrate leaching is occurring.

Water quality parameters to be measured will be similar to Metro's past monitoring efforts and will emphasize nitrates and metals. Surface water samples (e.g., Green River) will also include bacterial indices. Parameters to be monitored routinely are identified in Table 1. All routine monitoring samples are to be collected on a quarterly basis as a minimum for at least the first year. Sampling frequency and parameters will be reevaluated periodically. Background sampling will include at least two replicated samples collected prior to Silvigrow applications. A list of monitoring stations is also provided in Table 1.

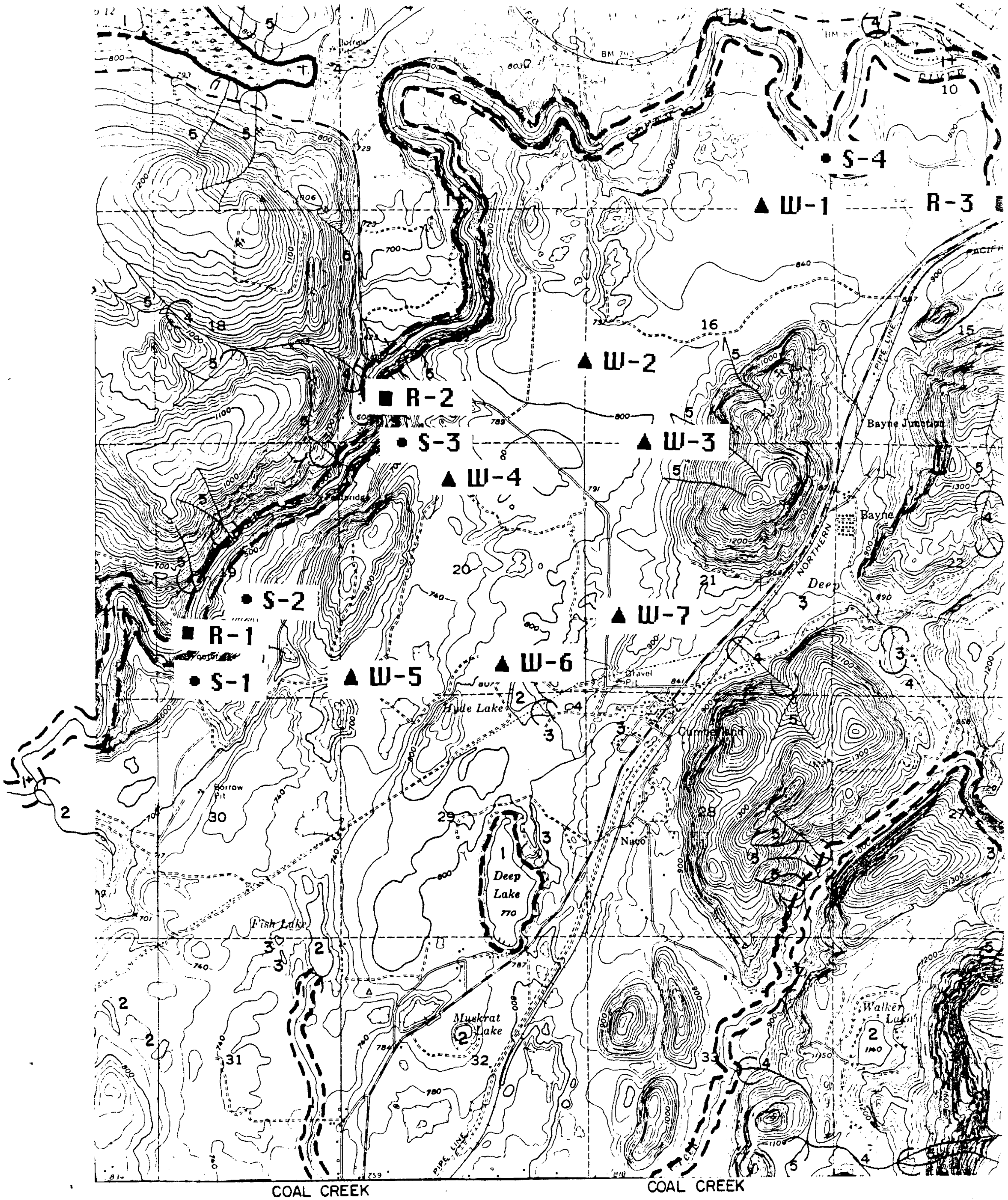
Table 1.

WATER QUALITY MONITORING - SECTION 16

	Stations	Parameters	Frequency
Surface Water			
Green River	R-1 Blk. Dmd. footbridge R-2 Gorge Resort R-3 Palmer	Fecal coliform Enterococcus Nitrate-Nitrite-N Ammonia-N Metals pH T°	Quarterly
Groundwater			
Springs	S-1 Blk. Dmd. springs S-2 Palmer Coking Coal spring S-3 Gorge spring S-4 Palmer-Kanaskat spring	Same as above	Quarterly
Wells	W-1 W-2 W-3 W-4 W-5 W-6 W-7	Depth to water Nitrate-Nitrite-N Ammonia-N pH T° Conductivity Metals	Quarterly
Lysimeters	35 - locations to be determined	Nitrate-Nitrite-N Ammonia-N Chloride Conductivity pH T°	Monthly during wet season (Nov. thru Apr.)

In addition, all drinking water supplies will be given a twice-yearly standard drinking water analysis by a certified lab.

All monitoring to be reassessed and fine-tuned periodically.



■ River

● Springs

▲ Wells

SECTION 16
MONITORING STATIONS

Figure 1.

Brown and Caldwell Analysis

BROWN AND CALDWELL
CONSULTING ENGINEERS

March 15, 1989

Mr. Howard Botts
Mayor
City of Black Diamond
25510 Lawson Street
Black Diamond, Washington 98010

14-4261-12

Subject: Hydrogeology of Black Diamond Springs

Dear Mr. Botts:

Brown and Caldwell is pleased to present our subject report on the hydrogeology of the Black Diamond springs. This report was prepared by Glen Wyatt, project manager, and Peter Barry, project geologist. The report was reviewed by Keith Olson, the Director of Public Works for the City of Black Diamond, Mr. William H. Lee, consultant to the City, George Mason of our staff, Metro's personel for their Silvigrow application project in the area near the springs (Pete Machno, Suzanne Schweitzer, Peggy Leonard, Roberta King) and Metro's consultants (Chen Wang and Dick Bain, of TCW Associates, Inc.).

We appreciate the opportunity to work with you and Keith during the project. If you have any questions on the information we have provided, please call Glen Wyatt.

Very truly yours,

BROWN AND CALDWELL

Glen M. Wyatt, for

Jack Warburton
Vice President

100 WEST HARRISON STREET SEATTLE, WASHINGTON 98119-4186 • (206) 281-4000 • FAX: (206) 283-5560

HYDROGEOLOGY OF BLACK DIAMOND SPRINGS

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CHAPTER 1

INTRODUCTION

Three springs south of the Green River in the south half of section 19, township 21 north (T21N), range 7 east (R7E) (Figure 1-1) supply the City of Black Diamond (City) with its water. Metro, the Municipality of Metropolitan Seattle, plans to utilize section 20, east of section 19, and section 16, northeast of section 20, for land application of municipal sewage sludge as part of Metro's Silvigrow program. This report summarizes the work performed by Brown and Caldwell for the City to identify the source of the springs, to characterize the quality of water discharged by the springs, and to determine if the land application of sludge will affect the springs.

SCOPE OF WORK

Background information on the hydrogeology of the area was obtained through a literature search and by contacting the U.S. Geological Survey and the Washington Departments of Ecology and Natural Resources. Well logs were obtained from the Department of Ecology for sections 20, 21, and 28 through 32 in T21N, R7E. No wells are recorded in sections 16, 17, 19, and 30. The well logs were reviewed to provide additional information on the groundwater conditions in the vicinity of the springs.

Field work was performed in November and December 1988. Field work included a reconnaissance of the local geology in the vicinity of Sections 16 through 21 near the springs and the adjacent sections where Metro plans to apply sludge. Two samples of Black Diamond spring water were obtained and analyzed for major constituents [calcium, magnesium, sodium, potassium, chloride, sulfate, bicarbonate, carbonate, nitrate, iron, manganese, total dissolved solids, pH, temperature, and specific conductance (SC)], coliform, and other parameters regulated by the Safe Drinking Water Act.

Additional well, spring, and surface water samples were obtained by Metro, their consultant (TCW Associates, Inc.), and Brown and Caldwell. These samples were analyzed for major constituents, coliform, pH, SC, and field temperature.

In addition to our field work, Brown and Caldwell inspected exploratory drilling by Metro and assisted with the installation, development, sampling, and aquifer testing of one monitoring well. TCW Associates, Inc., and Pacific Testing Laboratories supervised the drilling program The monitoring well is located approximately on the boundary between sections 19 and 20, about one-half mile east of the Black Diamond springs. A 4-inch diameter well was installed to a depth of approximately 100 feet. Following development of the well and installation of a pump by Metro, a slug-withdrawal aquifer test was conducted. A pumping test was not performed because of the low yield of the well (approximately 0.25 gallons per minute). A sample of the well water was analyzed for major constituents, pH, SC, coliform, and field temperature.

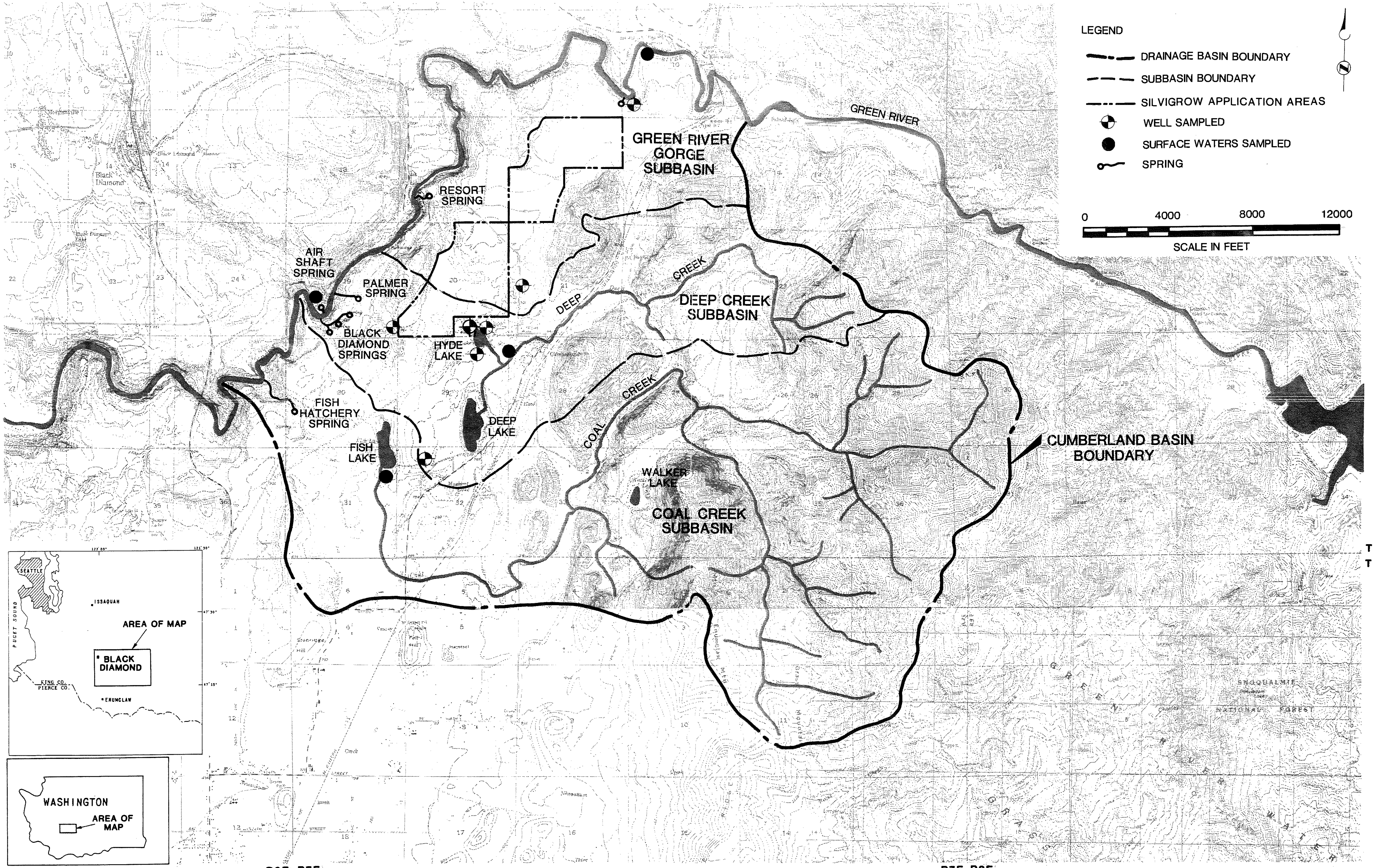


Figure 1-1 Study Area Map

STRATIGRAPHY

Rocks exposed in the Cumberland basin consist of the Eocene to early Oligocene Puget Group (Tp on Figure 2-1); unnamed early Oligocene volcaniclastic rocks (Tu); Tertiary andesitic intrusive rocks (Ti); and Quaternary glacial till (Qg) and terrace gravel and stratified drift (Qt) of the Vashon Drift. Unconsolidated alluvium (Qal) is present in the beds of the Green River and Coal Creek. Landslide debris (Ql) are also locally present in and adjacent to the Cumberland basin. The lithologies of these units from Vine (1969) and water-bearing properties from Luzier (1969) are summarized below:

Alluvium: fluvial sand and gravel, up to 600 feet thick in major river valleys. Flood plain and fan deposits of major rivers are significant aquifers.

Landslide debris: large landslides characterized by breakaway scarps, slump blocks, distorted bedding, and hummocky topography; up to 80 feet thick. Occurs in the unnamed volcanics, glacial drift, and Puget Group. Not a major source of groundwater because of low permeability.

Terrace gravel and stratified drift: Up to 300 feet of recessional and ice-contact sand and gravel deposited by and during the migration of the ancestral Green River along the front of the Vashon glacier. Major springs (1,000 to over 20,000 gallons per minute) discharge from recessional outwash and ice-contact deposits. May contain perched aquifers.

Glacial till: ground moraine consisting of compacted gray silty clay mixed with boulders and sand, generally 5 to 15 feet thick and up to 80 feet thick. Some shallow domestic wells (30 feet deep or less) in King County produce small amounts of water from till. Very low permeability, as shown by presence of peat bogs, swamps, and lakes; may be a confining or perching layer.

Intrusive rock: sills consisting of porphyritic andesite generally intruded into the Puget Group. Groundwater movement along joints and faults, but not a major source of water.

Unnamed volcanic rocks: continental andesitic tuff-breccia, tuff, volcanic sandstone and siltstone, interstratified with and conformably overlying the Puget Group. Groundwater movement along joints and faults. Not a major source of water.

Puget Group: continental arkosic and feldspathic micaceous sandstone, siltstone, claystone, and coal, at least 6,000 feet thick in the Green River area. Oligocene coal beds are present in the Kummer coal zone in the upper 1,400 feet of the unit. The Franklin coal zone is present from 1,400 to 4,500 feet from the top of the Puget Group, and includes the McKay and Gem beds at 3,350 and 2,600 feet below the top of the unit. Not a major source of water; groundwater movement along joints, faults, and bedding planes.

Information from Brown and Caldwell's well inventory and a previous well inventory for Metro's Silvigrow program by TCW Associates, Inc., are included in Appendix A. Appendix B contains data from Metro's drilling program and our slug test data. Laboratory analytical reports are in Appendix C.

During the project, Brown and Caldwell personnel met periodically with Metro and City personnel to discuss this project and Metro's work in sections 16 and 20. Meetings were held on December 1, 1988 and January 17, February 3, February 17, and March 3, 1989.

CHAPTER 2

DRAINAGE BASIN DESCRIPTION

To assist with identification of possible recharge sources to the springs, the drainage basin containing the Black Diamond springs was defined on the basis of topography. The Black Diamond springs are within a 25-square mile drainage basin which centers on the town of Cumberland in King County (Figure 1-1), and will be referred to as the Cumberland basin in this report. The City of Black Diamond (City) is located two to three miles west of the Green River, which forms the western and northern boundary of the drainage basin.

The remainder of the basin is bounded by a drainage divide which extends along the tops of ridges and hills throughout much of its length. We have assumed the surface water and groundwater boundaries of the basin are coincident, as drainage divides are usually groundwater boundaries (Toth, 1963). A small amount of groundwater may locally pass under the divide because of geologic structure or buried erosional surfaces.

The Cumberland basin divide extends south for two miles from near the fish hatchery in section 25, T21N, R6E and then east to Enumclaw Mountain. The divide continues along unnamed ridges southeast for about two miles, and then about 4 miles to the northeast, and then northwest for about four miles. The basin boundary again intercepts the Green River in the vicinity of Palmer.

We have subdivided the Cumberland basin into three subbasins. The locations of the subbasin divides are based on both topography and probable direction of groundwater flow. From north to south, the subbasins are the Green River Gorge, Deep Creek, and Coal Creek subbasins, with areas of approximately 4.5, 5.8, and 14.6 square miles, respectively.

DRAINAGE

The drainage basin is characterized by internally draining streams which feed lakes with no outlets. Coal Creek drains an area of about 13.7 square miles and discharges to Fish Lake. Deep Creek supplies both Deep and Hyde Lakes with water and drains an area of about 4.7 square miles. Flows in Coal Creek and Deep Creek were measured at 32.3 cubic feet per second (cfs) and 19.5 cfs, respectively, on February 17, 1989 (Richard Bain, personal communication). Local residents report that Coal Creek stops flowing during the summer in dry years and that the level of Fish Lake fluctuates by about 7 feet per year.

Both creeks originate in the foothills of the Cascade Range in the eastern half of the basin, where the highest elevation is about 3,000 feet. The lakes lie in the basin lowlands, where the elevation is about 700 to 800 feet. The lowest part of the Cumberland basin is along the Green River, which has cut a gorge to a minimum elevation of 320 feet southwest of Black Diamond springs.

SPRINGS

For the purposes of this report, the Black Diamond springs consist of three major springs in the southwest quarter of section 19. The springs are in a fenced area owned by the City. Access to the area is restricted by two locked gates.

The water supply to the City originates from a junction box which collects some of the flow from the springs. A six-inch pipeline provides water to Black Diamond. The City uses approximately 0.4 cfs for the drinking water supply (Keith Olson, personal communication). An 8-inch pipeline is used to power a booster pump which lifts the city water to a reservoir across the Green River.

Water from the south and north springs is piped to the junction box. The Black Diamond south spring's discharge area is covered with plastic sheeting and rubble; significant flow from the spring could not be directly observed. The Black Diamond middle spring is a set of seven springs which discharge along a pond approximately 200 feet long, about 500 feet northeast of the south spring. The discharge from these springs is collected in a culvert piping system to protect the spring water from surficial contamination. The Black Diamond north spring is about 1/4 mile northeast of the middle spring. The discharge zone of this spring is also protected by plastic sheeting and much of the flow is piped to the junction box.

At the junction box, excess discharge from the middle spring flows over a four-foot rectangular weir and into a stream. Measurements of the water height above the weir were supplied by Keith Olson, the City's Director of Public Works, and are given in Table 2-1. The average discharge over this weir in 1988 was about 10 cubic feet per second (cfs) or 4500 gallons per minute. The flow in the stream was 20 cfs on February 17, 1989 (Richard Bain, personal communication).

Approximately one-quarter mile northeast of the north spring is the Palmer spring. The spring surfaces inside of the fenced city property and its flow is used to supply drinking water to the picnic area owned by the Palmer Coking Coal Company. The flow from this spring was 10 cfs on February 17, 1989 (Richard Bain, personal communication). Many seeps are present on the hillside between the Black Diamond south spring and the Palmer spring.

Other springs also occur in the Cumberland basin. A spring in section 17 in the vicinity of the Green River Gorge resort is used for water supply by local residents. A large spring in section 30 supplies water to Icy Creek and the state fish hatchery; additional seeps near the fish hatchery pond were also noted. The flow in Icy Creek was 75 cfs on February 17, 1989 (Richard Bain, personal communication). A spring flows to the Green River from the boundary between sections 9 and 10 in the northern part of the Cumberland basin. Water also flows from an abandoned mine air shaft north of the Green River in section 19.

Table 2-1. Discharge From Black Diamond Springs

Date	Spring Water Depth (in)	Spring Discharge (cfs)	Treatment Plant Rainfall (in)	Buckley 1NE Rainfall (in)	Mud Mtn Dam Rainfall (in)	Palmer 3ESE Rainfall (in)
1/15/88	N/A	N/A	3.1	3.05	3.01	4.62
2/ 1/88	N/A	N/A	1.7	1.54	1.95	2.84
2/15/88	N/A	N/A	2.6	1.51	2.59	4.95
3/ 1/88	N/A	N/A	2.2	.24	.36	.72
3/15/88	N/A	N/A	2.4	3.05	3.91	4.04
3/29/88	10.00	9.7	2.0	4.38	5.48	8.28
4/15/88	N/A	N/A	2.6	4.16	4.71	5.64
4/28/88	11.00	11.2	.9	1.88	1.78	2.37
5/15/88	N/A	N/A	2.2	4.10	4.02	6.21
6/ 1/88	N/A	N/A	2.6	1.84	3.52	4.59
6/10/88	10.50	10.4	.9	M	1.55	2.01
6/16/88	10.50	10.4	.0	M	.15	.48
6/24/88	10.00	9.7	.0	M	.22	.29
6/28/88	10.00	9.7	.2	M	.00	.01
7/ 7/88	10.00	9.7	1.5	1.00	2.27	3.84
7/20/88	9.75	9.4	1.0	.85	.71	1.38
7/27/88	10.00	9.7	.0	.00	.00	.00
8/ 4/88	9.75	9.4	.0	.00	.00	.00
8/12/88	9.50	9.0	.0	.00	.00	.00
8/18/88	9.25	8.7	.8	.81	1.62	1.15
8/25/88	9.25	8.7	.0	.00	.00	.00
9/ 6/88	9.00	8.3	.2	.04	.12	.17
9/20/88	9.00	8.3	1.8	1.17	1.49	M
9/24/88	9.00	8.3	.0	.60	.31	M
9/30/88	8.50	7.7	.0	.90	1.87	M
10/ 4/88	10.00	9.7	.3	.22	.01	M
10/ 6/88	9.75	9.4	.0	.02	.26	.15
10/11/88	9.75	9.4	.1	.04	.04	.02
10/18/88	10.00	9.7	4.0	3.73	4.01	5.86
10/20/88	7.50	6.4	.0	.03	.47	.87
10/26/88	9.25	8.7	.4	.42	.75	1.44
11/ 3/88	10.00	9.7	3.1	.49	.33	1.02
11/16/88	11.25	11.5	5.5	N/A	N/A	N/A
11/22/88	11.25	11.5	4.2	N/A	N/A	N/A
12/ 3/88	11.50	11.9	1.0	N/A	N/A	N/A
12/ 7/88	11.50	11.9	.7	N/A	N/A	N/A
12/ 9/88	11.00	11.2	.0	N/A	N/A	N/A
12/15/88	11.00	11.2	.6	N/A	N/A	N/A
12/29/88	11.00	11.2	2.9	N/A	N/A	N/A
1/ 4/89	11.00	11.2	1.6	N/A	N/A	N/A
1/11/89	11.25	11.5	2.6	N/A	N/A	N/A

N/A: Data not available
M: Data missing (from NOAA Climatological Data for Washington)
Buckley 1NE station at 685 feet; Mud Mountain Dam station at 1308 feet; Palmer 3ESE station at 920 feet

CLIMATE

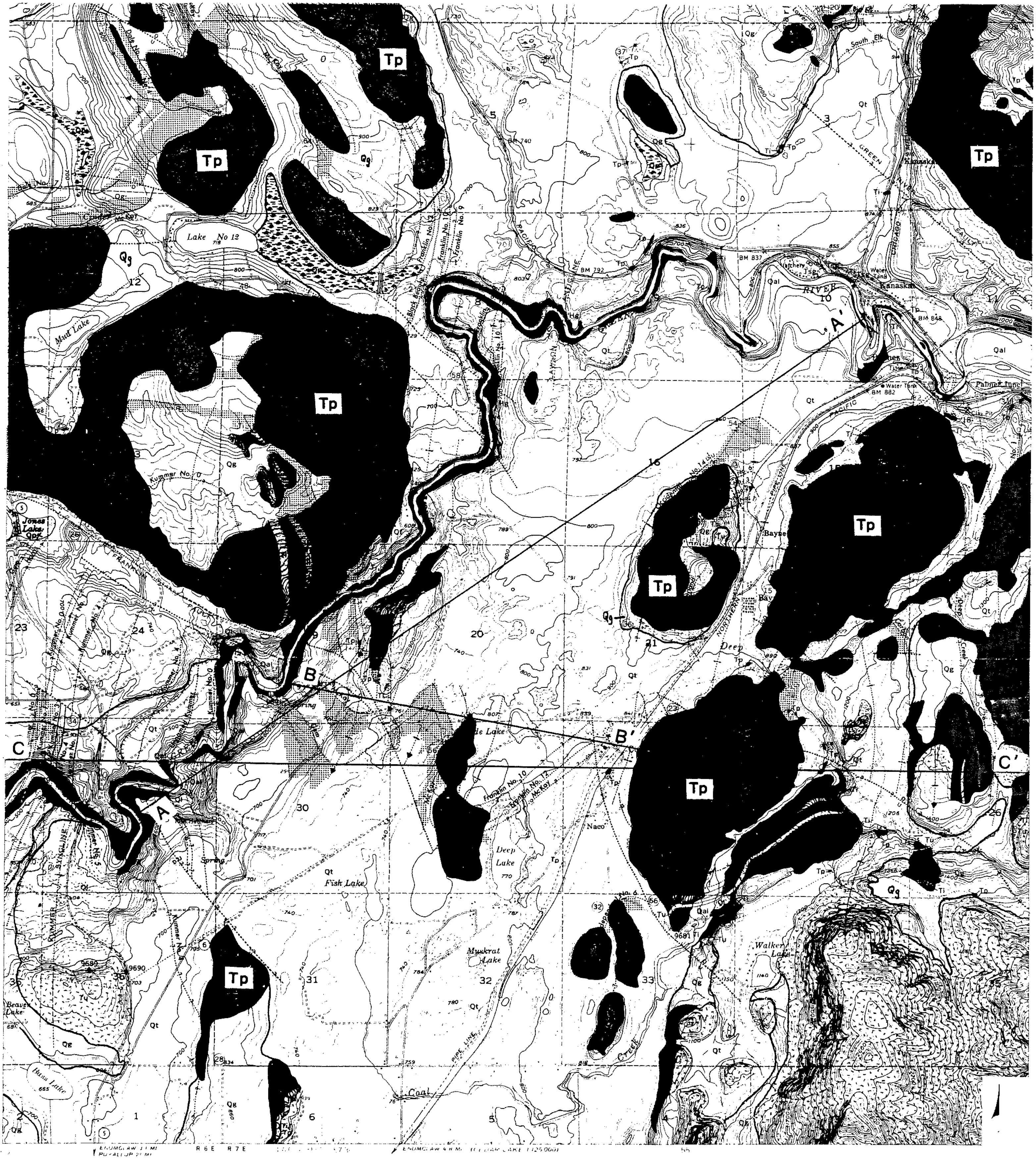
Published average annual temperature and precipitation data were available for three recording stations near the basin (NOAA, 1988). The three stations, Buckley 1NE, Mud Mountain Dam, and Palmer 3ESE, are located southwest, south, and northeast of the drainage basin. The Buckley station is about 10 miles south of Black Diamond at an elevation of 685 feet. The Mud Mountain Dam station is at the 1,308-foot elevation on the White River, about 9 miles south of Cumberland. The Palmer station is about 2.5 miles upstream of Palmer on the Green River at an elevation of 920 feet. Thirty year averages for the period from 1951 through 1980 are given in Table 2-2.

The driest and warmest months of the year are July and August. December and January are usually the wettest months. Precipitation in the basin increases to the east, toward the Cascade Range, as shown by the near doubling of the amount of precipitation from Buckley to Palmer.

Table 2-2. Temperature and Precipitation Averages

	Buckley		Mud Mtn Dam		Palmer	
Month	Temp (°F)	Pptn (in)	Temp (°F)	Pptn (in)	Temp (°F)	Pptn (in)
January	38.0	6.52	36.5	7.08	36.0	12.24
February	41.7	4.79	39.8	4.89	40.2	9.41
March	43.2	4.33	40.8	4.66	41.5	9.01
April	47.9	3.91	45.2	4.58	46.5	7.71
May	54.0	3.13	51.3	3.96	52.7	5.57
June	58.8	2.92	56.3	3.75	57.7	5.24
July	63.1	1.20	61.3	1.58	62.7	2.38
August	62.7	2.03	61.0	2.54	62.3	3.28
September	58.4	2.94	57.3	3.46	58.6	5.30
October	50.9	4.20	50.2	4.73	51.3	7.59
November	43.4	6.15	42.7	6.64	42.8	11.00
December	39.7	6.85	38.8	7.45	38.3	13.47
Annual	50.2	48.97	48.4	55.32	49.2	92.20

Table 2-1 shows precipitation data available from NOAA for January through October 1988. The table includes precipitation data from the Black Diamond treatment plant.



Source: Vine, 1969

Figure 2-1 Geologic Map

Drillers' well logs from the Cumberland area were examined to determine the thickness of unconsolidated deposits and the depth to sandstone or coal indicative of the Puget Group. Thickness of the unconsolidated deposits was based on drillers reporting sand, gravel, or boulders overlying sandstone and/or coal. The presence and thickness of till within the glacial drift was determined from the reporting of hardpan or till on the logs.

The cross-sections (Figures 2-2 and 2-3) show the relationship between the Puget Group, till, and terrace gravel and stratified drift. The sediments of the Puget Group and later unnamed volcanic rocks were deposited about 30 to 60 million years ago during the Tertiary Period. These rocks were subsequently folded and faulted. Glaciation of the Puget Sound area occurred during the Pleistocene Epoch (about 10,000 to 1.6 million years ago). The Vashon glacier was the most recent glacier, was about 5,000 feet thick in the Seattle area, and extended to about 12 miles south of Olympia.

Figure 2-4 shows the relative positions of the glacial deposits. Robinson and Noble (1972) stated that groundwater in the Vashon Drift flows within the Cumberland aquifer from the mountains in the eastern part of the Cumberland basin to the Green River. The Vashon Drift consists of outwash sand and gravel, till, and recessional terrace gravel. Advance outwash deposits generally consist of sand, gravel, cobbles, and boulders, deposited by meltwater streams during the advance of the glacier. These outwash gravels are highly permeable, but the deposits are usually too thin to support pumping from large-capacity wells.

Glacial till is a compacted mixture of clay, sand, and gravel. Because it was crushed and mixed by the advance and retreat of the glacier, the permeability of till is usually low. Perched groundwater, lakes, and bogs may form on the top of the till. In some areas, the till may act as a confining layer within the Cumberland aquifer. The till has not been mapped in the vicinity of the lowlands of the Cumberland basin, but is present near the base of the hill west of Bayne, in the higher reaches of Deep and Crow Creeks, and on the south side of the Green River about one mile downstream from the fish hatchery, in section 25, T21N, R6E. Figures 2-2 and 2-3 show the position of the till in the Cumberland basin as inferred from drillers' logs.

The recessional and ice-contact terrace and unstratified drift sediments were deposited by the ancestral Green River as the glacier receded and the Green River migrated from the Bayne-Walker Lake-Cumberland area to its present course. These sediments were deposited above the till and are highly permeable. Till was not mapped in the Green River gorge (Gower and Wanek, 1963; Vine, 1969). It appears that erosion by the Green River has removed the till in the vicinity of the Green River gorge, or that recessional deposits above the contact with the Puget Group have covered the till.

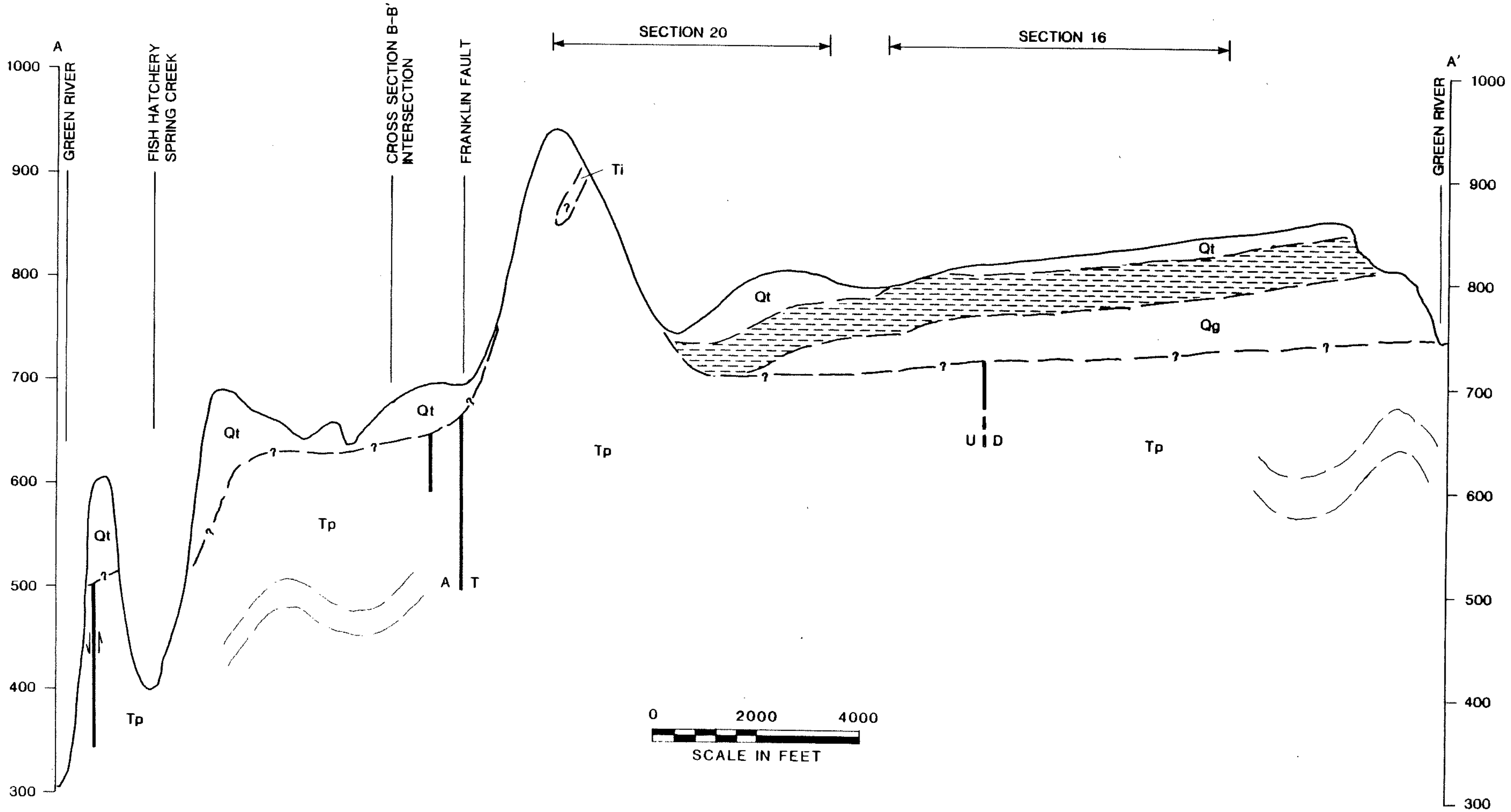


Figure 2-2 Cross-Section A-A'

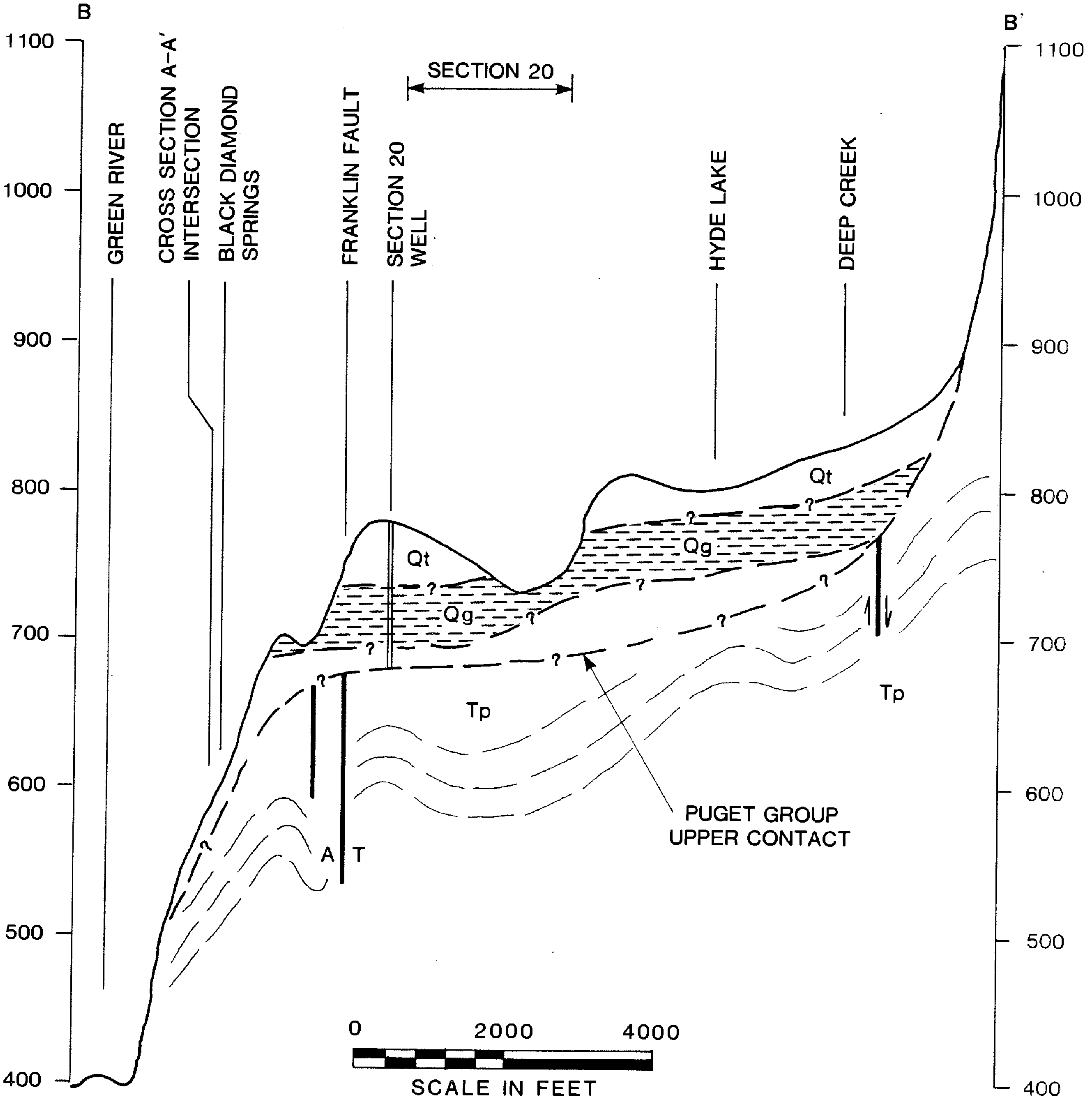


Figure 2-3 Cross-Section B-B'

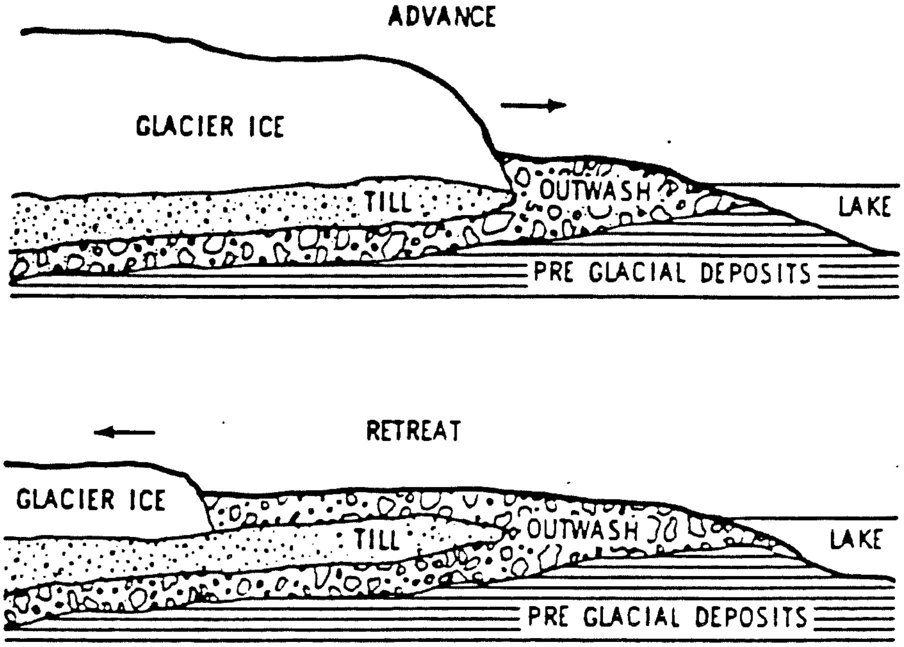
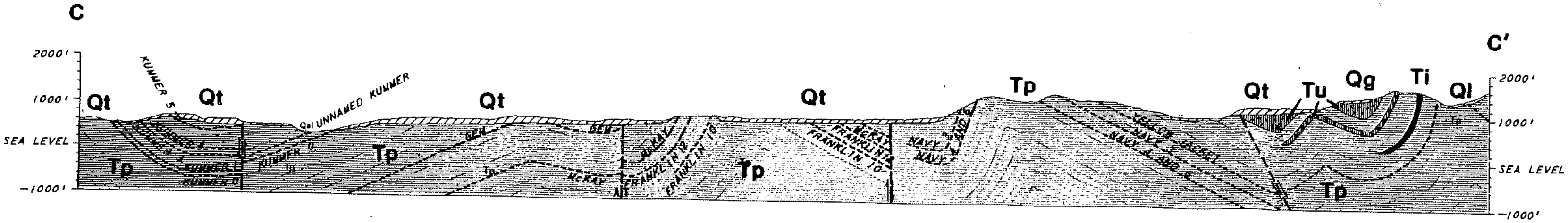


Figure 2-4 Illustration of Glaciation

STRUCTURAL GEOLOGY

The Cumberland basin is located in the Puget downwarp west of the Cascade Range. Major folding and concurrent faulting occurred in the early to middle Miocene during emplacement of the Cascades. Much of the geologic structure is obscured by Quaternary sediments, however bedrock is well exposed along the Green River, where generally north-trending folds are present. The Lawson anticline is exposed in sections 9 and 10. Its eastern limb dips 30 to 40 degrees and the dip of the western limb is about 80 degrees. The south-plunging Kummer syncline is about two miles to the west and an anticline-syncline couplet is between the Lawson and Kummer folds. Additional small folds are east of the Lawson anticline.

The above folds are cut by northwest trending faults. The Franklin fault crosses the Green River about 1/4 mile north of the Black Diamond springs. Right-lateral displacement on this fault has been about 1,000 feet. Figure 2-5 illustrates the geologic structure through the southern part of the drainage basin.



Source: Gower and Wanek, 1963; Vine, 1969

Figure 2-5 Cross-Section C-C'

CHAPTER 3

HYDROGEOLOGY

The presence of coal within the Puget Group has caused a number of previous investigations into the geology of the area, and groundwater conditions are mentioned in early geologic reports because of the adverse impact groundwater had on coal mining. The Franklin Mine began operating on the north side of the Green River, north of the Black Diamond springs, in the early 1880s (Willis, 1898) and by 1912 mining extended south to beneath the Green River (Evans, 1912). In 1897, the Green River drift, or Section 19 Mine, was driven northward along strike of the coal beds near the Green River. Other mines were operating in the Palmer, Bayne, Hyde Lake, and Cumberland areas by 1912. Almost all of the mines were affected by groundwater (Evans, 1912).

Two mechanisms for groundwater flow in the Black Diamond area were recognized by Evans: (1) flow along the contact between bedrock and overlying glacial deposits, and (2) flow in fractures and along fault planes within the sedimentary rocks of the Puget Group. The former mechanism affected development of the Morgan mine north of Black Diamond (southwest quarter of section 11, T21N, R6E). A "stream of sufficient volume to flood the mine" (Evans, 1912, p. 210) was encountered at the contact between the bedrock and glacial deposits. A "number of mines" were flooded when saturated terrace gravel and stratified drift were encountered unexpectedly, but the low permeability of the till caused little damage to the mines when it was encountered (Warren and others, 1945).

Groundwater flow was apparently structurally controlled in the mine near the Black Diamond springs. Before 1912, the New Franklin Mine commenced operation. This mine was south of the Green River in section 19. Originally, the Gem coal bed was followed to the southeast and it was planned that the underlying McKay bed would be intercepted by tunneling to the east. Evans (1912, p.168) states "the miners had not gone many hundred feet with this drift until an underground stream was struck." Additional water was encountered in another drift to the south. The groundwater was apparently coming from "fissures or open fault planes" (Evans, 1912, p.212).

DISCHARGE FROM SPRINGS

Evans did not specifically mention the Black Diamond springs, but did state that many springs flowed along the Green River downstream from the eastern boundary of section 9, T21N R7E, near Kanaskat. He did not state whether the springs were structurally or stratigraphically controlled. Luzier (1969) described these springs as originating from the contact between the Puget Group and the recessional deposits in the Vashon Drift. Robinson and Noble (1972) state that groundwater within the Cumberland aquifer "discharges into the Green River gorge through extensive springs." Discharge estimates reported by Luzier for springs in the Cumberland basin are given in Table 3-1.

Table 3-1. Discharge From Springs.

Section	Spring Name	Discharge (gpm)	Discharge (cfs)
17L1	Resort Spring	900 to 2,200	2 to 5
19K1	Palmer Spring	2,000 to 11,000	4 to 25
19Q1, P1	Black Diamond Springs	2,200 to 18,000	5 to 40
30N1	Fish Hatchery Spring	3,300 to 23,000	7 to 51

The above discharge measurements are believed to represent typical maximum and minimum discharge rates and are consistent with observations made during this study. Data from the weir at the Black Diamond middle spring indicate the excess discharge rate has been about 10 cubic feet per second (cfs) or 4,488 gallons per minute (gpm) in the last year (Figure 3-1). Assuming that this represents about half of the flow from the Black Diamond springs, their average total discharge is about 20 cfs.

Richardson and others (1968) stated that the fish hatchery spring, which supplies water to Icy Creek (not named on the current 7.5-minute Cumberland topographic map), is the largest spring in King County. In 1963 and 1964, the discharge of Icy Creek ranged from a minimum of 3.6 cfs (October 1963) to a maximum of 113 cfs (January 1964) and averaged 29 cfs.

An additional source of discharge is a tunnel which apparently drained a coal mine in the vicinity of Hyde Lake. The outlet of the tunnel is approximately 350 feet north of the footbridge across across the Green River in section 19. The flow from the tunnel was estimated at 2 cfs (Louis Fruste, U.S.G.S. Water-Resources Division, Tacoma, personal communication).

The locations of the springs suggests that springflow is controlled more by topography than by geologic structure. During the field reconnaissance, elevations of the springs on the east side of the Green River were measured. The springs generally discharge from hillsides or the toes of slopes at about 610 to 620 feet. There does not appear to be a great correlation between folding and faulting as shown on the published geologic map (Figure 2-1) and the presence of the springs. Instead, the springs apparently flow from zones where the downcutting of the Green River has incised a channel into the Puget Group.

RECHARGE

Groundwater is recharged in the Cumberland basin by preciptiation falling as rain or snow. The amount of recharge is affected by the rate of snow melt; rainfall intensity, duration, and distribution; infiltration rates of soils; runoff; and evapotranspiration. Precipitation in the Green River area of the basin is about 50 inches per year. About 90 inches per year falls in the hills in the eastern part of the basin (Table 2-2).

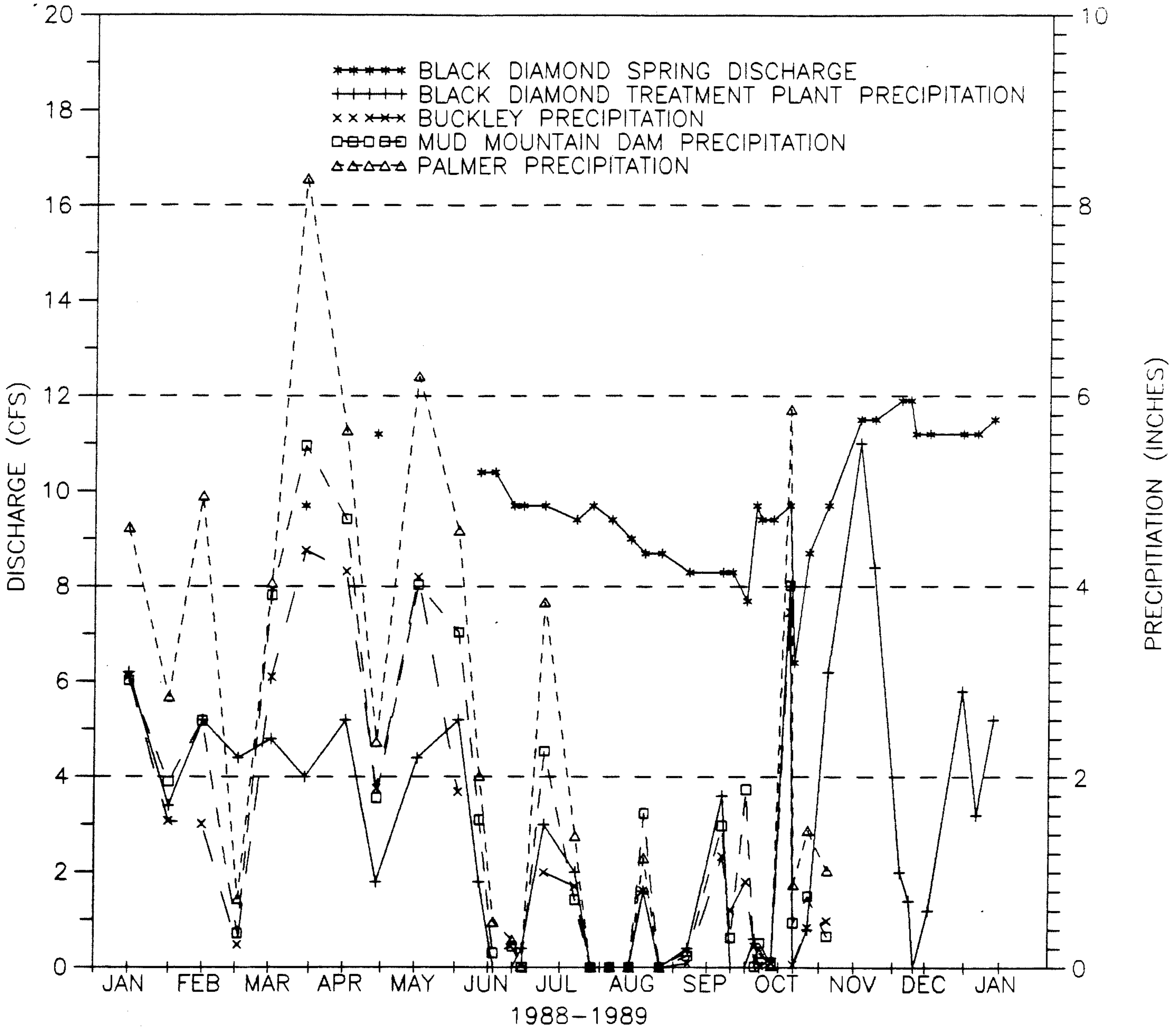


Figure 3-1 Discharge from Black Diamond Springs

Runoff is the amount of precipitation that reaches streams and is about 30 inches per year in the vicinity of the Green River to about 60 inches per year above the 900-foot elevation in the foothills of the Cascade Range in the Cumberland basin (Figure 3-2). Potential evapotranspiration is about 22 inches per year (Richardson and others, 1968).

Robinson and Noble (1972) state that "all of the runoff from the mountains east of the Cumberland aquifer passes through it as groundwater underflow" and that the aquifer could produce 15,000 gpm. Runoff estimates for the subbasin areas are given in Table 3-2, assuming 30 inches per year of runoff below the 900-foot elevation and 60 inches per year above that elevation.

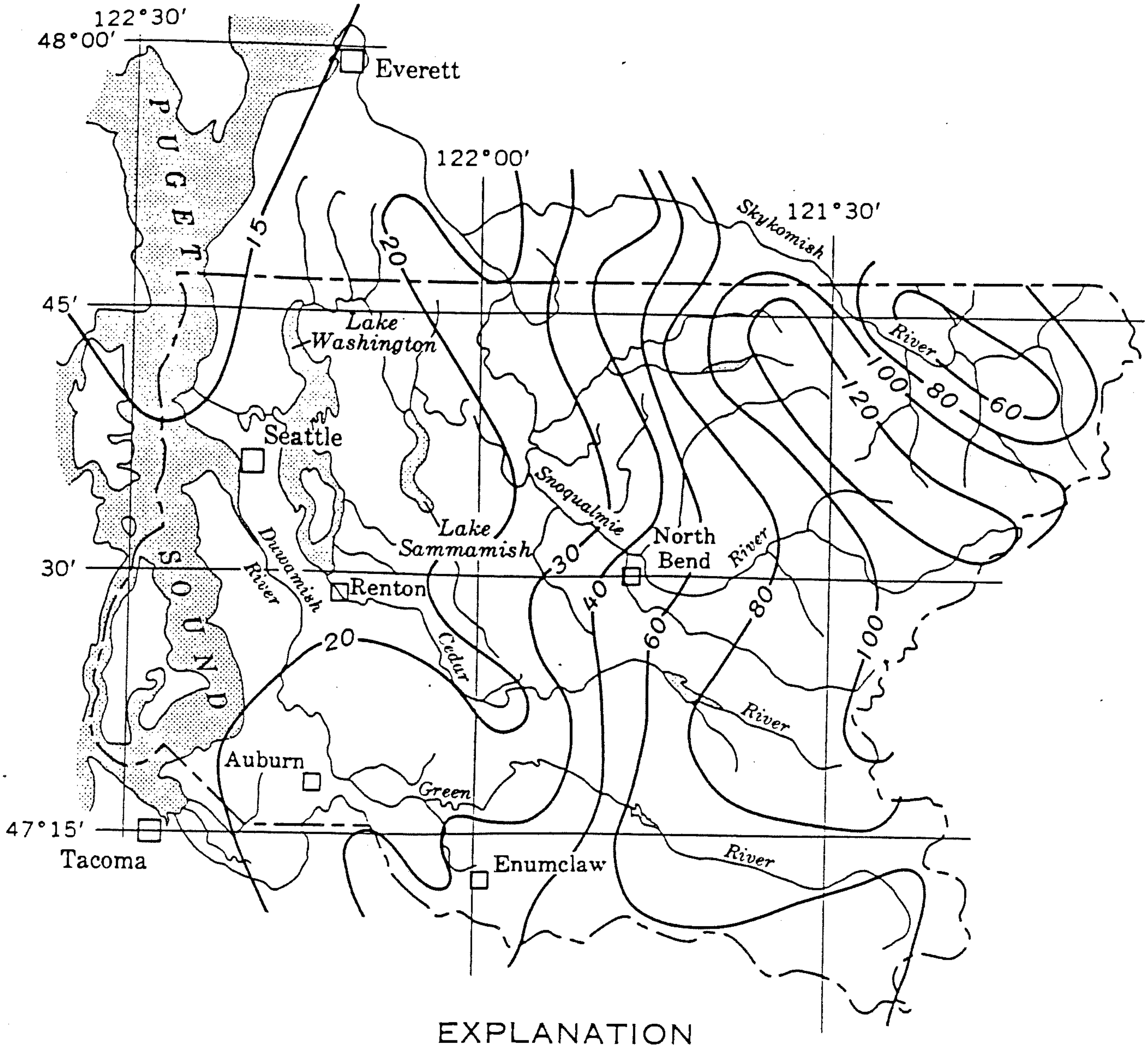
Table 3-2. Runoff Estimates

Subbasin	Area (mi^2)	Average Runoff (in/yr)	Computed Flow (cfs)
Coal Creek Subbasin, total	14.6	53	57
Coal Creek Drainage	13.7	54	55
Icy Creek Drainage	0.9	30	2
Deep Creek Subbasin, total	5.8	48	20
Deep Creek Drainage	4.7	52	18
Black Diamond Spring	1.1	30	2
Green River Gorge Subbasin	4.5	30	10

The above table provides order of magnitude estimates of runoff in the Cumberland basin and recharge to the Cumberland aquifer. The internally draining Deep and Coal Creeks discharge water to Deep, Hyde, and Fish Lakes. Deep Lake is a maximum of 74 feet deep and averages 33 feet deep. Fish Lake averages 13 feet deep and is a maximum of 24 feet deep. The depth of Hyde Lake is unknown. These lakes may act as windows in the till layer to allow recharge to the aquifer. Some of the water evaporates from the lakes, but the remainder seeps from the lakes and recharges the Cumberland aquifer.

The presence of low-permeability glacial till may locally restrict the recharge from other streams or from storm runoff. Perched groundwater may locally form on the top of till. The perched water may not recharge the Cumberland aquifer but may be used for plant growth, if the till is close to the surface. Figure 3-3 shows the elevation of the top of the till in the basin, based on well log data and information from Metro's drilling program in sections 16 and 20. The thickness of the till is reported as about 10 to 50 feet. In some areas, the till is not present and may have been eroded by the ancestral Green River.

The majority of recharge to the Cumberland aquifer, 73 cfs, apparently occurs in the vicinity of Hyde, Deep, and Fish Lakes from the flows of Deep Creek and Coal Creek. Assuming that 50 percent of the runoff in the Icy Creek drainage, Black Diamond spring drainage, and Green River gorge subbasin flows directly into the Green River and does not recharge the aquifer, the Cumberland aquifer receives about 80 cfs (36,000 gpm) of recharge.



EXPLANATION

——— 40 ———

Line of equal runoff

Shows average annual runoff. Interval, in inches, is variable

Source: Richardson and Others, 1968

Figure 3-2 Average Annual Runoff

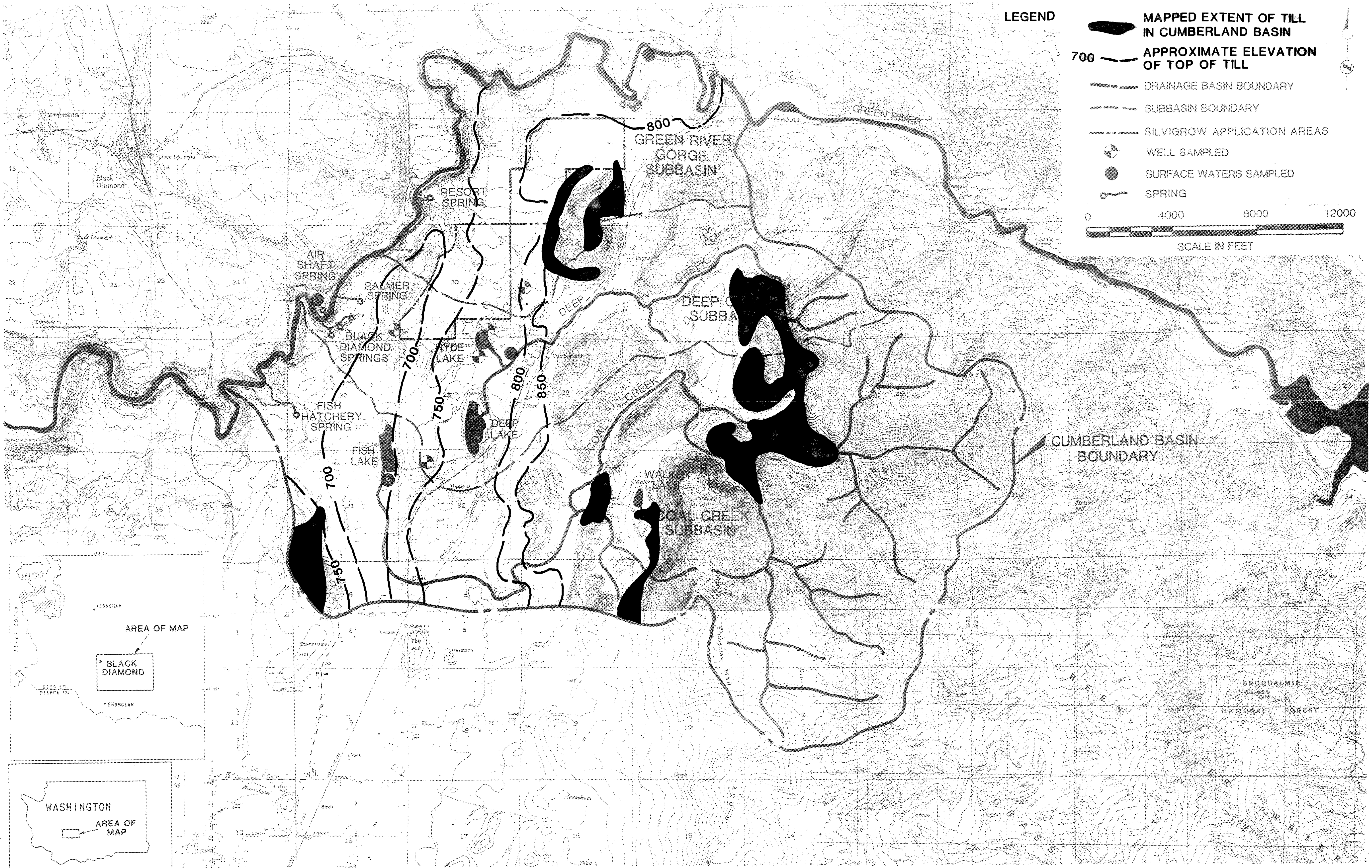


Figure 3-3 Extent of Till

A comparison of Table 3-2 and Table 3-1 shows that the Black Diamond, Palmer, and fish hatchery springs are supplied by groundwater and not surface water. The average discharges from these springs is much higher than the flow that would be possible if the springs were directly discharging surface water runoff. The calculated flow of Icy Creek (2 cfs) does not approach the measured average of 29 cfs discharged by the fish hatchery spring to Icy Creek. Similarly, the combined flow of the Black Diamond and Palmer springs is at least 20 cfs. Calculated runoff in the Black Diamond spring drainage is only about 2 cfs, and not all of that runoff is available to recharge the aquifer.

GROUNDWATER MOVEMENT

Data from the well inventory suggests that the majority of groundwater flow in the basin occurs within the Cumberland aquifer at the contact of the Puget Group and the overlying Vashon Drift. Well logs were obtained from the Department of Ecology for sections 20, 21, and 28 through 32 in T21N, R7E. No wells are recorded in sections 16, 17, 19, and 30. Tables A-1 through A-3 summarize the information from the well logs.

Wells in the Cumberland-Deep Lake area have been drilled using cable-tool or rotary methods and are completed in 6-inch diameter boreholes. Many of the wells are constructed of open-ended steel casing, however some wells have been completed with commercial well screen or slotted casing. Wells completed in sands and gravels are usually less than 100 feet deep and yield from about 5 to 10 gpm, but yields as high as 80 gpm are also reported. Deeper wells are completed in the Puget Group and yield from less than 1 to 60 gpm.

Transmissivity

The hydraulic conductivity, transmissivity, and storage coefficient are used to characterize the amount of water stored in an aquifer and the rate of movement of water in an aquifer. The permeability or hydraulic conductivity describes the rate at which a unit volume of water will flow through a unit cross-sectional area of material under a unit hydraulic gradient, expressed in gallons per day of water per square foot of the aquifer (gpd/ft^2). Transmissivity is the rate at which water will move through a unit width of an aquifer at a unit hydraulic gradient and is the product of the permeability multiplied by the aquifer thickness, expressed in gallons per day per foot (gpd/ft). The storage coefficient describes the volume of water an aquifer will lose or gain to storage per unit surface area per unit change in head, and is dimensionless. The hydraulic gradient is the change in static head or potential per distance along a path of flow, usually expressed in feet per mile.

The specific capacity of a well describes the well yield in gpm (Q) divided by the drawdown (s, in feet) necessary to produce the measured yield. The specific capacity of a well is a function of the transmissivity and storage coefficient of the aquifer and may be used to estimate the aquifer transmissivity in the vicinity of the well. Specific capacity data were obtained from well test information on the well logs.

The transmissivity of an aquifer may be estimated using the reported specific capacities and the following equation (Walton, 1962):

$$T(gpd/ft) = Q/s(264\log(T't/2693r^2S)-65.5),$$

where Q/s is specific capacity (gpm/ft), t is duration of the specific capacity test in minutes, r is borehole radius in feet, and S is an estimated storage coefficient (0.001). The above formula cannot be solved directly for transmissivity because transmissivity terms appear on both sides of the equation. A transmissivity estimate (T') for the right side of the formula was obtained by multiplying the calculated specific capacity by 2,000. The 2,000 factor was determined from Walton (1962, p.13) for the case of a 6-inch diameter well withdrawing water from a confined aquifer after a pumping period of 24 hours.

The calculated transmissivities will generally be accurate within plus or minus 50 percent, and provide order of magnitude estimates of the transmissivities of materials in the basin. Errors may be caused by having water only able to enter the well from the bottom of the casing, aquifer boundaries, and errors in field measurements. Additional errors include the initial transmissivity estimate and the storage coefficient estimate. Order of magnitude errors in the latter will not cause large errors in the calculated transmissivity because of the logarithmic term in the equation.

Transmissivities were calculated using data from 57 specific capacity tests: 39 from wells completed (screened, perforated, or open) above the glacial drift-Puget Group contact (Table A-1); 8 from wells completed with open casing terminating at the contact (Table A-2); and 10 wells completed in bedrock (Table A-3). The estimated transmissivities are given in Table 3-3.

Table 3-3. Transmissivity Estimates.

Well Completion	Transmissivity (gpd/ft) Minimum	Maximum	Average
Above Contact in Glacial Drift	49	36,500	5,400
At Puget Group Contact	4	4,800	1,600
Below Contact in Bedrock	12	5,900	880

The above table was calculated with the storage coefficient equaling 0.001, typical of semiconfined aquifers. Measurement of the storage coefficient requires the use of at least two wells during an aquifer test. No storage coefficient data were available, therefore the above value was used. If the storage coefficient for the sediments above the Puget Group is higher, for example 0.1, which may occur in unconfined aquifers, the minimum, maximum, and average transmissivity values are 22, 26,000, and 3,600 gpd/ft, respectively.

The estimated transmissivity is consistent with the Puget Group transmissivity of 1,000 gpd/ft based on the slug test results. The hydraulic conductivity of the sandstone (assuming a ten-foot saturated thickness) is 5×10^{-4} centimeters per second.

Given the difference in the average values of the transmissivity of the glacial drift and the sandstone, water will move at a higher rate in the glacial drift. Under the same hydraulic conditions, a greater volume of water will be discharged from the Cumberland aquifer than from the Puget Group.

Groundwater Flow Direction

Water levels recorded on the well logs generally are about 10 feet above the Puget Group-Vashon Drift contact. Water was not reported in the alluvium above the till. Approximate water-level contours are shown on Figure 3-4. The water-level contours were drawn using available data from the well inventory, therefore the locations of the contours are only approximate.

In the Cumberland-Deep Lake area, groundwater flows to the northwest parallel to the slope of the land surface, at gradients ranging from about 250 feet per mile in the Cumberland area to about 90 feet per mile in the lowlands of sections 29 to 31. The gradient is probably very steep in the vicinity of the Green River gorge, but no data were available.

The direction of groundwater flow in sections 16,17, 20, and 21 is probably to the north to northwest, with local movement to the southwest. There are no wells in these sections which may be used to determine the groundwater flow direction. Groundwater flow to the north or northwest would be consistent with the general flow direction toward the Green River. Flow to the north is indicated by the spring in near the section 9 and 10 boundary.

Flow to the southwest could occur if groundwater flow parallels the topography in section 16. A broad southwest-sloping gully extends from the northeast quarter of section 16 and probably represents a former channel of the Green River. A buried channel extending to the southeast from the vicinity of the Resort Spring may intercept groundwater flow from the former channel of the Green River.

The discharge rate of the Cumberland aquifer was estimated assuming a transmissivity (T) of 5,000 gpd/ft, hydraulic gradient (I) of 90 feet per mile, and discharge across a 25,000-foot long cross section of the aquifer (L) between the northest corner of section 16 and the southwest corner of section 31. Using the equation $Q=TLI$, the aquifer discharge (Q) is 2 million gallons per day or 3 cfs. This is much less than the discharge rate of the Black Diamond springs, therefore there are errors in the above assumptions or there is another mechanism for flow in the basin. Refinement of the discharge estimate is not possible within the scope of this project.

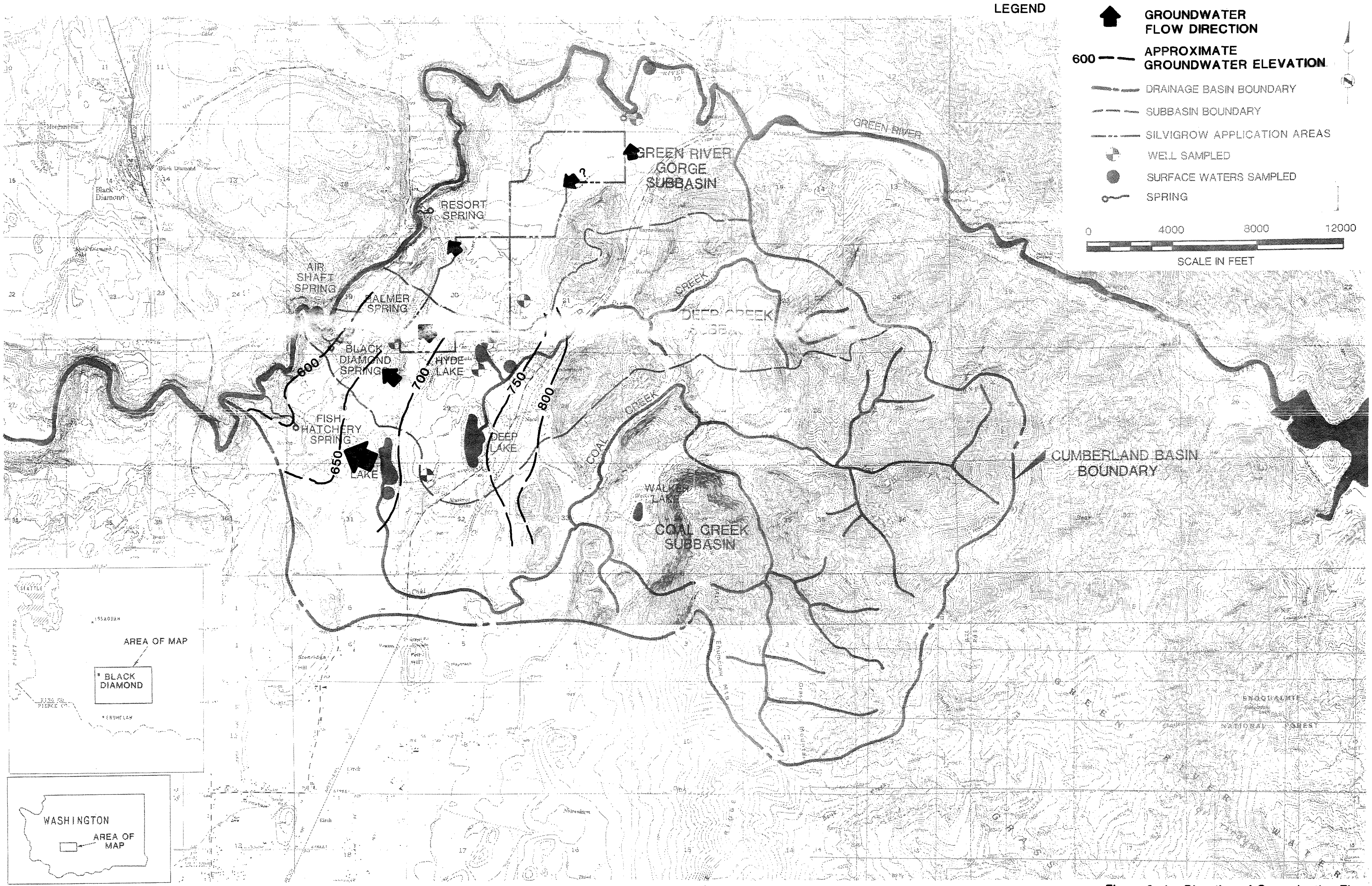


Figure 3-4 Direction of Groundwater Flow

CHAPTER 4

WATER QUALITY

Twenty-four water samples were obtained from streams, lakes, and springs in the Cumberland basin during the course of the investigation. Two samples were analyzed to provide baseline data on the organic and inorganic character of the Black Diamond springs. The primary reason for analyzing the water was to assist in determining the source of water to the springs along the Green River gorge.

DRINKING WATER SUPPLY

A sample from the junction box at the Black Diamond middle spring and a sample from the concrete retaining wall at the Black Diamond north spring were obtained on December 19, 1988 and analyzed to determine the concentrations of parameters regulated by the Safe Drinking Water Act. EPA Method 524 was used to determine if volatile organics were present in the water by the Department of Social and Health Services Public Health Laboratories in Seattle. The Seattle laboratory also analyzed the water for gross alpha. The state laboratory in Wenatchee analyzed the water for pesticides. The concentrations of these parameters were below the detection limits for each method. Laboratory analytical reports are included in Appendix C.

The samples had concentrations of heavy metals, nitrate, sulfate, sodium, chloride, and coliform bacteria well below the EPA maximum contaminant levels. These parameters were analyzed by Laucks Testing Laboratories, Inc.

An analysis of Black Diamond spring water from January 25, 1963 from Richardson and others (1968) is also shown in Table 4-1. The water quality has not changed significantly in 26 years, except for nitrate which has approximately doubled from 1.4 to about 3 milligrams per liter (mg/l).

MAJOR IONS

Major ion chemistry was used as a tool to aid in determining the source of the water discharged by the springs. Major ions include the cations (calcium, magnesium, sodium, and potassium) and the anions (chloride, sulfate, bicarbonate, and nitrate). To facilitate comparisons of analyses, the analytical results expressed in mg/l were converted to the units of milliequivalents per liter (meq/l). The use of meq/l units enables one to compare the amounts of dissolved ionic species on a chemically equivalent basis and recognizes variations in valences and atomic weights between analyzed parameters.

Table 4-1. Water Quality Analyses.

Parameter	Black Diamond Spring 1/25/63		Black Diamond Spring 7/88		Black Diamond Spring 12/19/88		Black Diamond N. Spring 12/19/88	
	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium	6.5	.32	8	.40	7	.35	8	.40
Magnesium	1.7	.14	2	.16	1.7	.14	2	.16
Sodium	3.2	.14	4	.17	2.8	.12	3.2	.14
Potassium	.1	.00	0	.00	0	.00	0	.00
Chloride	1.5	.04	4	.11	2	.06	2	.06
Sulfate	2.6	.05	4.5	.09	3	.06	3	.06
Bicarbonate	30	.49	31	.51	32	.52	34	.56
Nitrate (as NO3)	1.4	.02	2.2	.04	3.1	.05	3.1	.05
TDS (lab)	45				48		45	
pH (lab)	7.1		7.3		6.9		6.7	
SC (lab), umhos/cm	62		<100		69		76	
Total Cations, meq		.61		.74		.61		.70
Total Anions, meq		.61		.75		.69		.73
Error, %		.39		.83		6.32		1.63

Parameter	Palmer Spring 7/88		Palmer Spring 12/19/88		Fish Hatchery Spring 12/19/88		Air Shaft Spring 7/88	
	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium	12	.60	13	.65	6	.30	13	.65
Magnesium	3	.25	3.4	.28	1.3	.11	4	.33
Sodium	6	.26	5.2	.23	2.3	.10	9	.39
Potassium	0	.00	.2	.01	0	.00	0	.00
Chloride	3	.08	2	.06	2	.06	2	.06
Sulfate	9	.19	6	.12	2	.04	22.5	.47
Bicarbonate	49	.80	54	.89	27	.44	49	.80
Nitrate (as NO3)	3.5	.06	3.4	.05	3.1	.05	.09	.00
TDS (lab)	45		83		51		110	
pH (lab)	7.6		6.8		6.6		7	
SC (lab), umhos/cm	<100		110		60		190	
Total Cations, meq		1.11		1.16		.51		1.37
Total Anions, meq		1.13		1.12		.59		1.33
Error, %		1.12		1.69		7.68		1.48

Table 4-1, continued. Water Quality Analyses.

	Metro Well (Sec 20) 12/19/88		Gallagher House Well 12/22/88		Scott Paper Co. Well 12/22/88		Fehr House Well 12/22/88	
Parameter	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium	25	1.25	11	.55	26	1.30	8	.40
Magnesium	6.1	.50	2.9	.24	5.1	.42	2.5	.21
Sodium	2.3	.10	4	.17	16	.70	5	.22
Potassium	.3	.01	.3	.01	.7	.02	.2	.01
Chloride	2	.06	2	.06	3	.08	2	.06
Sulfate	3	.06	4	.08	21	.44	3	.06
Bicarbonate	98	1.61	46	.75	95	1.56	37	.61
Nitrate (as NO3)	5.3	.09	3	.05	5.8	.09	4.9	.08
TDS (lab)	110		65		140		53	
pH (lab)	7		7		6.7		6.6	
SC (lab), umhos/cm	190		95		220		82	
Total Cations, meq		1.86		.97		2.43		.83
Total Anions, meq		1.81		.94		2.17		.80
Error, %		1.27		1.42		5.61		1.42

	Smoke 'N Joe's Well 7/88		Kanasket-Palmer 12/88		Cunningham Well 12/88		Coal Creek 12/22/88	
Parameter	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium	16	.80	26	1.30	9.2	.46	6.2	.31
Magnesium	4	.33	6	.49	3.1	.26	1.1	.09
Sodium	7	.30	11	.48	7	.30	4	.17
Potassium	1	.03	1.1	.03	.71	.02	.31	.01
Chloride	4	.11	3	.08	2.2	.06	2.1	.06
Sulfate	10.5	.22	22	.46	.5	.01	1.6	.03
Bicarbonate	67	1.10	78	1.28	29	.48	27	.44
Nitrate (as NO3)	2.7	.04	.4	.01	.4	.01	.4	.01
TDS (lab)			126		48		104	
pH (lab)	7.5		7.6		6.9		7.3	
SC (lab), umhos/cm	160		210		96		51	
Total Cations, meq		1.46		2.30		1.04		.58
Total Anions, meq		1.47		1.83		.55		.54
Error, %		.53		11.39		30.33		3.58

Table 4-1, continued. Water Quality Analyses.

	Green River		Green River		Deep Creek		Deep Lake, 5 Feet	
	7/88		12/22/88		12/22/88		12/88	
Parameter	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium	8	.40	5	.25	6.6	.33	6.2	.31
Magnesium	2	.16	.87	.07	3.2	.26	3.3	.27
Sodium	4	.17	3	.13	7	.30	6	.26
Potassium	0	.00	.24	.01	.56	.01	.65	.02
Chloride	2	.06	1.5	.04	1.6	.05	2.9	.08
Sulfate	4.5	.09	.05	.00	2.2	.05	7.2	.15
Bicarbonate	37	.61	9.8	.16	29	.48	54	.89
Nitrate (as NO3)	.3	.00	.4	.01	.9	.01	.4	.01
TDS (lab)			84		124		46	
pH (lab)	7.6		7.37		7.5		7.1	
SC (lab)	<100		36		70		71	
Total Cations, meq		.74		.46		.91		.86
Total Anions, meq		.76		.21		.58		1.12
Error, %		1.58		37.01		22.16		13.36

	Deep Lake, 10 Feet		Deep Lake, 18 Feet		Fish Lake, 3 Feet		Fish Lake, 3 Feet	
	12/88		12/88		12/88		12/88	
Parameter	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium	6.3	.31	8.6	.43	5.5	.27	5.7	.28
Magnesium	2.7	.22	3.6	.30	1	.08	1.1	.09
Sodium	6	.26	6	.26	5	.22	4	.17
Potassium	.63	.02	.99	.03	.33	.01	.34	.01
Chloride	2.2	.06	2	.06	2.8	.08	1.7	.05
Sulfate	7.2	.15	20	.42	3.4	.07	3.1	.06
Bicarbonate	24	.39	41	.67	20	.33	20	.33
Nitrate (as NO3)	.4	.01	.4	.01	.4	.01	.9	.01
TDS (lab)	46		68		50		50	
pH (lab)	7.2		6.9		7.3		7.1	
SC (lab), umhos/cm	74		98		47		55	
Total Cations, meq		.81		1.01		.58		.56
Total Anions, meq		.61		1.15		.48		.45
Error, %		14.16		6.46		9.25		10.15

Laboratories, Inc., and BioMed Research Laboratories, Inc., of Seattle, and Soil Test of Moses Lake. Charge balance error calculations were performed based on the cations minus anions divided by the cation plus anion concentrations (in meq/l) and expressed as a percent. The laboratories were asked to recheck samples with charge balance errors exceeding 10 percent and data shown on Table 4-1 is based on laboratory reports following the reanalyses.

A trilinear diagram of ionic ratios was prepared using the method of Piper (1944), where each analysis is represented by three points. Each point in the left triangle of Figure 4-1 represents the relative proportion of the positively charged ions (cations) in meq/l normalized to 100 percent. Each apex of the triangle represents 100 percent of concentration for a given parameter. Each point in the right triangle represents the relative concentrations of the negatively charged anions.

The composition of a water sample, relative to the major ions, is represented by projecting the points from the lower triangles into the upper diamond-shaped field along lines parallel to the upper boundaries of this field. Waters which are similar in composition will be grouped together in this field.

The trilinear diagram may be used to describe the chemical type and character of a water sample. The chemical type of water and chemical character of a water sample were defined by Back (1966, p. A13). The dominant ion on a greater than 50 percent basis determines the cation or anion type of water. The the left triangle of Figure 4-1 shows that three cation types of water (calcium, sodium, and no dominant type) are present in the basin. The anion triangle shows that bicarbonate-type water is present in the basin.

The combination of dominant ion types determines the character of the water. Almost all of the water samples were of the calcium bicarbonate character. One sample, from the stream downstream of the Palmer spring is of sodium bicarbonate character. This sample may have been affected by road deicing or fertilizer applied near the stream.

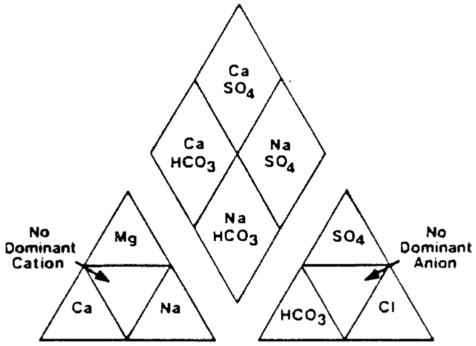
The spring, stream, lake, and well waters are of similar chemical character. This indicates that chemical precipitation, mixing, or solution is not affecting these waters to a great extent and that the waters generally come from the same source.

The well and spring water samples are low in total dissolved solids and are bicarbonate type. These two factors indicate that the groundwater is recharged from a relatively localized source. As groundwater flows from the recharge area to the discharge area in a regional aquifer, the groundwater dissolves minerals in the sediments within the aquifer, increasing the total dissolved solids, chloride, and sulfate concentration.

TEMPERATURE

Water temperature was also used to indicate that the springs derive their flow from groundwater. In general, stream temperatures will be closely related to monthly mean air temperatures. Groundwater is generally warmer than stream temperature in the winter and cooler in the summer, varying by only a few degrees from the mean annual air

1	8D Spring, 7/88
2	8D Spring, 12/19/88
3	8D North Spring, 12/19/88
4	Palmer Spring, 7/88
5	Palmer Spring, 12/19/88
6	Fish Hatchery Spring, 12/1/88
7	Metro Well (Sec 20), 12/19/88
8	Gallager Well, 12/22/88
9	Scott Paper Well, 12/22/88
10	Fehr Well, 12/22/88
11	Smoke 'N Joe's Well, 7/88
12	Palmer Stream, 12/88
13	Air Shaft Spring, 7/88
14	Green River, 7/88
15	Green River, 12/22/88
16	Deep Creek, 12/22/88
17	Coal Creek, 12/22/88
18	Kanasket-Palmer Well, 12/88
19	Deep Lake, 5.0' Depth, 12/88
20	Deep Lake, 10.0' Depth, 12/88
21	Deep Lake, 18.0' Depth, 12/88
22	Fish Lake, 3.0' Depth, 12/88
23	Fish Lake, 6.0' Depth, 12/88
24	Cunningham Well, 12/88



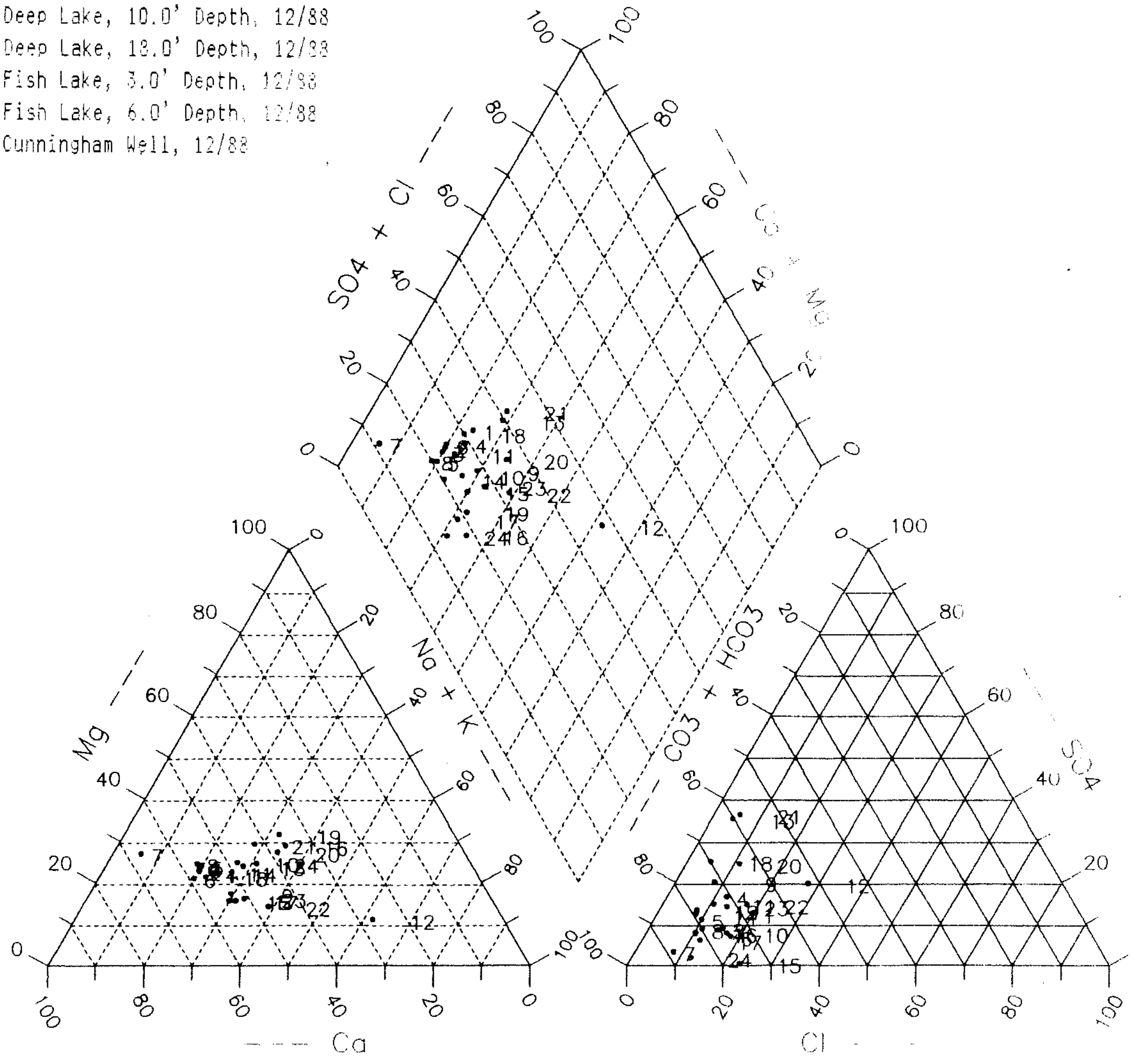


Figure 4-1 Trilinear Diagram

temperature. An example of this was cited by Richardson and others (1968, p. 48) for Icy Creek. The creek, which derives its flow from the fish hatchery spring, had temperature variations between 42° and 48°F. Its temperature was 47.5°F on November 30, 1988. The temperature of water flowing from the Palmer spring and Black Diamond springs in July and December 1988 was 47°F, which also was the temperature of the Black Diamond spring on January 25, 1963 (Richardson and others, 1968). These temperatures are very close to the mean annual air temperatures from the Buckley, Mud Mountain Dam, and Palmer precipitation station records (Table 2-2).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Groundwater flows from the higher elevations of the Cumberland basin in the east towards the Green River in the west. The groundwater flow direction could only be generally determined, and appears to be to the northwest in the Cumberland-Deep Lake area. The groundwater flow direction is not known in the area north of Cumberland because of the lack of wells. Groundwater probably flows to the northwest, but there may be a southwest flow component parallel to the general slope of the land in sections 16 and 20.

The majority of groundwater flow occurs in the Cumberland aquifer, composed of Vashon Drift sediments overlying the sandstones of the Puget Group. Many domestic wells in the basin withdraw water from the Cumberland aquifer, however, some wells have been completed in the Puget Group.

Hydrogeologic and groundwater quality data indicate that groundwater discharged by the Black Diamond springs and other springs along the Green River is recharged by precipitation in the Cumberland basin. The main sources of recharge are Coal Creek and Deep Creek, which supply approximately 73 cubic feet per second (cfs) of recharge to the aquifer.

POTENTIAL IMPACTS ON THE BLACK DIAMOND WATER SUPPLY

There are two potential impacts on the quality of water discharged by the Black Diamond and other local springs. Metro's Silvigrow program calls for the use of sections 16 and 20 for land application of sludge. Future growth in the Cumberland area population may also impact the quality of water.

Metro has purchased 1,175 acres in sections 16, 17, and 20 for the land disposal of municipal sewage sludge ("Silvigrow"). Of the 1,175 acres, only 785 acres are usable for sludge application by state standards. In a given year, the Silvigrow application area will vary. For example, Metro plans to apply Silvigrow to a 123-acre site in the northeast quarter and to 40 acres in the southwest quarter of section 16 in the spring and late summer of 1989. During the summer of 1989, 100 acres in the northwest quarter section 16 and 60 acres in the northeast quarter of section 20 will receive Silvigrow. Application rates for each part of the property are planned to coincide with the nutrient uptake requirements of the trees on the sites, to prevent nitrate contamination of the groundwater. Silvigrow contains about 5 percent total nitrogen (on a dry-weight basis) in the forms of organic nitrogen, ammonia, and nitrate. Not all of the nitrogen in Silvigrow will be converted to nitrate which may migrate to groundwater, however.

Using data from the "Best Management Practices For Use of Municipal Sewage Sludge" (Washington Department of Ecology, 1982) for sludge application to forest lands, 40 to 60 of tons of sludge per acre could be applied over a five-year period without causing the leaching of nitrogen. Metro plans a maximum loading rate of about 25 dry tons per acre over a 5-year period and will use less than 320 acres per year. Using the 30 inches per year of runoff for the area (Figure 3-2), one cfs of runoff would be generated from the 320 acres. This is less than 2 percent of the flow from the Palmer, Black Diamond, fish hatchery, and resort springs.

For a hypothetical worst-case example of the affect of Silvigrow application on the local groundwater, we assumed all of the nitrogen in a 320-acre, 5-percent nitrogen Silvigrow application area would be converted to free nitrate ions and that this amount of nitrate was added directly to the discharge from the resort spring or Black Diamond Springs. This is equivalent to adding approximately 708,000 pounds of nitrate to the spring flow. The amount of water discharged from the resort spring is about 2 cfs, or 3.9 billion pounds of water per year. This means that the added input of Silvigrow nitrate is less than 708,000 pounds of nitrate per year divided by 3,900,000,000 pounds of water discharged from this spring per year, or 0.0002 parts per million.

The EPA drinking water standard for nitrate is about 44 parts per million (10 milligrams per liter as nitrogen). Therefore, there should be no impact on the nitrate concentration in the resort spring water from Silvigrow application. The Black Diamond springs discharge about 10 times more water than the resort spring; therefore, the nitrate concentration in water discharged from these springs should also not be affected by Silvigrow application.

The presence of low-permeability glacial till beneath the ground surface may also act to retard the flow of nitrate-containing water from the Silvigrow application areas to local springs. From the above calculations, however, the presence (or even absence) of till beneath the application area should not be a major factor in the management of the Silvigrow application areas.

RECOMMENDATIONS

Metro plans to monitor soil moisture chemistry in the unsaturated zone beneath the Silvigrow application areas. Monitoring of groundwater quality upgradient from the springs should be performed to provide advance warning of contamination, whether from Silvigrow application or from increased population. One well was installed by Metro to monitor for potential groundwater contamination from the Silvigrow application area.

Because springs are the only source of water to Black Diamond and the Green River resort, we suggest that additional groundwater monitoring wells be installed. Four additional wells should be installed in sections 16 and 20 to provide further water quality and groundwater flow direction information. Wells should be installed along the north, west, and south boundaries of section 16. An additional well should be installed near the north boundary of section 20, upgradient from the resort spring. Additional house wells or monitoring wells should be used to provide background water quality data. A detailed monitoring plan was prepared by TCW Associates, Inc., based on discussions between Brown and Caldwell, Metro, the City of Black Diamond, and TCW Associates personnel.

CHAPTER 6

REFERENCES

Back, William, 1966, Hydrochemical facies and ground water flow patterns in northern part of Atlantic Coastal Plain: U.S. Geological Survey Professional Paper 498-A, p. A1 to A42.

Bouwer, Herman, 1978, Groundwater hydology: New York, McGraw-Hill.

Cedergren, H.R., 1967, Seepage, drainage, and flow nets: New York, John Wiley.

Cooper, H.H., Jr., Bredehoeft, J.D., and Papadopulos, I.S., 1967, Response of a finite diameter well to an instantaneous charge of water: Water Resources Research, v. 3, no. 1, p. 263-269.

Evans, G.W., 1912, The coal fields of King County: Washington Geological Survey Bulletin 3, 247 p.

Ferris, J.G., and Knowles, D.B., 1963, The slug-injection test for estimating the coefficient of transmissibility of an aquifer, <u>in</u> Methods of determining permeability, transmissibility, and drawdown: U.S. Geological Survey Water-Supply Paper 1536-I, p. 299-304.

Hvorslev, M.J., 1951, Time-lag and soil permeability in groundwater observations: U.S. Army Corps of Engineers Waterways Experiment Station, Bulletin No. 36.

Gower, H.D., and Wanek, A.A., 1963, Preliminary geologic map of the Cumberland quadrangle, King County, Washington: Washington Division of Mines and Geology Geologic Map GM-2, scale 1:24,000.

Luzier, J.E., 1969, Geology and ground-water resources of southwestern King County, Washington: Washington Department of Water Resources, Water-Supply Bulletin 28.

National Oceanic and Atmospheric Administration, 1988, Climatological data for Washington, monthly precipitation departure from individual station normals (1951-1980): National Climatic Data Center, Asheville, North Carolina, (November 1987 through October 1988).

Piper, A.M., 1944, A graphic procedure in the geochemical interpretation of water analyses: Transactions, American Geophysical Union, v. 25, p. 914-923.

Richardson, Donald, Bingham, J.W., and Madison, R.J., 1968, Water resources of King County Washington, with a section on Sediment in streams, by R.C. Williams: U.S. Geological Survey Water-Supply Paper 1852, 74 p.

Robinson, J.B., and Noble J.W., 1972, Water resource management study, City of Seattle; appendix A.

Toth, J., 1963, A theoretical analysis of groundwater flow in small drainage basins: Journal of Geophysical Research, v. 68, no. 16, p. 4795-4812.

Vine, J.D., 1969, Geology and coal resources of the Cumberland, Hobart, and Maple Valley quadrangles, King County, Washington: U.S. Geological Survey Professional Paper 624, 67 p.

Walton, W.C., 1962, Selected analytical methods for well and aquifer evaluation: Illinois State Water Supply Bulletin 49, 81 p..

Warren, W.C., Norbisrath, Hans, Grivetti, R.M., and Brown, S.P., 1945, Preliminary geologic map and brief description of the coal fields of King County, Washington: U.S. Geological Survey Coal Investigation Map (unnumbered), scale 1:31,680.

Washington Department of Ecology, 1982, Best management practices for use of municipal sewage sludge: WDOE 82-12, 88 p.

Willis, Bailey, 1886, Report on the coal fields of Washington Territory: U.S. Tenth Census, v. 15, p. 759-771.

Appendix A

Well Inventory

Table A-2. Cumberland Basin Well Inventory, T21N, R7E--Wells Completed at Puget Group Contact

Section	Owner	Borehole Depth (feet)	Casing Depth (feet)	Casing Diameter (inches)	Screened From (feet)	To	Static Water Level (feet)	Pumping Rate (gpm)	Specific Capacity (gpm/ft)	Test Duration (hrs)	Estimated T (gpd/ft)	Ground Elevation (feet)	Depth to Top of Till (feet)	Depth to Bottom of Till (feet)	Depth to Puget Group (feet)
20Q1	Cunningham	96	95	6	--	--	82	4	.67	2.5	925	800	--	--	95
29A1	Alexander	79	79	6	--	--	62	7	1	4	1480	800	3	62	79
29A3	Thiele	273	72	6	--	--	55	1	.005	4	4	800	50	72	72
29Q1	Gunderson	60	60	6	--	--	41	25	2.8	4	4474	780	3	56	60
32P3	Layton	78	78	6	--	--	60	25	3.1	2.5	4822	780	1	43	78?
32J2	Plese	200	144	6	--	--	100	2.5	.03	1	28	820	--	--	144
32N2	Fowler	136	136	6	--	--	60	8	.19	4	245	770	11	103	136
32Q3	Heigaard	118	118	6	--	--	71	10	.4	3.5	544	780	3	103	118
Average		130	98	6			66	10	1.0	3.2	1565	791			
Minimum		60	60	6			41	1	.005	1	4	770	1	43	60
Maximum		273	144	6			100	25	3.1	4	4822	820	50	103	144

Table A-3. Cumberland Basin Well Inventory, T21N, R7E--Wells Completed in Puget Group

Section	Owner	Borehole Depth (feet)	Casing Depth (feet)	Casing Diameter (inches)	Screened From (feet)	To	Static Water Level (feet)	Pumping Rate (gpm)	Specific Capacity (gpm/ft)	Test Duration (hrs)	Estimated T (gpd/ft)	Ground Elevation (feet)	Depth to Top of Till (feet)	Depth to Bottom of Till (feet)	Depth to Puget Group (feet)
28F1	Adcock	240	240	6	--	--	80	5	.05	1	49	860	--	--	45
28L2	Ross	160	160	4	140	160	21	12	.24	1	278	880	0	31	31
29B2	Walker	303	300	4	240	300	76	8	.04	1	38	810	5	104	104
29H2	Fehr	80	80	6	--	--	43	20	4	1	5919	810	20	56	60
29H3	Laier	300	300	6	260	300	80	60	1.2	1	1610	810	--	--	63
29H4	Moore	340	340	4	320	340	55	10	.07	1	71	810	--	--	56
29H5	Ferry	360	360	4	320	360	51	20	--	1	--	810	37	64	64
31G1	Bryant	180	180	4	120 150	140 170	40	16	.27	2.5	344	740	10	15	15
31L1	Puckett	165	165	4	115	135	25	.6	--	--	--	740	3	26	115
31M1	Bathke	120	120	6	--	--	64	8	.38	1	460	820	--	--	4
31N1	Isham	205	205	4	80 165	100 205	32	2.5	.015	1	13	820	--	--	4
31P1	Marshall	160	160	4	140	160	30	60	--	--	--	760	--	--	8
31P2	Henderkier	160	150	4	--	--	10	1.5	.013	2.5	12	760	--	--	14
Average		213	212	4.6	186	215	47	17	.6	1.3	879	802			
Minimum		80	80	4	80	100	10	.6	.013	1	12	740	0	15	4
Maximum		360	360	6	320	360	80	60	4	2.5	5919	880	37	104	115

Table A-1. Cumberland Basin Well Inventory, T21N, R7E--Wells Completed Above Puget Group Contact

Section	Owner	Borehole Depth (feet)	Casing Depth (feet)	Casing Diameter (inches)	Screened From (feet)	Screened To (feet)	Static Water Level (feet)	Pumping Rate (gpm)	Specific Capacity (gpm/ft)	Test Duration (hrs)	Estimated T (gpd/ft)	Ground Elevation (feet)	Depth to Top of Till (feet)	Depth to Bottom of Till (feet)	Depth to Puget Group (feet)
21M1	Scott Paper	125	100	6	77	83	76	8	1.1	1	1465	830	--	--	82
21N1	Houser	99	99	6	75	84	72	8	.67	1	854	830	11	20	84
28E1	Barquist	128	128	6	--	--	90	5	.27	1	316	840	84	114	)128
28F1	Adcock	240	240	6	--	--	80	5	.05	1	49	860	--	--	45?
28L1	Ehlers	89	89	6	--	--	42	80	4	1	5919	880	19	80	80
28L2	Ross	160	160	4	140	160	21	12	.24	1	278	880	0	31	31
28N1	Harmon	110	110	6	--	--	92	15	2.1	4.5	3314	880	3	72	115?
28N2	Krahn	120	120	6	--	--	87	30	1.7	1.5	2428	880	18	100	)120
29A2	Rogers	82	80	6	--	--	48	20	2	1	2800	800	7	56	)82
29A4	Elmendorf	80	80	6	--	--	50	30	1.5	1	2051	800	17	57	)80
29A5	Carstens	94	94	6	--	--	78	8	1.3	2.5	1893	800	3	68	)94
29B1	Norstrom	108	108	6	78	105	77	5	.31	4	417	810	3	19	105
29D1	Brozovic	77	77	6	--	--	32	40	5	1	7526	740	--	--	)77
29H1	Sonstang	74	74	6	--	--	60	15	3.8	3.5	6146	810	3	29	)74
31A1	Capelano	40	40	6	--	--	20	20	3.3	1	4810	720	22	31	)40
31B1	Markham	59	59	6	--	--	34	45	5.6	1	8502	720	0	49	)59
31J1	Petchwick	58	58	6	--	--	35	40	4	1.5	6105	740	3	49	)58
31J2	Harple	60	60	6	--	--	47	25	3.6	1	5283	740	2	53	)60
31L2	Folland	90	59	6	--	--	49	18	--	--	--	740	60	65	65
32P3	Layton	60	60	6	--	--	40	35	3.5	2.5	5493	780	1	43	)60
32C1	Metzler	80	80	6	--	--	50	30	2	2.5	3011	780	20?	60?	)80
32D1	Dunning	108	108	6	--	--	90	24	3	3	4718	740	--	--	)108
32D2	Gallagher	117	114	6	110	114	85	10	2	2	2959	740	15	92	)114
32E1	Gasser	79	79	6	--	--	45	45	4.5	1	6719	740	22	35	)79
32J1	Burris	98	98	6	--	--	79	20	1.4	1	1903	820	--	--	)98
32J2	Plese	100	100	6	--	--	83	15	1.7	1	2349	820	--	--	)100
32K1	Pinkerton	64	64	6	--	--	30	11	1.1	3	1603	800	0?	22?	)64
32L1	Olson	121	121	6	--	--	40	15	.25	3	322	780	14	23?	)121
32L2	Uhde	90	90	6	75	85	63	12	1.3	1	1756	780	1?	14?	)90
32M1	Scheiblenner	62	62	6	--	--	50	12	12	1	19268	760	52	60	)62
32M2	Benson	119	119	6	--	--	66	20	.65	1	826	760	86	118	)119
32M3	Hunt	90	90	6	--	--	58	25	2.1	3	3217	760	--	--	)90
32N1	Bullock	76	76	6	--	--	68	8	8	4	13745	760	3	71	)76
32N1	Bullock	102	102	6	--	--	77	10	1	4	1480	760	76	100	)102
32N3	Kent	74	74	6	69	74	50	20	20	4	36464	770	2	60	)74
32P1	Earley	169	139	6	--	--	60	20	.95	1	1249	760	54	61	)139
32Q1	Wedemeyer	78	73	6	--	--	60	20	6.7	2	10843	780	0	71	)78
32Q2	Koehn	60	60	6	--	--	42	25	3.1	2	4743	780	8	49	)60
32R1	Van Wierengen	96	96	6	--	--	60	20	1.2	1	1610	830	--	--	)96
32R2	Oster	101	101	--	--	--	88	--	--	--	--	--	--	--	--
32R2	Oster	120	120	6	--	--	95	16	16	2	27490	830	101?	106	)120
Average		97	94	6	89	101	60	21	3.4	1.9	5434	791			
Minimum		40	40	4	69	74	20	5	.05	1	49	720	0	19	31
Maximum		240	240	6	140	160	95	80	20	4.5	36464	880	86	118	105

Note: Top and bottom of till based on "hardpan" or "till" on drillers' logs
Estimated transmissivity (T) based on specific capacity (Q/s), pumping period data (t), and storage coefficient (S) of 0.001:
$T=Q/s(264 \log(T't/2693r^2S)-65.5)$, where r^2 is 0.25 ft^2 and $T'=2000$ Q/s.
Specific capacity data from bailer tests except for 20Q1, 29A5, 29B1, 31G1, 31L1, 31L2, 31P1, 32P3, 32C1, 32K1, and 32M3 where specific capacity test performed by air lift or submersible pump.

WELL LOGS IN THE VICINITY OF BLACK DIAMOND / CUMBERLAND SITE

T21N R7E SECTIONS 16 & 20

7	8	9	10
18	17	16	15
19	20	21	22
30	29	28	27

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

There is no well record found in Sections 9, 15, 16, 17, 18, 19, 20 & 30.

Well logs in Section 21:

NW¼/SW¼

0 - 40'	Gravel, large rock	Water level @ 76'	
40 - 79'	Gravel/boulder	Pumping rate	8 gpm
79 - 82'	Gravel, sand w/ some water	Drawdown	7'/1 hr.
82 - 125'	Sandstone		

SW¼/SW¼

0 - 3'	Topsoil	Water level @ 72'	
3 - 11'	Sand, gravel w/ some silt	Pumping rate	8 gpm
11 - 20'	Sand & gravel, cemented	Drawdown	12'/ 1 hr.
20 - 75'	Sand & gravel, dry		
75 - 84'	Sand & gravel, some water		
84 - 99'	Sandstone		

Well logs in Section 28:

NW¼/SW¼

0 - 1'	Topsoil	Water level @ 90'	
1 - 84'	Brown sand & gravel, dry	Pumping rate	5 gpm
84 - 106'	Blue till	Drawdown	18'/1 hr.
106 - 114'	Till, moisted		
114 - 128'	Sand & gravel, water bearing		

SE¼/NW¼

0 - 45'	Not recorded	Water level @ 80'	
45 - 240'	Sandstone, making water @ 195' to 240'	Pumping rate	5 gpm
		Drawdown	100'/1 hr.

SW¼/SW¼

0 - 3'	Topsoil	Water level @ 92'	
3 - 35'	Brown hardpan	Pumping rate	15 gpm
35 - 72'	Gray hardpan	Drawdown	7'/4½ hrs.
72 - 81'	Brown sand		
81 - 100'	Sand & gravel		
100 - 102'	Gray sand		
102 - 110'	Sand & gravel, water bearing		

NE¼/SW¼

0 - 2'	Topsoil	Water level @	42'
2 - 16'	Brown sand & gravel	Pumping rate	80 gpm
16 - 19'	Sand & gravel w/ some water	Drawdown	20'/1 hr.
19 - 80'	Till		
80 - 89'	Sand & gravel, water bearing		

SW¼/SW¼

0 - 3'	Topsoil	Water level @	87'
3 - 18'	Brown sandy loam	Pumping rate	30 gpm
18 - 36'	Brown hardpan	Drawdown	18'/1½ hrs.
36 - 39'	Coal		
39 - 90'	Gray hardpan		
90 - 100'	Gray hardpan w/ gravel		
100 - 120'	Sand & gravel, water bearing		

Well logs in Section 29:

NE¼/NE¼

0 - 2'	Topsoil	Water level @	55'
2 - 50'	Gravel	Pumping rate	1 gpm
50 - 72'	Till	Drawdown	205'/4 hrs.
72 - 240'	Sandstone		
240 - 273'	Sandstone, making water		

NE¼/NE¼

0 - 3'	Topsoil	Water level @	78'
3 - 7'	Red brown clay	Pumping rate	8 gpm
7 - 12'	Brown clay	Drawdown	6'/2½ hrs.
12 - 68'	Brown gravel with some clay		
68 - 94'	Gray gravel, water bearing		

NE¼/NE¼

0 - 1'	Topsoil	Water level @	48'
1 - 7'	Clayey gravel	Pumping rate	20 gpm
7 - 36'	Hardpan & boulders	Drawdown	10'/1 hr.
36 - 38'	Boulders		
38 - 56'	Hardpan		
56 - 61'	Sand with some silt, some seepage		
61 - 74'	Red sand & clay		
74 - 76'	Red sand, water bearing		
76 - 82'	Sand & gravel, water bearing		

NE¼/NE¼

0 - 2'	Topsoil	Water level @	50'
2 - 12'	Sandy clay	Pumping rate	30 gpm
12 - 17'	Sand & clay, some seepage	Drawdown	20'/1 hr.
17 - 23'	Clay		
23 - 57'	Hardpan & boulders		
57 - 59'	Boulders		
59 - 70'	Clay & gravel		
70 - 76'	Red clay & gravel		
76 - 80'	Red gravel with clay, water bearing		

NE¼/NE¼

0 - 3'	Topsoil
3 - 62'	Hardpan & gravel
62 - 74'	Sand & gravel
74 - 79'	Sand & gravel, water bearing

Water level	@ 62'
Pumping rate	7 gpm
Drawdown	7'/4 hrs

NW¼/NE½

0 - 3'	Topsoil
3 - 19'	Hardpan & boulders
19 - 20'	Black sand
20 - 80'	Loose sand & gravel, dry
80 - 83'	Sand & gravel, wet
83 - 105'	Sand, gravel & boulders
105 - 108'	Sandstone

Water level	@ 77'
Pumping rate	5 gpm
Drawdown	16'/4 hrs.

NW¼/NE¼

0 - 5'	Topsoil
5 - 24'	Hardpan & boulders
24 - 69'	Loose med. sand & fine gravel
69 - 84'	Brown silty sand w/ gravel
84 - 96'	Loose med. sand to fine gravel, wet
96 - 104'	Till
104 - 131'	Sandstone, some peat
131 - 139'	Peat
139 - 151'	Coal
151 - 160'	Sandstone
160 - 162'	Soft sandstone
162 - 383'	Layered peat, aandstone & coal

Water level	@ 76'
Pumping rate	8 gpm
Drawdown	200'/1 hr.

NW¼/NW¼

0 - 2'	Topsoil
2 - 60'	Sand & gravel w/ cobbles
60 - 77'	Sand & gravel, water bearing

Water level	@ 32'
Pumping rate	40 gpm
Drawdown	28'/1 hr.

SE¼/NE¼

0 - 20'	Black shale
20 - 32'	Gravel & clay
32 - 36'	Gravel w/ clay
36 - 40'	Gravel & boulders
40 - 60'	Gravel & clay
60 - 63'	Shale
63 - 64'	Sandstone
64 - 71'	Shale
71 - 118'	White sand & stone
118 - 130'	Coal
130 - 134'	White shale
134 - 180'	Black shale
180 - 193'	Sand w/ clay binder & coal
193 - 260'	Shale w/ clay and coal layers
260 - 272'	Sandstone & clay
272 - 300'	Basalt

Water level	@ 80'
Pumping rate	60 gpm
Drawdown	50'/1 hr.

SE¼/NE¼

0 - 20'	Sand & gravel
20 - 43'	Gravel w/ clay
43 - 56'	Hardpan & boulders
56 - 60'	Sand & gravel
60 - 80'	White sandstone

Water level @ 43'
Pumping rate 20 gpm
Drawdown 5'/1 hr.

SE¼/NE¼

0 - 20'	Sand w/ gravel
20 - 22'	Sand & gravel
22 - 56'	Gravel w/ clay
56 - 63'	Black coal
63 - 68'	Coal & sandstone
68 - 100'	Sandstone
100 - 120'	Shale
120 - 190'	Sandstone
190 - 220'	Black shale
220 - 250'	Basalt
250 - 263'	Shale
263 - 276'	Black coal
276 - 289'	Black coal & clay
289 - 340'	Shale

Water level @ 55'
Pumping rate 10 gpm
Drawdown 150'/1 hr.

SE¼/NE¼

0 - 3'	Topsoil
3 - 12'	Sand, gravel & cobble
12 - 37'	Cemented sand & gravel
37 - 64'	Blue till
64 - 120'	Sandstone
120 - 126'	Coal
126 - 187'	Sandstone
187 - 226'	White sandstone
226 - 231'	Brown sandstone
231 - 241'	White sandstone
241 - 250'	Coal
250 - 279'	Gray sandstone
279 - 295'	Gray siltstone
295 - 305'	Coal & shale
305 - 360'	Gray sandstone

Water level @ 51'
Pumping rate 20 gpm
Drawdown not recorded

SE¼/NE¼

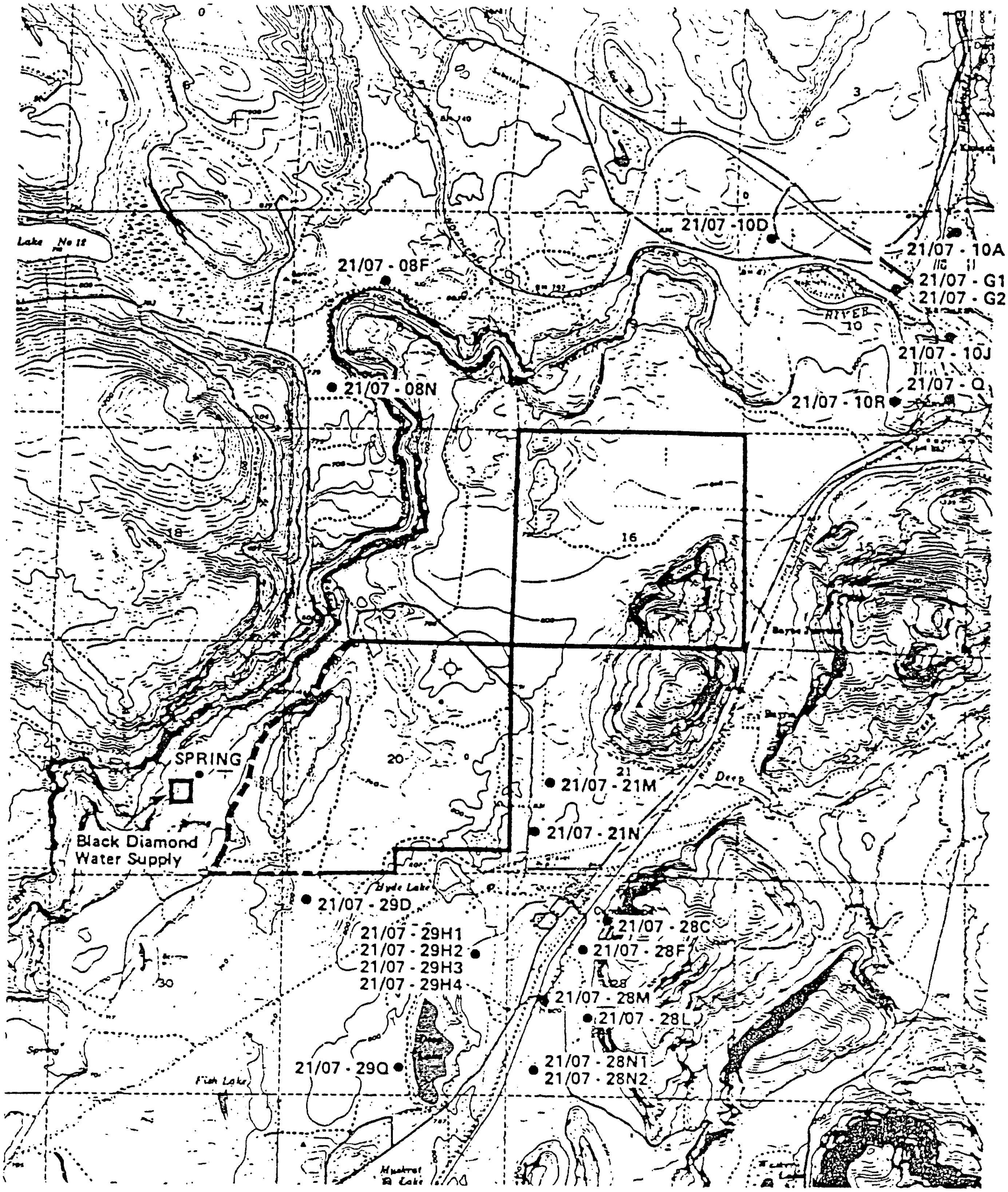
0 - 3'	Topsoil
3 - 29'	Hardpan
29 - 69'	Gravel
69 - 74'	Gravel, water bearing

Water level @ 60'
Pumping rate 15 gpm
Drawdown 4'/3½ hrs.

SW¼/SE¼

0 - 3'	Topsoil
3 - 56'	Hardpan
56 - 60'	Sand & gravel, water bearing
60 -	Bedrock

Water level @ 41'
Pumping rate 25 gpm
Drawdown 9'/4 hrs.



0 ½ 1

Scale in Miles

Township 21 North
Range 7 East

● Well Location
(from DOE Record)

-○- Location of Proposed
New Well

FIGURE

Weyerhaeuser Cumberland
Site Location Map

Appendix B

Field Data

APPENDIX

FIELD EXPLORATION

Nine test holes were drilled during the exploration. Test hole locations were selected based on the topographic feature, accessibility, available open space and without interrupting traffic flow. The locations are indicated on Figure 1, Vicinity Map. Except Test Hole B1, all other test holes were drilled primarily to explore whether glacial till underlies the site, the characteristics of overburden soils and ground water conditions. These test holes were terminated either in older soils, if glacial till was not encountered (Test Hole B3) or at a depth several feet into the till material (Test Holes B2 and B4 through B9). Test Hole B1 was drilled as a groundwater monitoring well as well as a subsurface exploration test hole. It was terminated in bedrock. The soils and ground water conditions encountered in the test holes are presented on Plate 1 through Plate 9.

Air-rotary drilling equipment was used for drilling. The presence of large boulders in the soil limits the choice of the method of drilling. An 8-inch diameter casing was used during the drilling of B1 and a 6-inch diameter casing was used for all other test holes. Except Test Hole B1, all other test holes were backfilled with bentonite grout after the completion of drilling. A 4-inch diameter Schedule 40 PVC pipe and screen was installed in Test Hole B1. The construction of monitoring well is described on Plate 1b.

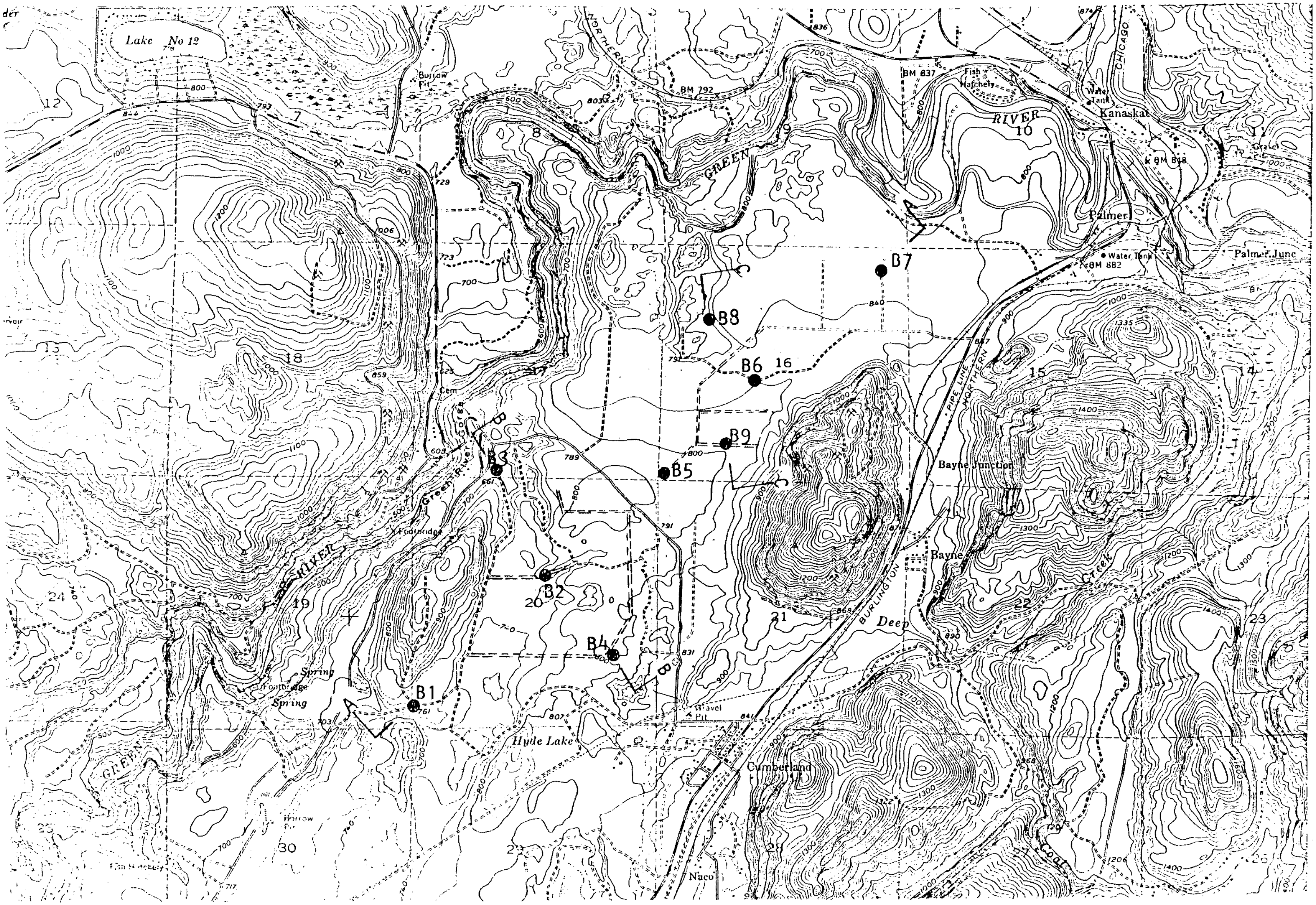
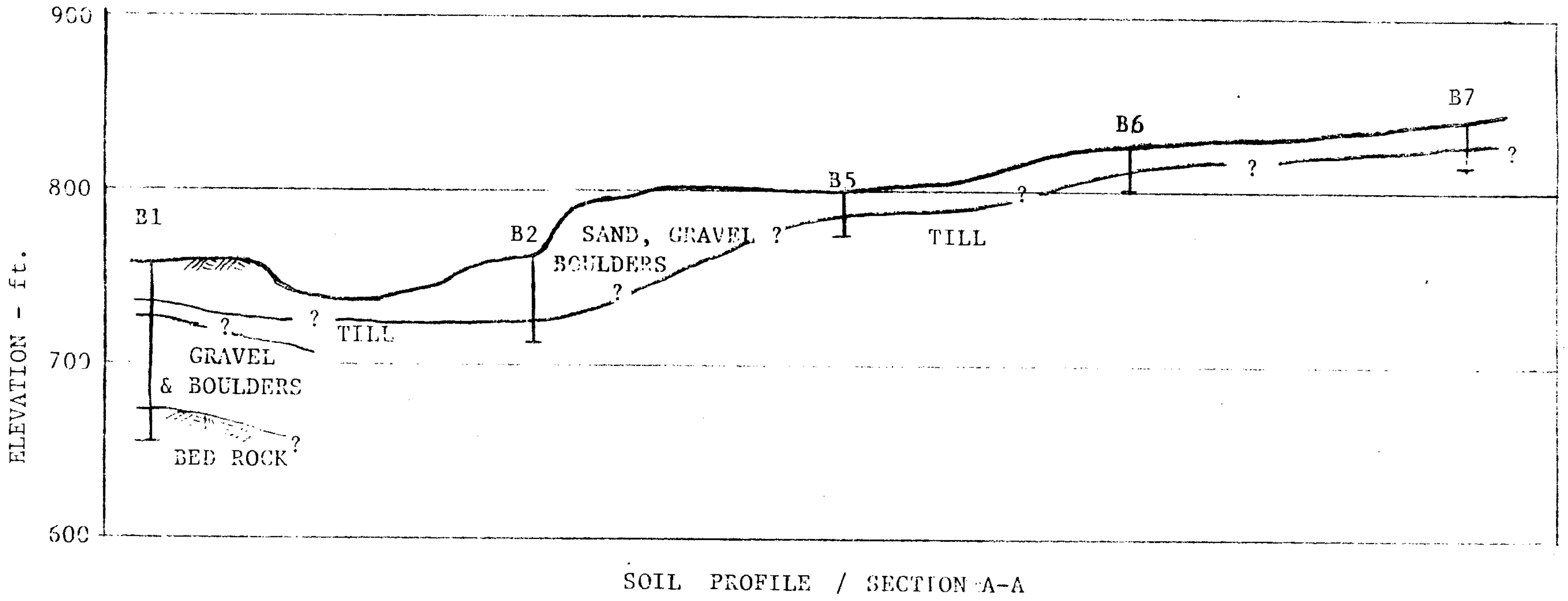


FIGURE 1. VICINITY MAP



NOTE: Section taken from southwest corner of Section 20 to northeast corner of Section 16

FIGURE 2. SOIL PROFILE / SECTION A-A

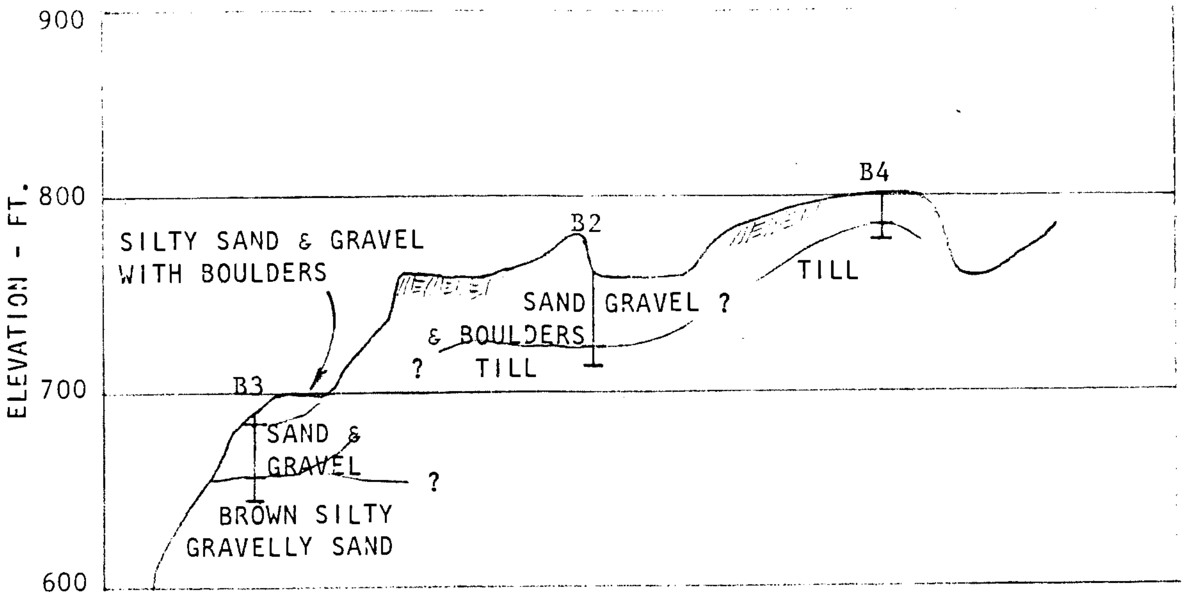


FIGURE 3. SOIL PROFILE / SECTION B-B

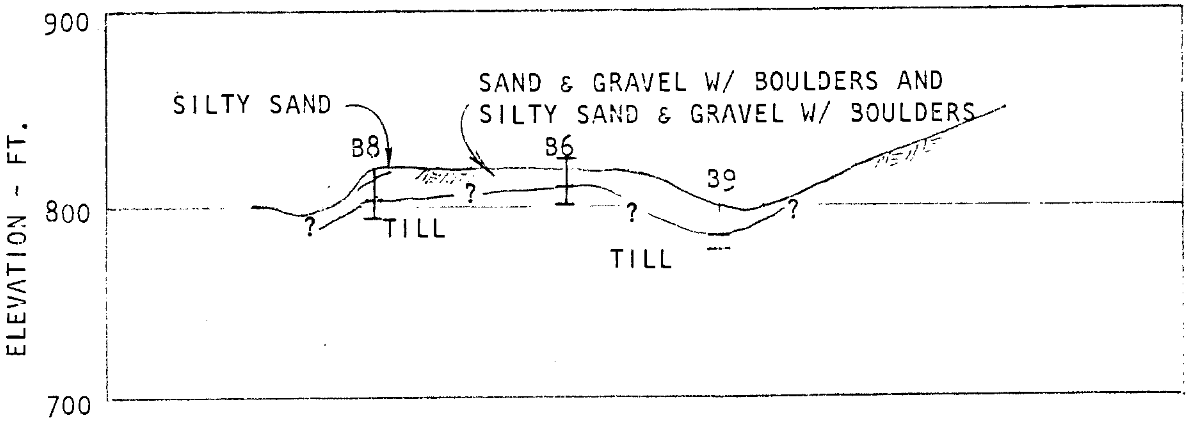


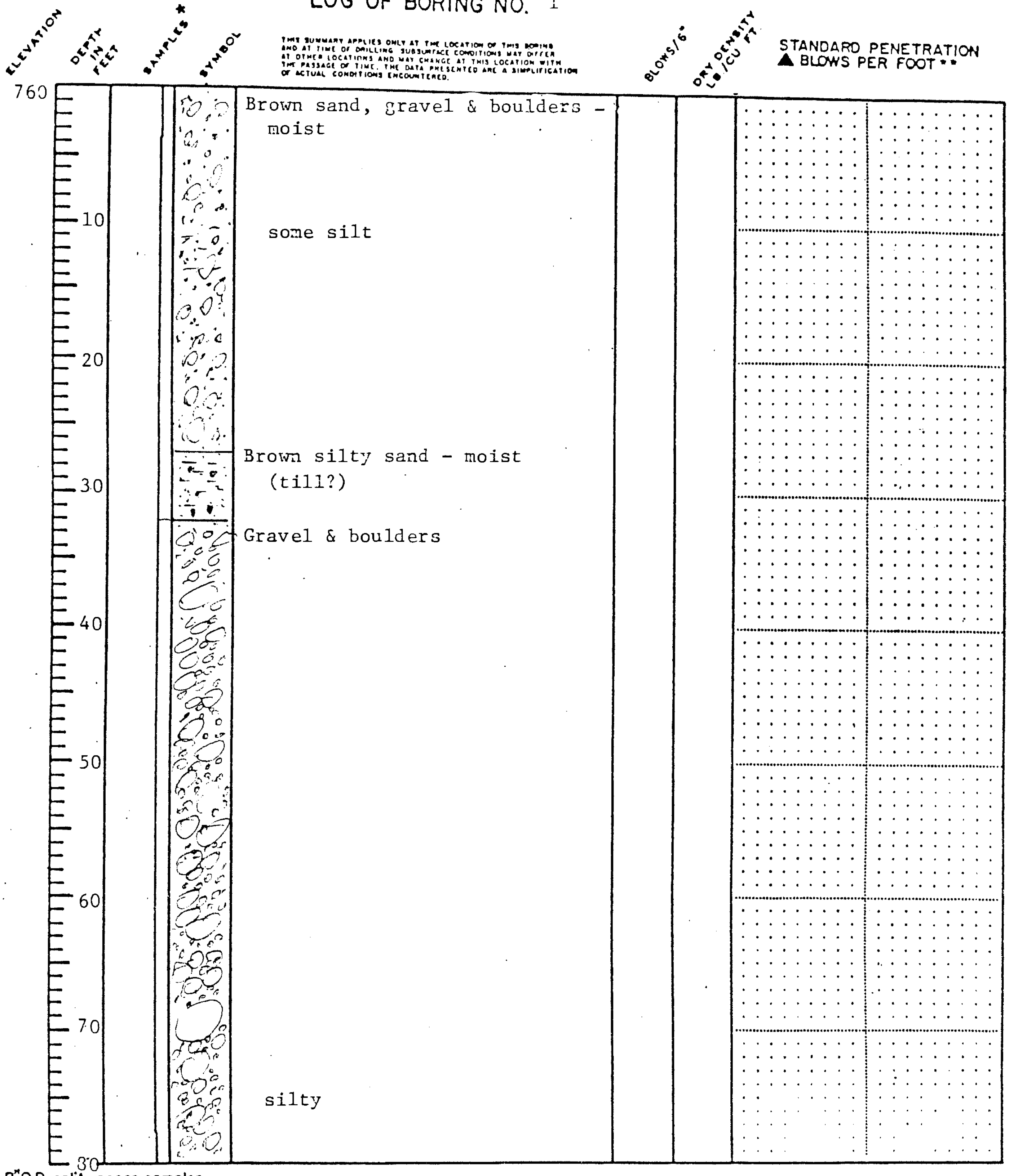
FIGURE 4. SOIL PROFILE / SECTION C-C

TCW

DATE DRILLED 11-9, 10-88

LOG OF BORING NO. 1

THIS SUMMARY APPLIES ONLY AT THE LOCATION OF THIS BORING AND AT TIME OF DRILLING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED ARE A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.



Brown sand, gravel & boulders - moist

some silt

Brown silty sand - moist (till?)

Gravel & boulders

silty

* A. 2" O.D. split-spoon sampler
B. 3" O.D. thin-wall sampler
C. 3-1/4" O.D. x 2-1/2" liner
D. 3-1/2" O.D. split barrel sampler
X. sample not recovered

** Standard Penetration Resistance except for 2" O.D. split-spoon samples estimated using non-standard procedures.

▽ water level
impervious seal
piezometer tip

WATER CONTENT - % dry weight
plastic limit ● liquid limit
natural water content

DATE DRILLED 11-9, 10-88

LOG OF BORING NO. 1 continued

ELEVATION	DEPTH IN FEET	SAMPLES*	SYMBOL		BLOWS/6"	DRY DENSITY LB/CU FT	STANDARD PENETRATION ▲ BLOWS PER FOOT**
680	80						
				Bed rock encountered water @ EL 673 overnight WL @ EL 672.3 producing rate 1 gpm			
	90						
	100			Upon completion, set 4" diameter PVC Schedule 40 pipe and screen in hole, pipe from 1' to 73' and 98' to 100', screen from 73' to 98'. Hole backfilled with No. 10/20 sand from 62' to 102', bentonite pellet from 60' to 62', bentonite & cement grout from surface to 60'.			

*
- A. 2" O.D. split-spoon sampler
- B. 3" O.D. thin-wall sampler
- C. 3-1/4" O.D. x 2-1/2" liner
- D. 3-1/2" O.D. split barrel sampler
- X. sample not recovered

** Standard Penetration Resistance except for 2" O.D. split-spoon samples estimated using non-standard procedures.

▽ water level
impervious seal
piezometer tip

WATER CONTENT - % dry weight
plastic limit ● liquid limit
natural water content

REPORT NUMBER **LR** Nº 3343

PREVIOUS RP'T. NO. 33434

PACIFIC TESTING LABORATORIES

ENGINEERING CONSULTATION
CONSTRUCTION INSPECTION
MATERIAL TESTING
ROOFING INSPECTION

EXECUTIVE OFFICES
3220 - 17TH AVENUE WEST • SEATTLE, WASHINGTON 98119
TELEPHONE (206) 282-0666 • TELECOPIER 282-0710

ULTRASONIC EXAMINATION
GEOLOGICAL SURVEYS
SOIL TEST BORING
CHEMICAL ANALYSIS

MAILING ADDRESS
METRO SATTELITE OFFICE
13547 S.E. 27TH PL
SUITE 3C
BELLEVUE WA 98

REPORTED BY SOGGE
DATE 11/10/88
PERMIT NUMBER —
CERTIFICATE NUMBER 8811-4005
ARCHITECT —
PROJECT METRO SLUDGE DISPOSAL SITE
ENGINEER METRO
LOCATION BLACK DIAMOND WA
PURCH. ORD. NUMBER VERBAL
CONTRACTOR RICHARDSON DRILLIN

DRILLING COMMENCED 9:15 AM AND CEASED AT 16:00 HOURS. 44 LINEAL FEET OF BORING MW#1 WAS COMPLETED. MATERIALS FROM 28 - 85 FEET ARE CHARACTERIZED AS GRAVELS WITH FREQUENT BOULDERS & COBBLES. AT 85 FEET BEDROCK WAS ENCOUNTERE AND CASING COULD NO LONGER BE ADVANCED. DRILLING WAS CONTINUED TO A DEPTH OF 102 FEET WITH NO CHANGE IN CONDITIONS. A SMALL QUANTITY OF STATIC WATER WAS ENCOUNTERED IN THE ROCK. A PRODUCTION RATE CHECK ACHIEVED ABOUT 1 GPM. DRILLING WAS SLOW DUE TO MATERIALS ENCOUNTERED AND 2 RIG BREAKDOWNS (HYDRAULIC PUMPING SYSTEM & HYDRAULIC HOSE FAILURE). THE ATTENDING DRILL CREW WAS EFFICIENT, HELPFUL AND VERY COOPERATIVE.

"This certification attests to the accuracy of the results obtained from the actual test performed and/or observations made within the scope of the work as defined above. Certification shall not be construed to represent inspection, approval or acceptance of other associated work or a warranty of design or workability of the specification requirements."

Certified Report by
Pacific Testing Laboratories

K Sogge

DATE 11/10/88

Copies to:

HOURS					MILE-AGE	OTHER EXPENSES	
COST CODE	ON	OFF	RT	OT		KIND	AMOUNT
10T10 40	7:15	12:00	4.75				
	12:30	17:00	4.5		72		
		TOTAL HOURS	9.25			TOTAL	

TIME VERIFIED BY:
REMARKS:
BILLED ON INVOICE NO.

04997

Certificate Number: 8811-4005 METRO BLACK DIAMOND SLUDGE DISPOSAL
Borehole Number : MW#1 - MONITORING WELL IN SECTION 20
Location : TOWNSHIP 21 NORTH RANGE 7 EAST SECTION 20
Date : NOVEMBER 9 & 10, 1988 8" borehole
* - Elevation approximated from topographic map.

Depth	Soil Type	Sample Number	Description	Elev.
0.0				760.0*
			DRILL RATE = 150 FT/HR	
5.0	SP	S1	Brown, GRAVELLY COARSE SAND, Moist	755.0
			DRILL RATE = 38 FT/HR BOULDERS	
10.0	SP	S2	Lt. Brown, GRAVELLY F-M SAND, Slightly Higher Silt Content, Moist BOULDERS DRILL RATE = 16 FT/HR	750.0
15.0	SP	S3	Olive Brown, GRAVELLY COARSE SAND, Moist DRILL RATE 23 FT/HR BOULDERS	745.0
20.0	SP	S4	Olive Brown, GRAVELLY SAND w/ROCK FRAGMENTS, Moist	740.0
			BOULDERS	
			DRILL RATE = 30 FT/HR	
27.0				733.0
30.0	SM	S5	Brown, SILTY SAND, Moist	730.0
32.0				728.0
			DRILL RATE = 7 FT/HR	
35.0			BOULDERS & COBBLES	
37.0	GP	S6	GRAVEL, Wet (Drill Water)	723.0
			DRILL RATE = 27 FT/HR	
40.0			BOULDERS & COBBLES	

PACIFIC TESTING LABORATORIES
3220 17th AVE. W. SEATTLE, WA.
98119 206-282-0666

METRO SLUDGE DISPOSAL
SITE - BLACK DIAMOND,
WASHINGTON

PROJECT NO. 8811-4005
DATE 11/10/88
DRAWN
ENGR./GEOL.
APPROVED

Certificate Number: 8811-4005 METRO BLACK DIAMOND SLUDGE DISPOSAL
Borehole Number : MW#1 CONTINUED PAGE 2
Location :
Date :

Depth	Soil Type	Sample Number	Description	Elev.
40.0			BOULDERS & COBBLES	720.0
			DRILL RATE = 27 FT/HR	
45.0	GP	S7	GRAVEL w/FRAGMENTS, Wet (Drill Water)	715.0
			COBBLES DRILL RATE = 30 FT/HR	
50.0	GP	S8	GRAVEL w/FRAGMENTS, Wet (Drill Water)	710.0
			COBBLES DRILL RATE 12 FT/HR	
55.0	GP	S9	GRAVEL w/FRAGMENTS, Wet (Drill Water)	705.0
			DRILL RATE = 9FT/HR	
			BOULDERS & COBBLES	
65.0	GP	S10	GRAVEL w/FRAGMENTS, Wet (Drill Water)	695.0
			Reduced BOULDERS & COBBLES	
			DRILL RATE = 46 FT/HR	
75.0	GP GM	S11	GRAVEL - SILTY GRAVEL w/FRAGMENTS, Wet (Drill Water)	685.0
			DRILL RATE = 19 FT/HR	
80.0	GP	S12	GRAVEL, Wet (Drill Water)	680.0

PACIFIC TESTING LABORATORIES

3220 17th AVE. W. SEATTLE, WA.
98110 206-282-0666

METRO SLUDGE DISPOSAL
SITE - BLACK DIAMOND,
WASHINGTON

PROJECT NO. 8811-4005
DATE 11/10/88
DRAWN
ENGR./GEOL.
APPROVED

04997

Certificate Number: 8811-4005 METRO - BLACK DIAMOND SLUDGE DISPOSAL
Borehole Number : MW#1 CONTINUED PAGE 3
Location :
Date :

Depth	Soil Type	Sample Number	Description	Elev.
80.0				680.0
85.0	ROCK		ENCOUNTERED BEDROCK Could no longer advance steel casing with additional drilling. Continued drilling open hole.	675.0
97.0	ROCK	S13	ROCK FRAGMENTS, Red-Gray-Tan	663.0
102.0	ROCK		BOTTOM OF HOLE	

87'8" ▼
11/11/88,
1245 hrs.

Some water encountered in rock formation. Drill water air lifted to clean out then hole allowed to stabilize. Water air lifted out of hole produced rate of about 1GPM.

PACIFIC TESTING LABORATORIES

3220 17th AVE. W. SEATTLE, WA.
98119 206-282-0666

METRO SLUDGE DISPOSAL
SITE - BLACK DIAMOND,
WASHINGTON

PROJECT NO. 8811-4005
DATE 11/10/88
DRAWN
ENGR./GEOL.
APPROVED

BROWN AND CALDWELL
CONSULTING ENGINEERS

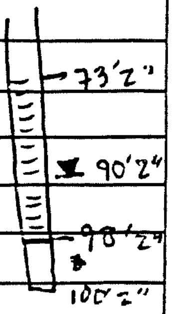
DAILY FIELD ACTIVITY LOG

DAILY LOG			
DATE	12	09	88
NO.			
SHEET	1	OF	2

ROJECT NAME: Black Diamond
PROJECT NUMBER: 4261
PROJECT MANAGER: G.Wyatt

DESCRIPTION OF DAILY ACTIVITIES AND EVENTS INCLUDING TIME:

1000: Arrived at site.
Static water level: 87'8" below T.O.C
2'6" T.O.C below vault
8' of water above bottom of screen



Setting pump intakes at: 95'6" below T.O.C.
Riser pipe: 3/4" i.d. poly pipe (black)
water service pipe: PE-3408, ASTM D-2239
Bottom of sounding pipe: 2'6" above intakes (sounder at 93' b.T.O.C.
1215: Static w.l. after pump installation: 87'8½" above T.O.C.

1220: Pump ready, hosing connected
initial water: 2.25 mV, orangish brown
Pumped for 2mins., began pumping air. ≈ 15 gals.
1228: w.l. @ 91'2" (not pumping) → minus 11.5" (riser) = 90'2½"
1238: w.l. @ 88'11" (T.O.C)
1242: 88'6½"
1249: 88'3"
1252: throttled down pump:
56: 1 bucket
59: 2nd bucket : S.Cond: 2.1 mV
1302: 2/3 buckets, pump shut off
1304: 92'4"
1305: 91'5¾"
1307: 90'9¼"

VISITORS ON SITE:
1311: 89'10½"

IMPORTANT TELEPHONE CALLS:
Static W.L. at 87'8" below T.O.C.
T.O.C. 2'6" below vault surface
Riser: 3/4" i.d., rises 11.5" above T.O.C.

WEATHER CONDITIONS:

B+C PERSONNEL ON SITE:

SIGNED:
DATE:

BROWN AND CALDWELL
CONSULTING ENGINEERS

DAILY FIELD ACTIVITY LOG

DAILY LOG
DATE 12 09 88
NO.
SHEET 2 OF 2

PROJECT NAME: Black Diamond
PROJECT NUMBER: 4261
PROJECT MANAGER:

DESCRIPTION OF DAILY ACTIVITIES AND EVENTS INCLUDING TIME:

1313: pumped w/throttle wide open
1314: 1 bucket, pumped dry
1325: 89'6" w.l.
1330: 89' 1/2" w.l.
1331.5: pumping
1332.5 " "
[illegible] dry
1345: began pumping
1346: 1.5 buckets, dry S.C.: 1.85 mV
1400: pumped 1.5 buckets, SC: 1.75 mV
1426: pumped 1.5 buckets: S.C: 1.65 mV
1440: " " " S.C.: 1.65 mV: water still orangish brown
Well will need to be pumped another 6-10 times at least, before water clears
1500: Left site

VISITORS ON SITE:

IMPORTANT TELEPHONE CALLS:

WEATHER CONDITIONS:

B+C PERSONNEL ON SITE:

SIGNED: Peter P. Bay Jr

DATE: 12/09/88

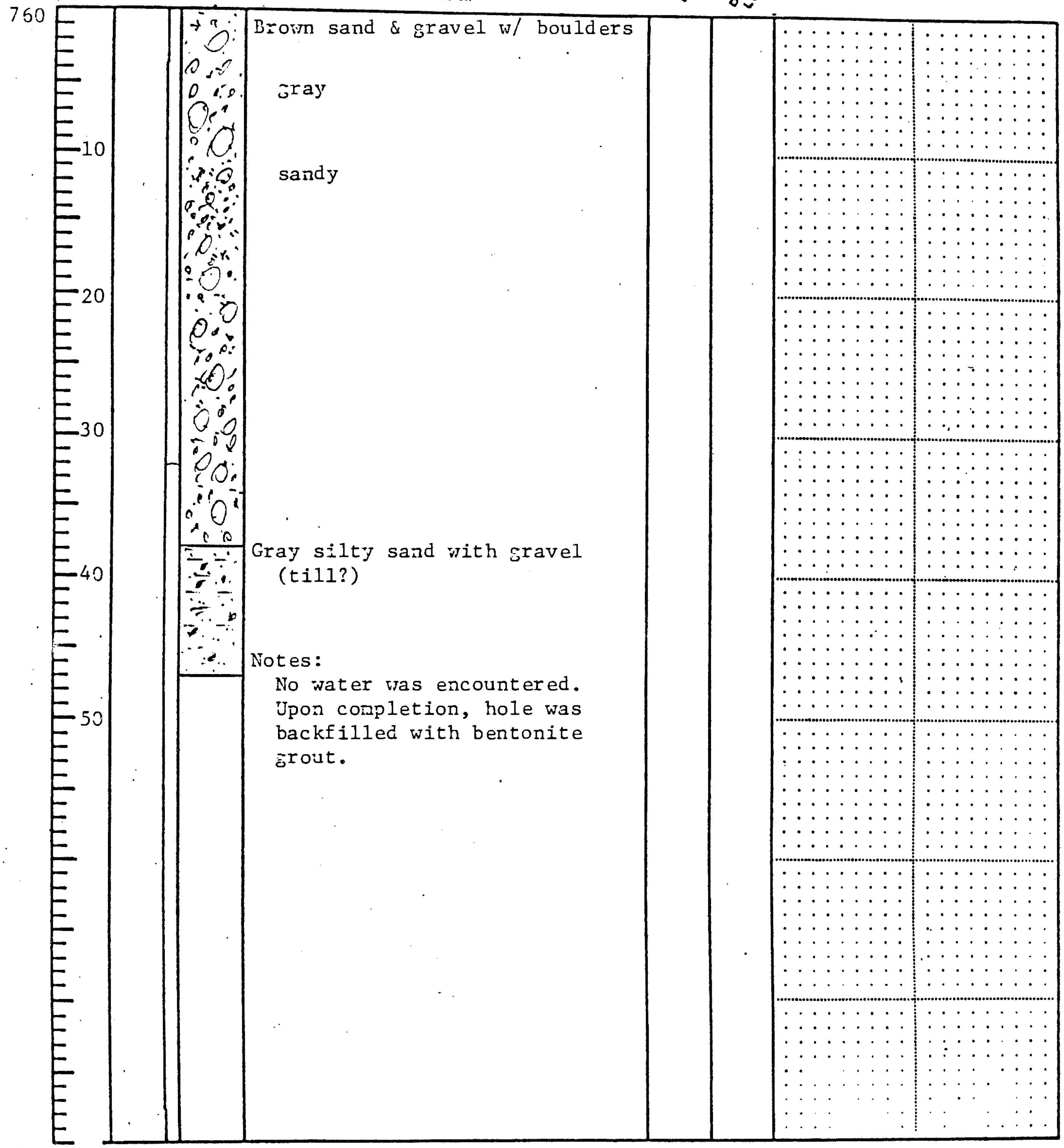
TCW

DATE DRILLED 11-14-88

LOG OF BORING NO. 2

THIS SUMMARY APPLIES ONLY AT THE LOCATION OF THIS BORING AND AT TIME OF DRILLING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED ARE A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.

ELEVATION | DEPTH IN FEET | SAMPLES * | SYMBOL | BLOWS/6" | DRY DENSITY LB/CU FT | STANDARD PENETRATION ▲ BLOWS PER FOOT **



Brown sand & gravel w/ boulders

gray

sandy

Gray silty sand with gravel (till?)

Notes:
No water was encountered. Upon completion, hole was backfilled with bentonite grout.

* A. 2" O.D. split-spoon sampler
B. 3" O.D. thin-wall sampler
C. 3-1/4" O.D. x 2-1/2" liner
D. 3-1/2" O.D. split barrel sampler
X. sample not recovered

** Standard Penetration Resistance except for 2" O.D. split-spoon samples estimated using non-standard procedures.

▽ water level
impervious seal
piezometer tip

WATER CONTENT - % dry weight
plastic limit ●— liquid limit
natural water content

TCW ASSOCIATES, INC.

DATE DRILLED 11-16-88

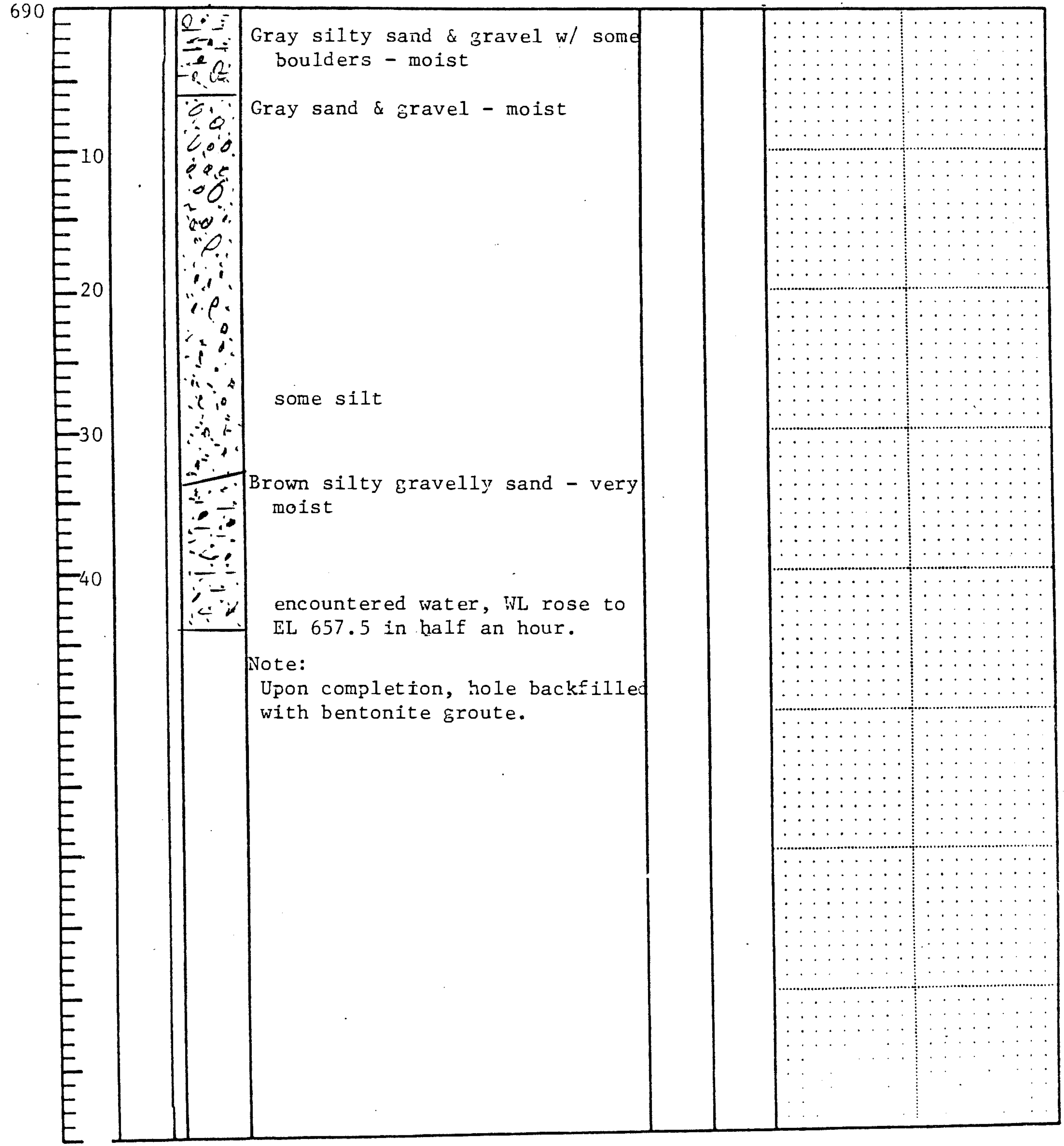
LOG OF BORING NO. 3

ELEVATION | DEPTH IN FEET | SAMPLES* | SYMBOL

THIS SUMMARY APPLIES ONLY AT THE LOCATION OF THIS BORING AND AT TIME OF DRILLING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED ARE A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.

BLOWS/6" | DRY DENSITY LB/CU FT

STANDARD PENETRATION
▲ BLOWS PER FOOT**



Gray silty sand & gravel w/ some boulders - moist

Gray sand & gravel - moist

some silt

Brown silty gravelly sand - very moist

encountered water, WL rose to EL 657.5 in half an hour.

Note:
Upon completion, hole backfilled with bentonite groute.

*
A. 2"O.D. split-spoon sampler
B. 3"O.D. thin-wall sampler
C. 3-1/4" O.D. x 2-1/2" liner
D. 3-1/2" O.D. split barrel sampler
X. sample not recovered

** Standard Penetration Resistance except for 2" O.D. split-spoon samples estimated using non-standard procedures.

water level
impervious seal
piezometer tip

WATER CONTENT - % dry weight
plastic limit ● liquid limit
natural water content

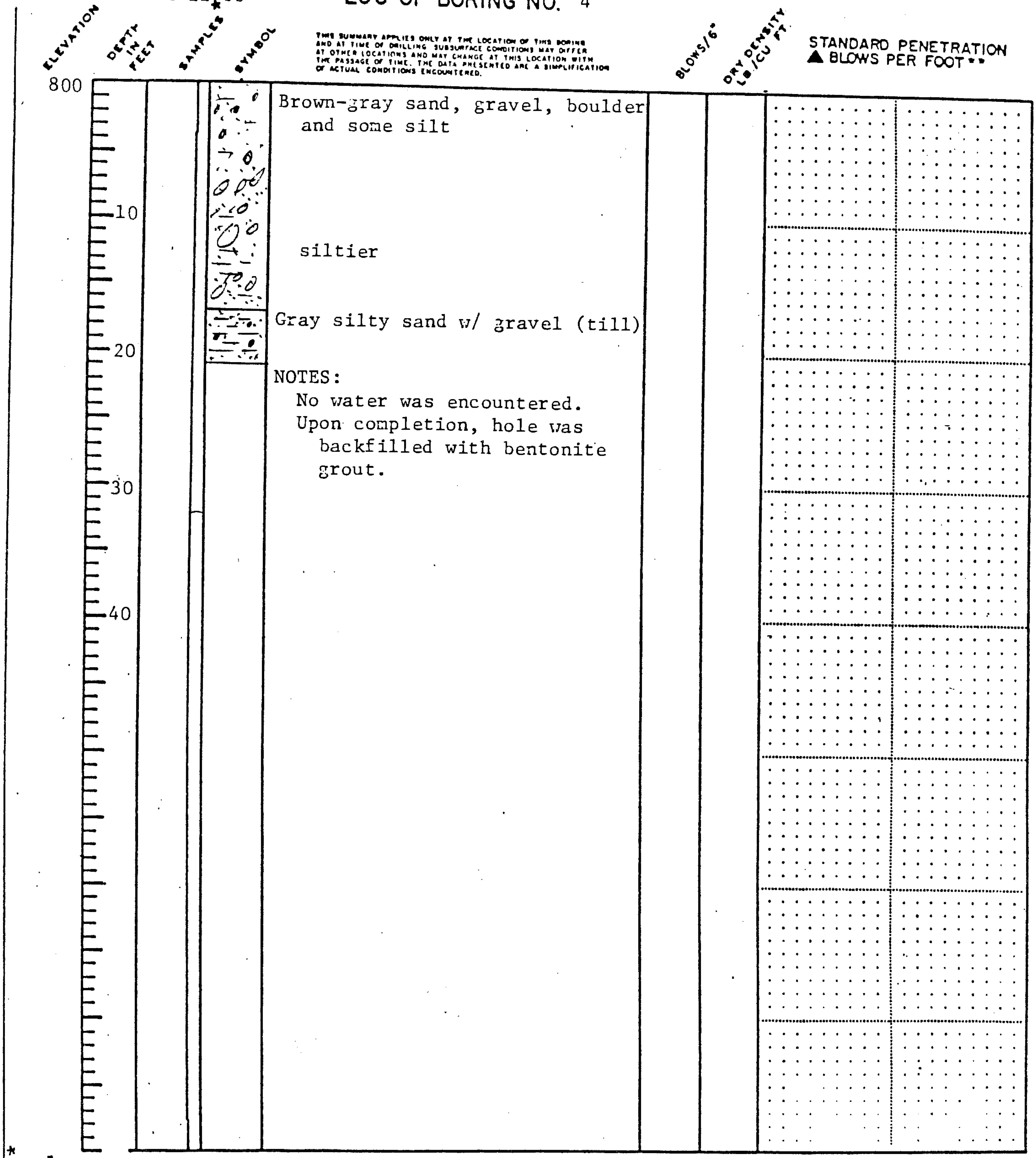
Approved for publication ______) ______

ICW

DATE DRILLED 11-22-88

LOG OF BORING NO. 4

THIS SUMMARY APPLIES ONLY AT THE LOCATION OF THIS BORING AND AT TIME OF DRILLING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED ARE A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.



Brown-gray sand, gravel, boulder and some silt

siltier

Gray silty sand w/ gravel (till)

NOTES:

No water was encountered.

Upon completion, hole was backfilled with bentonite grout.

*
A. 2" O.D. split-spoon sampler
B. 3" O.D. thin-wall sampler
C. 3-1/4" O.D. x 2-1/2" liner
D. 3-1/2" O.D. split barrel sampler
X. sample not recovered

** Standard Penetration Resistance except for 2" O.D. split-spoon samples estimated using non-standard procedures.

▽ water level
impervious seal
piezometer tip

WATER CONTENT - % dry weight
plastic limit ● liquid limit
natural water content

DATE DRILLED 11-22-88

LOG OF BORING NO. 5

ELEVATION

DEPTH IN FEET

SAMPLES*

SYMBOL

THIS SUMMARY APPLIES ONLY AT THE LOCATION OF THIS BORING AND AT TIME OF DRILLING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED ARE A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.

BLOWS/6"

DRY DENSITY LB/CU FT

STANDARD PENETRATION
▲ BLOWS PER FOOT**

800

10

20

30

Brown silty sand & gravel - moist

Gray sand & gravel w/ boulders

Gray silty sand with gravel (till)

NOTES:

No water was encountered.

Upon completion, hole was backfilled with bentonite grout.

*
A. 2" O.D. split - spoon sampler
B. 3" O.D. thin - wall sampler
C. 3-1/4" O.D. x 2-1/2" liner
D. 3-1/2" O.D. split barrel sampler
X. sample not recovered

** Standard Penetration Resistance except for 2" O.D. split - spoon samples estimated using non - standard procedures.

▽ water level

impervious seal

piezometer tip

WATER CONTENT - % dry weight

plastic limit ●— liquid limit

natural water content

Approved for publication

PLATE 5

TCW ASSOCIATES, INC.

DATE DRILLED 11-22-88

LOG OF BORING NO. 6

THIS SUMMARY APPLIES ONLY AT THE LOCATION OF THIS BORING AND AT TIME OF DRILLING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED ARE A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.

ELEVATION	DEPTH IN FEET	SAMPLES*	SYMBOL		BLOWS/6"	DRY DENSITY LB/CU FT	STANDARD PENETRATION ▲ BLOWS PER FOOT**
825				Brown silty sand & gravel w/ boulders			
				Gray sand & gravel w/ some silt & boulders			
	10						
				Gray silty sand w/ gravel (till)			
	20						
	30						

NOTES:
No water was encountered.
Upon completion, hole was backfilled with bentonite grout.

* A. 2" O.D. split-spoon sampler
B. 3" O.D. thin-wall sampler
C. 3-1/4" O.D. x 2-1/2" liner
D. 3-1/2" O.D. split barrel sampler
X. sample not recovered

** Standard Penetration Resistance except for 2" O.D. split-spoon samples estimated using non-standard procedures.

▽ water level
impervious seal
piezometer tip

WATER CONTENT - % dry weight
plastic limit ● liquid limit
natural water content

Approved for publication ________ by ________

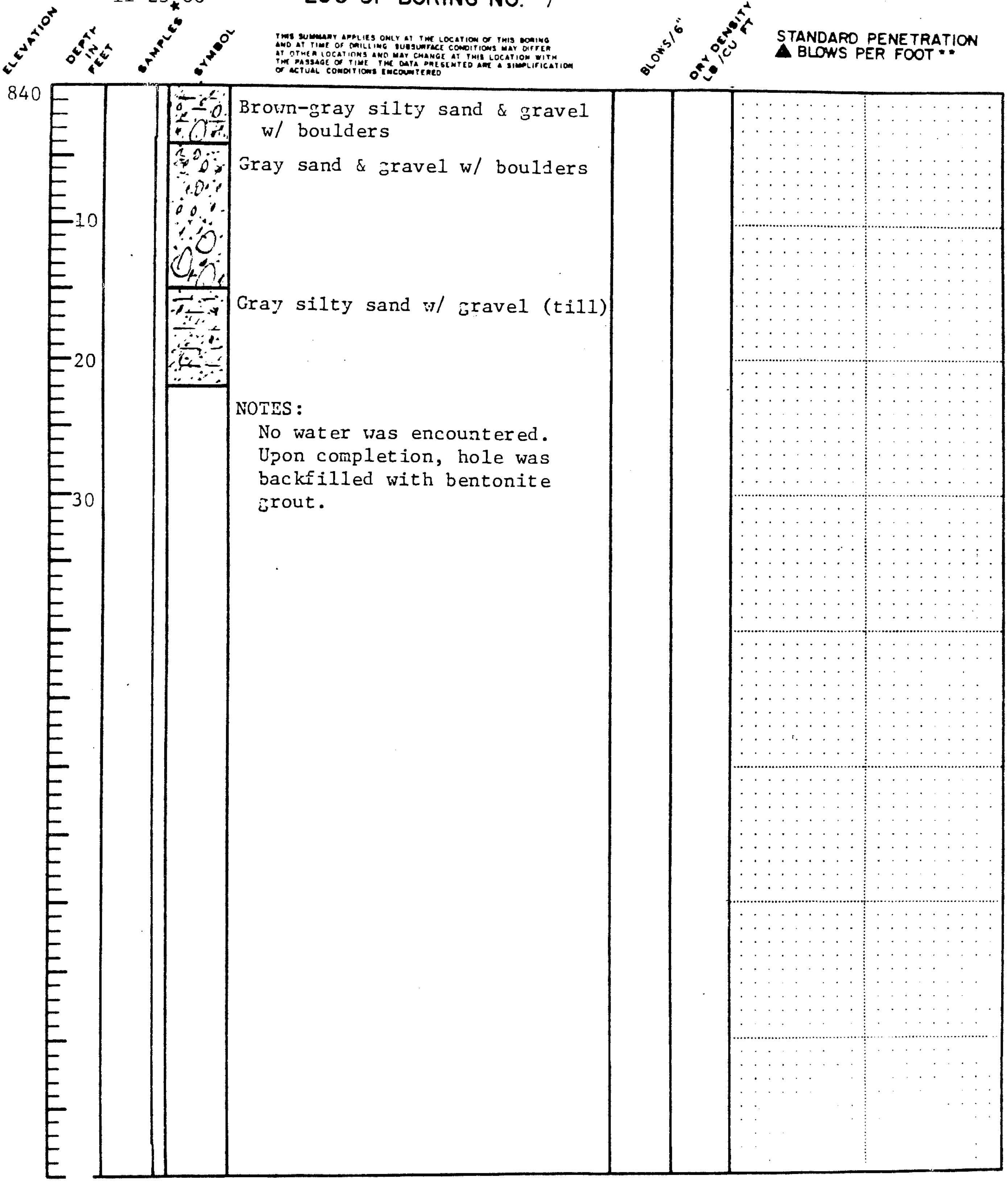
PLATE 6

TCW ASSOCIATES, INC.

DATE DRILLED 11-23-88

LOG OF BORING NO. 7

THIS SUMMARY APPLIES ONLY AT THE LOCATION OF THIS BORING AND AT TIME OF DRILLING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED ARE A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.



Brown-gray silty sand & gravel w/ boulders

Gray sand & gravel w/ boulders

Gray silty sand w/ gravel (till)

NOTES:
No water was encountered. Upon completion, hole was backfilled with bentonite grout.

*
A. 2" O.D. split-spoon sampler
B. 3" O.D. thin-wall sampler
C. 3-1/4" O.D. x 2-1/2" liner
D. 3-1/2" O.D. split barrel sampler
X. sample not recovered

** Standard Penetration Resistance except for 2" O.D. split-spoon samples estimated using non-standard procedures.

▽ water level
impervious seal
piezometer tip

WATER CONTENT - % dry weight
plastic limit ●— liquid limit
natural water content

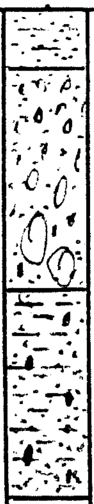
Approved for publication ______ by ______

PLATE 7

TCW ASSOCIATES, INC.

DATE DRILLED 11-23-88

LOG OF BORING NO. 8

ELEVATION	DEPTH IN FEET	SAMPLES*	SYMBOL	THIS SUMMARY APPLIES ONLY AT THE LOCATION OF THIS BORING AND AT TIME OF DRILLING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED ARE A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.	BLOWS/6"	DRY DENSITY LB/CU FT	STANDARD PENETRATION ▲ BLOWS PER FOOT**
820				Brown silty sand - wet			
				Gray sand & gravel w/ boulders			
	10						
				Gray silty sand with gravel (till)			
	20						
				NOTES: No water was encountered. Upon completion, hole was backfilled with bentonite grout.			
	30						

* A. 2" O.D. split-spoon sampler
B. 3" O.D. thin-wall sampler
C. 3-1/4" O.D. x 2-1/2" liner
D. 3-1/2" O.D. split barrel sampler
X. sample not recovered

** Standard Penetration Resistance except for 2" O.D. split-spoon samples estimated using non-standard procedures.

▽ water level
impervious seal
piezometer tip

WATER CONTENT - % dry weight
plastic limit ● liquid limit
natural water content

Approved for publication ________ by ________

TCW

DATE DRILLED 11-23-88

LOG OF BORING NO. 9

THIS SUMMARY APPLIES ONLY AT THE LOCATION OF THIS BORING AND AT TIME OF DRILLING. SUBSURFACE CONDITIONS MAY DIFFER AT OTHER LOCATIONS AND MAY CHANGE AT THIS LOCATION WITH THE PASSAGE OF TIME. THE DATA PRESENTED ARE A SIMPLIFICATION OF ACTUAL CONDITIONS ENCOUNTERED.

ELEVATION	DEPTH IN FEET	SAMPLES*	SYMBOL		BLOWS/6"	DRY DENSITY LB/CU FT	STANDARD PENETRATION ▲ BLOWS PER FOOT**
800				Gray silty sand & gravel with boulders and with sand & gravel layers			
	10						
				Gray silty sand with gravel (till)			
	20						
				NOTES: No water was encountered. Upon completion, hole was backfilled with bentonite grout.			
	30						

*
A. 2" O.D. split-spoon sampler
B. 3" O.D. thin-wall sampler
C. 3-1/4" O.D. x 2-1/2" liner
D. 3-1/2" O.D. split barrel sampler
X. sample not recovered

** Standard Penetration Resistance except for 2" O.D. split-spoon samples estimated using non-standard procedures.

water level
impervious seal
piezometer tip

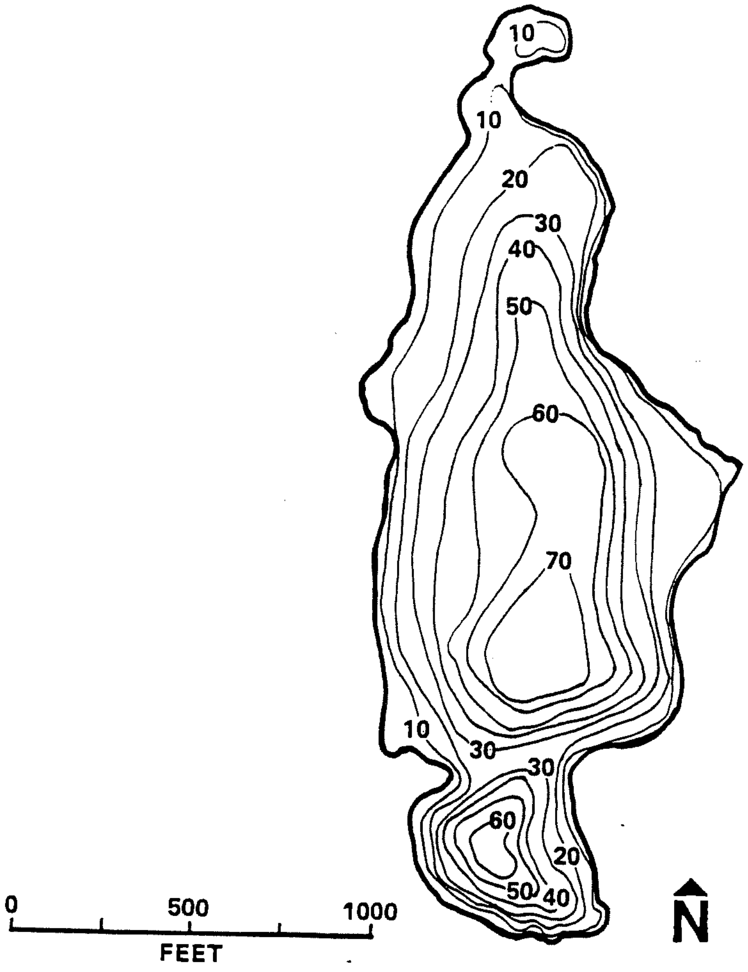
WATER CONTENT - % dry weight
plastic limit ● liquid limit
natural water content

WELL # SEC 20

WELL DIAMETER= 8.00 INCHES
CASING DIAMETER= 4.00 INCHES
VOLUME OF WATER REMOVED OR ADDED TO WELL=-6.50 GALLONS
LENGTH OF AQUIFER TESTED= 10.00 FEET
VALUE OF H0= 9.96 FEET
STATIC WATER LEVEL= 88.92 FEET

SLUG TEST DATA:

TIME SINCE TEST BEGAN (MINUTES)	WATER LEVEL (FEET)	DRAWDOWN (FEET)	HEAD RATIO	RECIPROCAL TIME (1/MINUTES)
1.67	92.44	3.52	.353	.600
2.22	91.76	2.84	.285	.451
2.90	91.46	2.54	.255	.345
3.55	91.22	2.30	.231	.282
4.78	90.87	1.95	.196	.209
5.25	90.75	1.83	.184	.190
5.80	90.65	1.73	.174	.172
6.50	90.53	1.61	.162	.154
7.27	90.42	1.50	.151	.138
7.77	90.36	1.44	.145	.129
8.57	90.26	1.34	.135	.117
9.62	90.15	1.23	.124	.104
11.60	90.00	1.08	.108	.086
13.37	89.85	.93	.093	.075
15.17	89.70	.78	.078	.066
18.33	89.50	.58	.058	.055
21.63	89.35	.43	.043	.046
25.97	89.20	.28	.028	.039



Deep Lake

Bathymetric map from Lakes of Washington, 1965.

NO DATA AVAILABLE

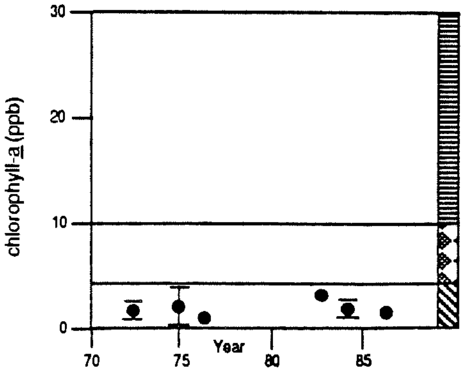


Figure A. Chlorophyll - a (May through October data)

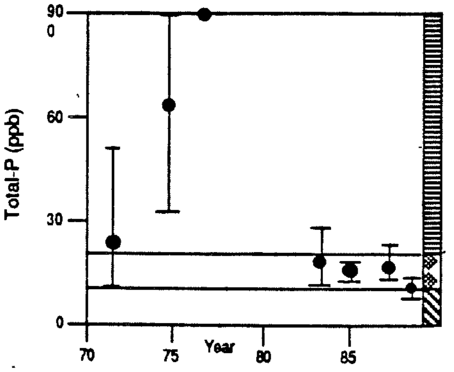


Figure B. Total-Phosphorus (January through May data)

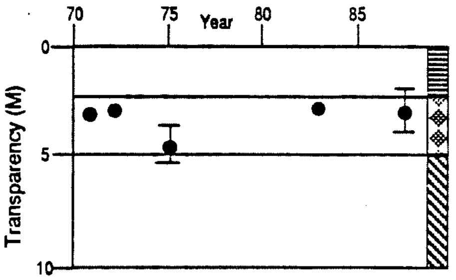


Figure C. Transparency (May through October data)

Maximum	Eutrophic Range ▤
● Average	Mesotrophic Range ▩
Minimum	Oligotrophic Range ▧

Figures A - C: Historical summary of chlorophyll (A), total - phosphorus (B), and transparency values (C).

DEEP LAKE KING COUNTY

LATITUDE 47°16'13" LONGITUDE 121°56'19" T21N-R7E-32
GREEN-DUWAMISH RIVER BASIN

PHYSICAL DATA

DRAINAGE AREA	3.92 SQ MI
ALTITUDE	770. FT
LAKE AREA	37. ACRES
LAKE VOLUME	1200. ACRE-FT
MEAN DEPTH	33. FT
MAXIMUM DEPTH	74. FT
SHORELINE LENGTH	1.3 MI
SHORELINE CONFIGURATION	1.6
DEVELOPMENT OF VOLUME	0.45
BOTTOM SLOPE	5.2 %
BASIN GEOLOGY	SED./META.
INFLOW	PERENNIAL
OUTFLOW CHANNEL	ABSENT

CULTURAL DATA

RESIDENTIAL DEVELOPMENT	5 %
NUMBER OF NEARSHORE HOMES	1
LAND USE IN DRAINAGE BASIN	
RESIDENTIAL URBAN	0 %
RESIDENTIAL SUBURBAN	1 %
AGRICULTURAL	6 %
FOREST OR UNPRODUCTIVE	91 %
LAKE SURFACE	2 %
PUBLIC BOAT ACCESS TO LAKE	--

WATER-QUALITY DATA (IN MG/L UNLESS OTHERWISE INDICATED)

SAMPLE SITE	1	
DATE	7/13/73	
TIME	1000	1010
DEPTH (FT)	3.	66.
TOTAL NITRATE (N)	0.13	0.42
TOTAL NITRITE (N)	0.01	0.00
TOTAL AMMONIA (N)	0.05	0.04
TOTAL ORGANIC NITROGEN (N)	0.13	0.10
TOTAL PHOSPHORUS (P)	0.011	0.015
TOTAL ORTHOPHOSPHATE (P)	0.005	0.005
SPECIFIC CONDUCTANCE (MICROMHOS)	62	72
WATER TEMPERATURE (DEG C)	19.9	4.9
COLOR (PLATINUM-COBALT UNITS)	10	25
SECCHI-DISC VISIBILITY (FT)	15	
DISSOLVED OXYGEN	9.8	1.2

LAKE SHORELINE COVERED BY EMERSED PLANTS	LITTLE OR NONE
LAKE SURFACE COVERED BY EMERSED PLANTS	NONE OR <1 %

DATE	7/13/73
TIME	1010
NUMBER OF FECAL COLIFORM SAMPLES	2
FECAL COLIFORM, MINIMUM (COL./100ML)	<1
FECAL COLIFORM, MAXIMUM (COL./100ML)	2
FECAL COLIFORM, MEAN (COL./100ML)	1

REMARKS

VERY FEW AQUATIC PLANTS WERE OBSERVED. THE INFLOW VIA DEEP CREEK DRAINS A LARGE AGRICULTURAL AREA AND THE SMALL TOWN OF CUMBERLAND. METRO OF SEATTLE STUDIED THE LAKE IN 1971-72.

FISH LAKE

KING COUNTY

LATITUDE 47*16' 7" LONGITUDE 121*57'17" T21N-R7E-31
GREEN-DUWAMISH RIVER BASIN

PHYSICAL DATA

DRAINAGE AREA	14.2 SQ MI
ALTITUDE	710. FT
LAKE AREA	18. ACRES
LAKE VOLUME	240. ACRE-FT
MEAN DEPTH	13. FT
MAXIMUM DEPTH	24. FT
SHORELINE LENGTH	0.99 MI
SHORELINE CONFIGURATION	1.7
DEVELOPMENT OF VOLUME	0.55
BOTTOM SLOPE	2.4 %
BASIN GEOLOGY	SED./META.
INFLOW	PERENNIAL
OUTFLOW CHANNEL	ABSENT

CULTURAL DATA

RESIDENTIAL DEVELOPMENT	5 %
NUMBER OF NEARSHORE HOMES	1
LAND USE IN DRAINAGE BASIN	
RESIDENTIAL URBAN	0 %
RESIDENTIAL SUBURBAN	0 %
AGRICULTURAL	5 %
FOREST OR UNPRODUCTIVE	95 %
LAKE SURFACE	<1 %
PUBLIC BOAT ACCESS TO LAKE	YES

WATER-QUALITY DATA (IN MG/L UNLESS OTHERWISE INDICATED)

SAMPLE SITE		
DATE	1	
TIME	7/10/73	
DEPTH (FT)	1500	1510
TOTAL NITRATE (N)	3.	15.
TOTAL NITRITE (N)	0.14	0.04
TOTAL AMMONIA (N)	0.01	0.00
TOTAL ORGANIC NITROGEN (N)	0.06	0.21
TOTAL PHOSPHORUS (P)	0.14	0.47
TOTAL ORTHOPHOSPHATE (P)	0.017	0.064
SPECIFIC CONDUCTANCE (MICROMHOS)	0.014	0.010
WATER TEMPERATURE (DEG C)	52	68
COLOR (PLATINUM-COBALT UNITS)	18.8	9.4
SECCHI-DISC VISIBILITY (FT)	5	15
DISSOLVED OXYGEN		8
	11.2	4.6

LAKE SHORELINE COVERED BY EMERSED PLANTS	1- 10 %
LAKE SURFACE COVERED BY EMERSED PLANTS	NONE OR <1 %

DATE	
TIME	7/10/73
NUMBER OF FECAL COLIFORM SAMPLES	1535
FECAL COLIFORM, MINIMUM (COL./100ML)	2
FECAL COLIFORM, MAXIMUM (COL./100ML)	9
FECAL COLIFORM, MEAN (COL./100ML)	17
	13

REMARKS

THE PERENNIAL INFLOW VIA COAL CREEK DRAINS A LARGE AREA COMPARED TO THE SIZE OF THE LAKE. THE LITTORAL BOTTOM IS SILT AND MUCK.

```
     WELL # SEC 20

--------------------

  PERMEABILITY BASED ON COOPER, BREDEHOEFT, AND PAPADOPULOS METHOD

            PERMEABILITY=1.41E-03/ MATCH TIME (IN MINUTES)
            STORAGE COEF=  .25    * ALPHA
       COMPUTER CALCULATES
            ALPHA= .10     MATCH TIME=  2.7
            PERMEABILITY= 5.29E-04 CM/SEC     STORAGE COEF=2.50E-02
            CORRELATION NUMBER=  1.00

--------------------

  PERMEABILITY BASED ON REGRESSION FIT OF HEAD RATIO DATA

            HVORSLEV PERMEABILITY=2.40E-03 / LAG TIME

       CALCULATED PERMEABILITY IS INVALID
       CALCULATIONS INDICATE THAT A VALUE OF   4.92 FEET FOR H0
            OR A VALUE OF    5.690 INCHES FOR EFFECTIVE CASING DIA.
            MAY YIELD BETTER RESULTS

--------------------

  PERMEABILITY BASED ON REGRESSION FIT OF DATA --- FERRIS & KNOWLES METHOD

            PERMEABILITY=3.51E-03 / SLOPE
            PERMEABILITY=4.11E-04 CM/SEC
                 REGRESSION STATISTICS
                      X ON Y
                        INTERCEPT=  .24
                        SLOPE=  8.3
                      Y ON X
                        INTERCEPT=  .17
                        SLOPE=  8.8
                      CORRELATION COEFFICIENT=  .97
```

DEEP LAKE

Deep Lake is in Nolte State Park near Cumberland, Washington (4 miles southeast of Black Diamond). This lake is the most remotely located of the 24 lakes studied in 1987. The lake covers only 37 acres but drains 2,500 acres of forest, much of which is harvested by the Weyerhauser Company. The lake deserves its name since its maximum depth is 74 feet and its average depth is 33 feet. The drainage basin is the least developed for residential use, of those lakes studied.

The lake cannot be rated for 1987 since no summer samples were taken, but the winter data show that the total-phosphorus concentration was just barely in the mesotrophic range and that the chlorophyll-a concentrations were in the oligotrophic range. Overall, the lake appears to be in the same condition as last year.

Several years ago, concern was expressed that logging activities in the drainage basin might have an adverse impact on the lake. Some siltation was noted during runoff events while the logging was in progress; however, long-term effects have not been apparent.

1987 Water Quality Data From Deep Lake
Lake Monitoring Volunteer - None

Date	Depth (Meters)	Total PO4 (ppm)	Chlor-a (ppb)	Trans (Meters)	Cond (µmho)	pH	Temp (°C)	DO (ppm)
Feb 26	1.0	.010	2.06	4.3	74	7.1	4.6	11.6
	5.0	.009			74	7.1	4.1	11.5
	10.0	.006			74	7.1	3.7	9.0
	18.0	.015			72	7.2	3.7	8.6
Mar 12	1.0	.015	2.64	3.0	70	8.1	7.1	11.6
	5.0	.008			70	7.9	5.9	11.2
	10.0	.001			70	7.9	4.7	9.9
	18.0	.012			70	8.2	4.8	6.0

Appendix C

Water Quality Data

Laucks 81 years
Testing Laboratories, Inc.
940 South Harney St., Seattle, WA 98108 (206) 767-5060 FAX 767-5063
Chemistry, Microbiology, and Technical Services

Certificate

BROWN & CALDWELL
SEATTLE

CLIENT: Brown & Caldwell
100 West Harrison Street
Seattle, WA 98119
ATTN: Glen Wyatt

LABORATORY NO. 13744

DATE: Jan. 10, 1989

Job No. 4261-11

REPORT ON: WATER

SAMPLE IDENTIFICATION: Submitted 12/20/88 and identified as shown below:

1) Sec 20 12/19/88 12:00 (Metro's monitoring well, Section 20)
2) BDWS 12/19/88 14:20 (Junction box for City water)
3) BDW Spring 3 12/19/88 15:00 (Black Diamond North Spring)

TESTS PERFORMED AND RESULTS:

	1	2	3
Total Coliform Count, MPN per 100mls	4.	<2.	<2.
Fecal Coliform Count, MPN per 100mls	<2.	<2.	<2.
pH, glass electrode at 25°C	7.0	6.9	6.7
Specific Conductivity, micromhos/cm at 25°C	190.	69.	76.
Color, units	--	<5.	<5.
Odor	--	1.	1.
Turbidity, Nephelometer units	--	<0.5	<0.5

Brown & Caldwell

LABORATORY NO. 13744

	parts per million (mg/L)		
	1	2	3
Total Dissolved Solids	110.	48.	45.
Dissolved Calcium	25.	7.	8.
Dissolved Magnesium	6.1	1.7	2.0
Dissolved Sodium	2.3	2.8	3.2
Dissolved Potassium	0.3	<0.1	<0.1
Dissolved Bicarbonate Alkalinity as CaCO3	80.	26.	28.
Dissolved Carbonate Alkalinity as CaCO3	<1.	<1.	<1.
Dissolved Chloride	2.	2.	2.
Dissolved Nitrate as N	1.2	0.7	0.7
Dissolved Sulfate as SO4	3.	3.	3.
MBAS	--	<0.1	<0.1
Total Hardness as CaCO3	--	24.	31.
Total Iron	2.2	0.03	<0.01
Total Manganese	0.13	<0.002	<0.002
Total Copper	--	<0.002	<0.002
Total Zinc	--	0.004	0.003
Total Arsenic	--	<0.005	<0.005
Total Barium	--	<0.02	<0.02
Total Cadmium	--	<0.002	<0.002
Total Chromium	--	<0.005	<0.005
Total Lead	--	<0.01	<0.01
Total Mercury	--	<0.001	<0.001
Total Selenium	--	<0.005	<0.005
Total Silver	--	<0.002	<0.002
Total Fluoride	--	<0.2	<0.2

Brown & Caldwell

LABORATORY NO. 13744

Note:

Samples for dissolved metals analysis were filtered by the laboratory through 0.45 micron filter prior to appropriate preservation and testing.

Key

< indicates "less than"

Respectfully submitted,

Laucks Testing Laboratories, Inc.

JM Owens

J. M. Owens

JMO:laj

Brown & Caldwell

LABORATORY NO. 13744

APPENDIX A

Method Blank Summary

Blank Name	Sample Numbers	Analyte	Result	Units	SDL	MDL
B1221AS.W01	2-3	Arsenic	<0.005	mg/L	0.005	0.005
B1221SE.W01	2-3	Selenium	<0.005	mg/L	0.005	0.005
B1222MBA.W01	2-3	MBAS	<0.1	mg/L	0.1	0.1
B1222IAI.W01	1-3	Chloride	<1.	mg/L	1.	1.
B1222IAI.W01	1-3	Nitrate	<0.2	mg/L	0.2	0.2
B1222IAI.W01	1-3	Sulfate	<1.	mg/L	1.	1.
B1222IAI.W01	2,3	Fluoride	<0.2	mg/L	0.2	0.2
B1227HG.W01	2,3	Mercury	<0.002	mg/L	0.001	0.001
B1228ALK.W01	1-3	Alkalinity	2.	mg/L	1.	1.
B0103HRD.W01	2,3	Hardness	<1.	mg/L	1.	1.
B0103TDS.W01	1-3	TDS	<2.	mg/L	2.	2.

SDL = Sample Detection Limit.
MDL = Method Detection Limit.

Brown & Caldwell

LABORATORY NO. 13744

APPENDIX B

Copy of Chain-of-Custody Document Attached

Laucks
Testing Laboratories, Inc.
940 South Harney St. Seattle Washington 98108 (206)767-5060

CHAIN OF CUSTODY RECORD

DATE 12/19/88 PAGE 1 OF 1

NAME Brown and Caldwell
ADDRESS 100 West Harrison, Ste 255
Seattle WA 98119
ATTENTION: GLENN WYATT
PROJECT NAME BENCH MARKING
JOB/P.O. NO. 4261-11
SAMPLER (SIGNATURE) (PRINTED NAME) GLENN M. WYATT

LAB NO.	LAB SA #	SAMPLE NO.	DATE	TIME	LOCATION	pH, SC, TDS	Total Fecal Coliform	Fe, Mn	Ca, Mg, Na, K	HCO_3, CO_3, Cl	NO_3, SO_4	Color, Odor, Turbidity	Cu, Surfactants, Zn	Hardness (total)	As, Ba, Cd, Cr, F	Pb, Hg, Se, Ag			NO. OF CONTAINERS	OBSERVATIONS, COMMENTS, SPECIAL INSTRUCTIONS
1		Sec 20	12/19	1200	Sec 20 well	X	X	X	X	X	X								4	Filter samples for
2		BDWS	12/19	1420	Wtr supply	X	X	X	X	X	X	X	X	X	X	X			6	major cations + anions
3		BASMAN63	12/19	1500	Abeln Spring	X	X	X	X	X	X	X	X	X	X	X			5	through 0.45 micron
																				filter before preserving;
																				report as dissolved.

RELINQUISHED BY
SIGNATURE
PRINTED NAME
COMPANY
DATE 12/19/88
TIME 1100

RECEIVED BY
SIGNATURE
PRINTED NAME
COMPANY
DATE
TIME

RELINQUISHED BY
SIGNATURE
PRINTED NAME
COMPANY
DATE
TIME

RECEIVED BY
Pam Johnson
SIGNATURE
Pam Johnson
PRINTED NAME
LAUCKS TESTING LABS
COMPANY
DATE 12/20
TIME 4:00

TOTAL NUMBER OF CONTAINERS:

INSTRUCTIONS:

1. Shaded areas for lab use only.
2. Complete in ballpoint pen. Draw one line through errors and initial.
3. Be specific in test requests.
4. Check off tests to be performed for each sample.
5. Retain final copy after signing.
6. Provide name and telephone of your contact person.

NAME GLENN WYATT
TELEPHONE 281-4000

SHIPMENT METHOD:

SPECIAL SHIPMENT, HANDLING OR STORAGE REQUIREMENTS:

Laucks 81 years
Testing Laboratories, Inc.
940 South Harney St., Seattle, WA 98108 (206) 767-5060 FAX 767-5063

Chemistry, Microbiology, and Technical Services

RECEIVED
17
BROWN & CALDWELL
SEATTLE

Certificate

CLIENT: Brown & Caldwell
100 West Harrison Street
Seattle, WA 98119
ATTN: Glen Wyatt

LABORATORY NO. 13758

DATE: Jan. 12, 1989

REPORT ON: WATER

SAMPLE IDENTIFICATION: Submitted 12/21/88 and identified as shown below:

1) 4261 No. 1 11:20 (Gallagher) (NW ¼, Sec 32)
2) 4261 No. 2 12:45 (Scott Paper) (SW ¼, Sec 21)
3) 4261 No. 3 13:05 (Fehr) (NE ¼, Sec 29)

TESTS PERFORMED AND RESULTS:

	1	2	3
Total Coliform Count, MPN per 100mls	<2.	<2.	<2.
Fecal Coliform Count, MPN per 100mls	<2.	<2.	<2.
pH, glass electrode at 25°C	7.0	6.7	6.6
Specific Conductivity, micromhos/cm at 25°C	95.	220.	82.
	parts per million (mg/L)		
Total Dissolved Solids	65.	140.	53.
Dissolved Iron	0.07	2.3	0.04
Dissolved Manganese	0.003	0.019	<0.002
Dissolved Calcium	11.	26.	8.
Dissolved Magnesium	2.9	5.1	2.5
Dissolved Sodium	4.	16.	5.
Dissolved Potassium	0.3	0.7	0.2
Bicarbonate Alkalinity as CaCO3	38.	78.	30.
Carbonate Alkalinity as CaCO3	<1.	<1.	<1.
Chloride	2.	3.	2.
Nitrate as N	0.7	1.3	1.1
Sulfate as SO4	4.	21.	3.
Ammonia as N	<0.01	<0.01	0.06

Brown & Caldwell

LABORATORY NO. 13758

Note

Samples for dissolved metals analysis were filtered by the laboratory through 0.45 micron filter prior to appropriate preservation and testing.

Key

< indicates "less than"

Respectfully submitted,

Laucks Testing Laboratories, Inc.

JM Owens

J. M. Owens

JMO:laj

Brown & Caldwell

LABORATORY NO. 13758

APPENDIX A

Method Blank Summary

Blank Name	Sample Numbers	Analyte	Result	Units	SDL	MDL
B1222IAI.W01	1-3	Chloride	<1.	mg/L	1.	1.
B1222IAI.W01	1-3	Nitrate	<0.2	mg/L	0.2	0.2
B1222IAI.W01	1-3	Sulfate	<1.	mg/L	1.	1.
B1228ALK.W01	1-3	Alkalinity	2.	mg/L	1.	1.
B1221TDS.W01	1-3	TDS	<2.	mg/L	2.	2.
B0111NH3.W01	1-3	Ammonia	<0.01	mg/L	0.01	0.01

SDL = Sample Detection Limit.
MDL = Method Detection Limit.

Brown & Caldwell

LABORATORY NO. 13758

APPENDIX B

Copies of Chain-of-Custody Documents Attached

CHAIN OF CUSTODY RECORD

BC Log Number ____________

Client name BROWN + CALDWELL

Project or PO# 4261

Address 100 W. Harrison St. #205

Phone # 281-4000

City, State, Zip Seattle WA

Report attention Glen Wyatt

Sampled by Peter Barry

Lab Sample number	Date sampled	Time sampled	Type* See key below	Sample description	Number of containers	Total Coliform	Fecal Coliform						Hazardous sample Special handling required	Remarks
1	11/22/88	0810	AQ	#1 Gallager	2	+	+							
2	(	0800	(	#2 Scott Paper	2	+	+							
3	)	0750	)	#3 Fehr	2	+	+							

	Signature	Print Name	Company	Date	Time
Relinquished by					
Received by					
Relinquished by					
Received by					
Relinquished by	Peter P. Barry Jr	Peter P. Barry Jr	Brown + Caldwell	12/22/88	0905
Received by Laboratory	Judy Ecklund	Judy Ecklund	Laucks Testing Lab	12/22/88	0905

BROWN AND CALDWELL LABORATORIES

☐ 1255 Powell Street, Emeryville, CA 94608 (415) 428-2300

☐ 373 South Fair Oaks Avenue, Pasadena, CA 91105 (818) 795-7553

☐ 1200 Pacifico Avenue, Anaheim, CA 92805

Note:

Samples are discarded 30 days after results are reported unless other arrangements are made.
Hazardous samples will be returned to client or disposed of at client expense.

*KEY: AQ—Aqueous NA—Nonaqueous SL—Sludge GW—Groundwater SO—Soil OT—Other PE—Petroleum

Laucks
Testing Laboratories, Inc.
940 South Harney St. Seattle Washington 98108 (206)767-5060

CHAIN OF CUSTODY RECORD

DATE 12/21/88 PAGE 1 OF 1

NAME BROWN + CALDWELL
ADDRESS 100 W. Harrison St. #205
Seattle WA 98119
ATTENTION: Glen Wyatt
PROJECT NAME Black Diamond
JOB/P.O. NO.

SAMPLER (SIGNATURE) (PRINTED NAME) Peter P. Barry Jr.

LAB NO.	LAB SA #	SAMPLE NO.	DATE	TIME	LOCATION	pH, SC, TDS	Total + Fecal Coliform	Fe, Mn, Ca, Mg	Na, K, HCO$_3$, CO$_3$	Cl, NO$_3$, SO$_4$	NO. OF CONTAINERS	OBSERVATIONS, COMMENTS, SPECIAL INSTRUCTIONS
1		#1	12/21/88	1120	Gallinger	X	X	X	X	X	4	Filter samples for major cations, anions, through 0.45 micron filter before preserving report as dissolved
2		#2	(	1245	Scott Paper	X	X	X	X	X	4	
3		#3	)	1305	Fehr	X	X	X	X	X	4	

RELINQUISHED BY
SIGNATURE
PRINTED NAME
COMPANY
DATE
TIME

RECEIVED BY
SIGNATURE
PRINTED NAME
COMPANY
DATE
TIME

RELINQUISHED BY
SIGNATURE
PRINTED NAME Peter P. Barry Jr.
COMPANY Brown and Caldwell
DATE 12/21/88
TIME 1440

RECEIVED BY Pam Johnson
SIGNATURE
PRINTED NAME Pam Johnson
LAUCKS TESTING LABS
COMPANY
DATE 12/21
TIME 5:40

TOTAL NUMBER OF CONTAINERS:

INSTRUCTIONS:

1. Shaded areas for lab use only.
2. Complete in ballpoint pen. Draw one line through errors and initial.
3. Be specific in test requests.
4. Check off tests to be performed for each sample.
5. Retain final copy after signing.
6. Provide name and telephone of your contact person.

NAME
TELEPHONE

SHIPMENT METHOD:

SPECIAL SHIPMENT, HANDLING OR STORAGE REQUIREMENTS:

Laucks 81 years
Testing Laboratories, Inc.
940 South Harney St., Seattle, WA 98108 (206) 767-5060 FAX 767-5063
Chemistry, Microbiology, and Technical Services

Certificate

CLIENT: Brown & Caldwell
100 West Harrison Street
Seattle, WA 98119
ATTN: Glen Wyatt

LABORATORY NO. 13434

DATE: Jan. 10, 1989

Job No. 4261-11

REPORT ON: WATER

SAMPLE IDENTIFICATION: Submitted 12/01/88 and identified as shown below:

1) Palmer 11/30/88 16:10 Palmer Spring
2) Fish 11/30/88 15:00 Fish Hatchery Spring

TESTS PERFORMED AND RESULTS:

	1	2
Total Coliform Count, MPN per 100mls	<2.	<2.
Fecal Coliform Count, MPN per 100mls	<2.	<2.
Specific Conductivity, micromhos/cm at 25°C	110.	60.
pH, glass electrode at 25°C	6.8	6.6
	parts per million (mg/L)	
Calcium	13.	6.0
Magnesium	3.4	1.3
Sodium	5.2	2.3
Potassium	0.2	<0.1
Chloride	2.	2.
Bicarbonate Alkalinity as CaCO3	44.	22.
Carbonate Alkalinity as CaCO3	<1.	<1.
Nitrate + Nitrite as N	0.76	0.69
Iron	0.07	0.03
Manganese	<0.002	<0.002
Total Dissolved Solids	83.	51.
Sulfate as SO4	6.	2.

Brown & Caldwell

LABORATORY NO. 13434

Key

< indicates "less than"

Respectfully submitted,

Laucks Testing Laboratories, Inc.

J. M. Owens

J. M. Owens

JMO:laj

Brown & Caldwell

LABORATORY NO. 13434

APPENDIX

Copy of Chain-of-Custody Document Attached

Laucks
Testing Laboratories, Inc.
940 South Harney St. Seattle. Washington 98108 (206)767-5060

CHAIN OF CUSTODY RECORD

DATE 12/1/88 PAGE 1 OF 1

NAME [illegible]
ADDRESS [illegible]
[illegible] 98117
ATTENTION: [illegible]
PROJECT NAME [illegible]
JOB/P.O. NO. 4261-11
SAMPLER (SIGNATURE) (PRINTED NAME)

TESTING PARAMETERS

LAB NO.	LAB SA #	SAMPLE NO.	DATE	TIME	LOCATION	Ca, Mg, Na, K	Cl, HCO_3, CO_3, NO_3	Fe, Mn, TDS, pH, SC	Total + Fecal Coliform										NO. OF CONTAINERS	OBSERVATIONS, COMMENTS, SPECIAL INSTRUCTIONS
		[illegible]	11/10	1610	[illegible]	✓	✓	✓	✓										4	Filter samples for
		[illegible]	11/10	1500	Fish [illegible]	✓	✓	✓	✓										4	cation + anion analysis
																				through 0.45 micron
																				filter prior to
																				preserving

RELINQUISHED BY
SIGNATURE
PRINTED NAME
COMPANY
DATE 12/1/88
TIME 1350

RECEIVED BY
SIGNATURE
PRINTED NAME
COMPANY
DATE
TIME

RELINQUISHED BY
SIGNATURE
PRINTED NAME
COMPANY
DATE
TIME

RECEIVED BY
SIGNATURE
PRINTED NAME
LAUCKS TESTING LABS
COMPANY
DATE
TIME

TOTAL NUMBER OF CONTAINERS: 8

SHIPMENT METHOD:

SPECIAL SHIPMENT, HANDLING OR STORAGE REQUIREMENTS:

INSTRUCTIONS:

1. Shaded areas for lab use only.
2. Complete in ballpoint pen. Draw one line through errors and initial.
3. Be specific in test requests.
4. Check off tests to be performed for each sample.
5. Retain final copy after signing.
6. Provide name and telephone of your contact person.

NAME

TELEPHONE

Please Print Plainly

JSE HEAVY PENCIL

Health Services Division
PUBLIC HEALTH LABORATORIES
1610 N.E. 150TH ST., SEATTLE, WA 98155-7224

WASHINGTON STATE DEPARTMENT OF SOCIAL & HEALTH SERVICES

WATER SAMPLE INFORMATION FOR RADIATION CHEMICAL ANALYSES

LAB. NUMBER	SYSTEM NAME:	SYSTEM I.D. NO.	SYSTEM CLASS (circle one)	SOURCE NUMBER
2939	City of Black Diamond Sample BDWS		1 2 3 4	

s this follow up of a previous out of compliance sample? Yes ☐ No ☑

If yes, what was the laboratory number of the previous sample?

COUNTY: King

SOURCE TYPE: ___ 1. SURFACE ✓ 2. SPRING ___ 3. WELL ___ 4. PURCHASE

IF SOURCE IS LAKE OR STREAM, ENTER NAME

IF SAMPLE WAS DRAWN FROM DISTRIBUTION SYSTEM IT WAS COLLECTED FROM SYSTEM AT: (ADDRESS)

DATE OF FINAL REPORT: 01/27/89

	DATE COLLECTED	DATE RECEIVED
1	12/19/88	12/20/88

SEND REPORT TO: (PRINT FULL NAME & ADDRESS)

Glen A. Wyatt
NAME
Brown and Caldwell
100 West Harrison
STREET
Seattle WA 98119
CITY ZIP CODE
TELEPHONE: (206) 281 4000
AREA CODE

Job # 4261-11

LABORATORY REPORT
(DO NOT WRITE BELOW THIS LINE)

ANALYSES	LESS THAN <	RESULTS pCi/L	*MCL pCi/L	COMPLIANCE YES	COMPLIANCE NO	CHEMIST INITIALS
Gross Alpha	<	1.0		✓		[illegible]
Uranium		.				
Gross Alpha minus Uranium		.	15			
Radium-226		.	3			
Radium-228		.				
Radium-226 Plus Radium-228		.	5			
		.				
		.				
		.				
Gross Beta		.	50			
Strontium-89		.	80			
Strontium-90		.	8			
Cesium-134		.	80			
Iodine-131		.	3			
Tritium		.	20,000			

LABORATORY SUPERVISOR (Name or Initials) MS

CHARGE: $45.00

REMARKS:

*MCL is the maximum contaminant Level Allowed
pCi/L is picoCuries per liter

DSHS 4-92H (Rev. 3/88) -68-

DISTRIBUTION: White—DSHS Laboratory & Data Processing Green—DSHS Billing Yellow—Water Supplier Pink—Seattle Engineer Office Gold—District Engineer or Local Health Dept.

HEAVY PENCIL

Health Services Division
PUBLIC HEALTH LABORATORIES
1610 NE 150th Seattle, Washington 98155

WATER SAMPLE INFORMATION FOR TRIHALOMETHANE CHEMICAL ANALYSES

RECEIVED
27
BROWN & CALDWELL
SEATTLE

OTE
O NOT WRITE IN SHADED AREAS

UMBER	CO.	CITY	DATE RECEIVED	DATE COLLECTED	COLLECTED BY
970048	—	—	12/21/88	12/19/88	Gle Wyatt Brown + Caldwell TELEPHONE 206 281 4000

[illegible] NO ----

SYSTEM NAME BDWS
City of Black Diamond

COUNTY King

MPLE LOCATION /—

THIS SAMPLE TAKEN
U BEFORE ✓ TREATMENT
T AFTER —

IF TAKEN AFTER TREATMENT IT WAS
— FILTERED — FLUORIDATED
— CHLORINATED — WATER SOFTENER TYPE USED

OR SOURCE
MPLE ONLY

SOURCE TYPE: — 1 SURFACE ✓ 2 SPRING — 3 WELL — 4 PURCHASE

SOURCE NO.

IF SOURCE IS LAKE OR STREAM, ENTER NAME

OR DISTRIBUTION
AMPLE ONLY

IF SAMPLE WAS DRAWN FROM DISTRIBUTION SYSTEM, IT WAS COLLECTED FROM SYSTEM AT (ADDRESS OR LOCATION)

DATE OF FINAL REPORT: 1/19/89

RKS:

SEND REPORT TO: (PRINT FULL NAME & ADDRESS)

Glen M. Wyatt
Name
Brown and Caldwell
100 West Harrison
Street
Seattle WA 98119
City Zip Code
Telephone: (206) 281 4000
Area Code

(DO NOT WRITE BELOW THIS LINE)

LABORATORY REPORT

Contaminant	Maximum Allowable Level (mg/l)	Found mg/l	MRL mg/l	Compliance	
				In	Out
Chloroform		N.D.	0.0005	✓	
Dichlorobromomethane		N.D.	0.0005	✓	
Dibromochloromethane		N.D.	0.0005	✓	
Bromoform		N.D.	0.0005	✓	
Total Trihalomethane	0.100	N.D.		✓	

MRL = Minimum Reporting Level

State of Washington
Department of Social and Health Services
Division of Health
Public Health Laboratories
1610 N.E. 150th St., Seattle, WA 98155
(206)361-2898

RECEIVED
JAN 12 1989
BROWN & CALDWELL
SEATTLE

Lab Number : 5400793
Date collected : 12/19/88
Date Received : 12/20/88
Date Tested : 12/21/88 18:53
Data File : >1L21M::D4

Customer : BLACK DIAMOND WATER SUPPLY/GLEN WYATT
Address : BROWN & CALDWELL 100 W. HARRISON
City : SEATTLE
State, Zip : WA., 98119
County : KING

Miscellaneous Sample Information : 5400793

System ID Number : 072207
System Name : BLACK DIAMOND WATER

Non-Composited Samples

DSHS Source Number : NA
Source Name : BDWS

Composited Samples

Number of Sources Used in Composite : NA
DSHS Source #'s Composited : NA

Analysis of Individual Sources Necessary: NA

Analyst : PAMELA MS
Instrument : 1

Date of Report : 1/4/89
Analyst's Initials : PWN
Supervisor's Initials : JD

charge \$200$^{\underline{00}}$

Results of Analysis by EPA Method 524

REGULATED COMPOUNDS

EPA Code #	Compound Name	MCL(ug/l)	* Amount (ug/l)	Compliance
2976	VINYL CHLORIDE	2	0.0	YES
2977	1,1-DICHLOROETHYLENE	7	0.0	YES
2981	1,1,1-TRICHLOROETHANE	200	0.0	YES
2982	CARBON TETRACHLORIDE	5	0.0	YES
2990	BENZENE	5	0.0	YES
2980	1,2-DICHLOROETHANE	5	0.0	YES
2984	TRICHLOROETHYLENE	5	0.0	YES
2969	P-DICHLOROBENZENE	75	0.0	YES

*Note: An Amount of 0.0 ug/l indicates that the true concentration is less than the detection limit of the method (0.5 ug/l for all compounds).

Lab Number : 5400793
Data File : >1L21M::D4

Results of Analysis by EPA Method 524
(continued)

Unregulated Compounds

Monitoring Required

EPA Code #	Compound Name	*Amount (ug/l)
2210	CHLOROMETHANE	0.0
2214	BROMOMETHANE	0.0
2216	CHLOROETHANE	0.0
2979	T-1,2,-DICHLOROETHYLENE	0.0
2978	1,1-DICHLOROETHANE	0.0
2416	2,2-DICHLOROPROPANE	0.0
2380	CIS-1,2-DICHLOROETHYLENE	0.0
2941	CHLOROFORM (THM)	0.0
2410	1,1-DICHLOROPROPENE	0.0
2983	1,2-DICHLOROPROPANE	0.0
2408	DIBROMOMETHANE	0.0
2943	BROMODICHLOROMETHANE (THM)	0.0
2991	TOLUENE	0.0
2985	1,1,2-TRICHLOROETHANE	0.0
2987	TETRACHLOROETHYLENE	0.0
2412	1,3-DICHLOROPROPANE	0.0
2944	CHLORODIBROMOMETHANE (THM)	0.0
2989	CHLOROBENZENE	0.0
2986	1,1,1,2-TETRACHLOROETHANE	0.0
2992	ETHYL BENZENE	0.0
2995	M/P-XYLENE	0.0
2997	O-XYLENE	0.0
2996	STYRENE	0.0
2942	BROMOFORM (THM)	2.2
2993	BROMOBENZENE	0.0
2414	1,2,3-TRICHLOROPROPANE	0.0
2988	1,1,2,2-TETRACHLOROETHANE	0.0
2965	O-CHLOROTOLUENE	0.0
2966	P-CHLOROTOLUENE	0.0
2967	M-DICHLOROBENZENE	0.0
2968	O-DICHLOROBENZENE	0.0

*Note: An Amount of 0.0 ug/l indicates that the true concentration is less than the detection limit of the method (0.5 ug/l for all compounds).

Lab Number : 5400793
Data File : >1L21M::D4

Results of Analysis by EPA Method 524
(continued)

Unregulated Compounds

Discretionary

EPA Code #	Compound Name	*Amount (ug/l)
2218	TRICHLOROFLUOROMETHANE	0.0
2430	BROMOCHLOROMETHANE	0.0
2994	ISOPROPYLBENZENE	0.0
2998	N-PROPYLBENZENE	0.0
2424	1,3,5-TRIMETHYLBENZENE	0.0
2426	TERT-BUTYLBENZENE	0.0
2418	1,2,4-TRIMETHYLBENZENE	0.0
2428	SEC-BUTYLBENZENE	0.0
2030	P-ISOPROPYLTOLUENE	0.0
2422	N-BUTYLBENZENE	0.0
2378	1,2,4-TRICHLOROBENZENE	0.0
2248	NAPHTHALENE	0.0
2246	HEXACHLOROBUTADIENE	0.0
2420	1,2,3-TRICHLOROBENZENE	0.0

*Note: An Amount of 0.0 ug/l indicates that the true concentration is less than the detection limit of the method (0.5 ug/l for all compounds).

Please Print Plainly

USE HEAVY PENCIL

Health Services Division

PUBLIC HEALTH LABORATORIES

1610 N.E. 150TH ST., SEATTLE, WA 98155-7224

WASHINGTON STATE DEPARTMENT OF SOCIAL & HEALTH SERVICES

WATER SAMPLE INFORMATION FOR RADIATION CHEMICAL ANALYSES

LAB. NUMBER	SYSTEM NAME:	SYSTEM I.D. NO.	SYSTEM CLASS (circle one)	SOURCE NUMBER
2238	City of Black Diamond BD SPRING 3		1 2 3 4	

Is this follow up of a previous out of compliance sample? Yes ☐ No ☑

If yes, what was the laboratory number of the previous sample? _ _ _ _ _ _ _

COUNTY King

SOURCE TYPE: __ 1. SURFACE __ 3. WELL ✓ 2. SPRING __ 4. PURCHASE

IF SOURCE IS LAKE OR STREAM, ENTER NAME

IF SAMPLE WAS DRAWN FROM DISTRIBUTION SYSTEM IT WAS COLLECTED FROM SYSTEM AT: (ADDRESS)

DATE OF FINAL REPORT 02/27/89

	DATE COLLECTED	DATE RECEIVED
1	12/19/88	12/20/88

SEND REPORT TO: (PRINT FULL NAME & ADDRESS)

NAME Glen M. Wyatt

Brown and Caldwell

STREET 100 West Harrison

CITY Seattle WA ZIP CODE 98119

TELEPHONE: (206) 281-4000 AREA CODE

Job #4261-11

LABORATORY REPORT
(DO NOT WRITE BELOW THIS LINE)

ANALYSES	LESS THAN <	RESULTS pCi/L	*MCL pCi/L	COMPLIANCE YES	COMPLIANCE NO	CHEMIST INITIALS
Gross Alpha	<	1.0		✓		
Uranium		.				
Gross Alpha minus Uranium		.	15			
Radium-226		.	3			
Radium-228		.				
Radium-226 Plus Radium-228		.	5			
Gross Beta		.	50			
Strontium-89		.	80			
Strontium-90		.	8			
Cesium-134		.	80			
Iodine-131		.	3			
Tritium		.	20,000			

LABORATORY SUPERVISOR (Name or Initials) MS

CHARGE: $45.00

REMARKS:

*MCL is the maximum contaminant Level Allowed
pCi/L is picoCuries per liter

DSHS 4-92H (Rev. 3/88) -88-

DISTRIBUTION: White—DSHS Laboratory & Data Processing Green—DSHS Billing Yellow—Water Supplier Pink—Seattle Engineer Office Gold—District Engineer or Local Health Dept.

F HEAVY PENCIL

Health Services Division
PUBLIC HEALTH LABORATORIES
1610 NE 150th Seattle, Washington 98155

WATER SAMPLE INFORMATION FOR TRIHALOMETHANE CHEMICAL ANALYSES

NOTE
DO NOT WRITE IN SHADED AREAS

NUMBER 39T0007
CO.
CITY
DATE RECEIVED 12/21/88
DATE COLLECTED 12/19/88
COLLECTED BY Glen Wyatt Brown and Caldwell
TELEPHONE 206 281 4000

SYSTEM NAME BD SPRING 3 CITY OF BLACK DIAMOND
COUNTY KING

SAMPLE LOCATION 1 —

THIS SAMPLE TAKEN U BEFORE ✓ / T AFTER — TREATMENT

IF TAKEN AFTER TREATMENT IT WAS
— FILTERED — FLUORIDATED
— CHLORINATED — WATER SOFTENER TYPE USED

FOR SOURCE SAMPLE ONLY

SOURCE TYPE: — 1 SURFACE ✓ 2 SPRING — 3 WELL — 4 PURCHASE

SOURCE NO.

IF SOURCE IS LAKE OR STREAM, ENTER NAME

FOR DISTRIBUTION SAMPLE ONLY

IF SAMPLE WAS DRAWN FROM DISTRIBUTION SYSTEM, IT WAS COLLECTED FROM SYSTEM AT (ADDRESS OR LOCATION)

DATE OF FINAL REPORT: 1/19/89

REMARKS:

SEND REPORT TO: (PRINT FULL NAME & ADDRESS)

Glen M. Wyatt
Name
Brown and Caldwell
100 West Harrison
Street
Seattle WA 98119
City Zip Code
Telephone: (206) 281 4000
Area Code

(DO NOT WRITE BELOW THIS LINE)

LABORATORY REPORT

Contaminant	Maximum Allowable Level (mg/l)	Found mg/l	MRL mg/l	Compliance	
				In	Out
Chloroform		N.D.	0.0005	✓	
Dichlorobromomethane		N.D.	0.0005	✓	
Dibromochloromethane		N.D.	0.0005	✓	
Bromoform		N.D.	0.0005	✓	
Total Trihalomethane	0.100	N.D.		✓	

MRL = Minimum Reporting Level

State of Washington
Department of Social and Health Services
Division of Health
Public Health Laboratories
1610 N.E. 150th St., Seattle, WA 98155
(206)361-2898

Lab Number : 5400794
Date collected : 12/19/88
Date Received : 12/20/88
Date Tested : 12/21/88 19:33
Data File : >1L21N::D4

Customer : BLACK DIAMOND WATER SUPPLY/GLEN WYATT
Address : BROWN & CALDWELL 100 W. HARRISON
City : SEATTLE
State, Zip : WA., 98119
County : KING

Miscellaneous Sample Information : 5400794

System ID Number : 072207
System Name : BLACK DIAMOND WATER

Non-Composited Samples

DSHS Source Number : NA
Source Name : BDSPRING 3

Composited Samples

Number of Sources Used in Composite : NA
DSHS Source #'s Composited : NA

Analysis of Individual Sources Necessary: NA

Analyst : PAMELA MS
Instrument : 1

Date of Report : 1/4/89
Analyst's Initials : PYN
Supervisor's Initials : JD

Charge 200^{\underline{00}}$

Results of Analysis by EPA Method 524

REGULATED COMPOUNDS

EPA Code #	Compound Name	MCL(ug/l)	* Amount (ug/l)	Compliance
2976	VINYL CHLORIDE	2	0.0	YES
2977	1,1-DICHLOROETHYLENE	7	0.0	YES
2981	1,1,1-TRICHLOROETHANE	200	0.0	YES
2982	CARBON TETRACHLORIDE	5	0.0	YES
2990	BENZENE	5	0.0	YES
2980	1,2-DICHLOROETHANE	5	0.0	YES
2984	TRICHLOROETHYLENE	5	0.0	YES
2969	P-DICHLOROBENZENE	75	0.0	YES

*Note: An Amount of 0.0 ug/l indicates that the true concentration is less than the detection limit of the method (0.5 ug/l for all compounds).

Lab Number : 5400794
Data File : >1L21N::D4

Results of Analysis by EPA Method 524
(continued)

Unregulated Compounds

Monitoring Required

EPA Code #	Compound Name	*Amount (ug/l)
2210	CHLOROMETHANE	0.0
2214	BROMOMETHANE	0.0
2216	CHLOROETHANE	0.0
2979	T-1,2,-DICHLOROETHYLENE	0.0
2978	1,1-DICHLOROETHANE	0.0
2416	2,2-DICHLOROPROPANE	0.0
2380	CIS-1,2-DICHLOROETHYLENE	0.0
2941	CHLOROFORM (THM)	0.0
2410	1,1-DICHLOROPROPENE	0.0
2983	1,2-DICHLOROPROPANE	0.0
2408	DIBROMOMETHANE	0.0
2943	BROMODICHLOROMETHANE (THM)	0.0
2991	TOLUENE	0.0
2985	1,1,2-TRICHLOROETHANE	0.0
2987	TETRACHLOROETHYLENE	0.0
2412	1,3-DICHLOROPROPANE	0.0
2944	CHLORODIBROMOMETHANE (THM)	0.0
2989	CHLOROBENZENE	0.0
2986	1,1,1,2-TETRACHLOROETHANE	0.0
2992	ETHYL BENZENE	0.0
2995	M/P-XYLENE	0.0
2997	O-XYLENE	0.0
2996	STYRENE	0.0
2942	BROMOFORM (THM)	0.0
2993	BROMOBENZENE	0.0
2414	1,2,3-TRICHLOROPROPANE	0.0
2988	1,1,2,2-TETRACHLOROETHANE	0.0
2965	O-CHLOROTOLUENE	0.0
2966	P-CHLOROTOLUENE	0.0
2967	M-DICHLOROBENZENE	0.0
2968	O-DICHLOROBENZENE	0.0

*Note: An Amount of 0.0 ug/l indicates that the true concentration is less than the detection limit of the method (0.5 ug/l for all compounds).

Lab Number : 5400794
Data File : >1L21N::D4

Results of Analysis by EPA Method 524
(continued)

Unregulated Compounds

Discretionary

EPA Code #	Compound Name	*Amount (ug/l)
2218	TRICHLOROFLUOROMETHANE	0.0
2430	BROMOCHLOROMETHANE	0.0
2994	ISOPROPYLBENZENE	0.0
2998	N-PROPYLBENZENE	0.0
2424	1,3,5-TRIMETHYLBENZENE	0.0
2426	TERT-BUTYLBENZENE	0.0
2418	1,2,4-TRIMETHYLBENZENE	0.0
2428	SEC-BUTYLBENZENE	0.0
2030	P-ISOPROPYLTOLUENE	0.0
2422	N-BUTYLBENZENE	0.0
2378	1,2,4-TRICHLOROBENZENE	0.0
2248	NAPHTHALENE	0.0
2246	HEXACHLOROBUTADIENE	0.0
2420	1,2,3-TRICHLOROBENZENE	0.0

*Note: An Amount of 0.0 ug/l indicates that the true concentration is less than the detection limit of the method (0.5 ug/l for all compounds).

METRO
Municipality of Metropolitan Seattle
Exchange Building • 821 Second Ave. • Seattle, WA 98104-1598

NOV - 8 1988

November 7, 1988

Mr. George Mason
Brown and Caldwell
100 West Harrison St.
Seattle, WA 98119

Dear George,

We have completed the chemical analysis of six local water sources in the area of Metro's proposed Silvigrow Section 16 operation and have enclosed these for your information.

These analyses were undertaken in response to your work plan approach, i.e. to help make a preliminary characterization of water believed to come from the Cumberland aquifer. Major cation and anion concentrations as well as pH, etc. were determined. The concentrations of four ions are directly comparable with acceptable Maximum Contaminant Levels (MCL) set by the United States Environmental Protection Agency's (EPA) Safe Drinking Water Standards. The MCL for sodium concentration in drinking water is an EPA recommended value only. These standards have been presented below for your convenience.

Element	EPA MCL Standard (mg/l)
Sodium	20
Sulfate - Sulfur	250
Chloride	250
Nitrate - Nitrogen	10

A comparison of the results of this sampling with EPA MCLs for these four ions reveals that all six water sources tested are in compliance with established standards. The only exception to this is the sodium concentration (31 mg/l) observed at the Palmer Coking Coal lower spring, which exceeded the recommended EPA MCL of 20 mg/l. Water samples for these analyses were collected by TCW environmental consultants and analyzed by Soiltest Farm Consultants, Inc.

I have also enclosed copies of letters sent by me to Keith Olson Director of the Public Works Department at the City of

Black Diamond, and William Kombol Manager of Palmer Coking Coal Company. These letters were sent to inform these parties of the results of the analyses of their respective water sources.

I am also passing on to you an updated draft of the Silvigrow Section 16 Work Plan. As you know we are proceeding with the drilling of the monitoring well and the test bores on the Section 16 property.

I am looking forward to our early November meeting that Mollie Bigger of our staff is scheduling with you. If I can provide any further information please contact me at (206) 684-1243

Sincerely,

Suzanne

Suzanne Schweitzer
Silvigrow Project Manager
Senior Water Quality Planner

SOILTEST FARM CONSULTANTS, INC.

WATER ANALYSIS

Client:
TCW Associates, Inc.
426 Ave West
Seattle, WA 98119

Date Received 7/12/88

Report No. 263-1

SAMPLE I.D.	#1 Black Diamond Water Supply Middle Spring	#2 Air Shaft Spring SW Sec 19
pH	7.3	7.3
SODIUM ABSORPTION RATIO	0.3	0.6
CLASSIFICATION OF WATER	C1-S1 Low Sodim Hazard Low Salinity Hazard	C1-S1 Low Sodium Hazard Low Salinity Hazard
CONDUCTIVITY (Ec X 103 at 25 C)	< 0.1	< 0.1
CALCIUM (Ca meq/l)	.40 (8 ppm)	.65 (13 ppm)
MAGNESIUM (Mg meq/l)	.16 (2 ppm)	.33 (4 ppm)
SODIUM (Na meq/l)	.17 (4 ppm)	.39 (9 ppm)
POTASSIUM (K meq/l)	.00 (0 ppm)	(0 ppm)
CARBONATE (CO_3 meq/l)	—	—
BICARBONATE (HCO_3 meq/l)	0.5 (31 ppm)	0.8 (49 ppm)
SULFATE SULFUR (SO_4S meq/l)	0.09 (1.5 ppm) 4.5 as SO_4	0.47 (7.5 ppm) 22.5
CHLORIDE (Cl meq/l)	0.11 (4 ppm)	0.06 (2 ppm)
NITRATE NITROGEN (NO_3N meq/l)	0.04 (0.5 ppm) 2.2 as N	0.01 (0.2 ppm) 0.9
ORTHO-PHOSPHATE PHOSPHORUS (PO_4P meq/l)		
MANGANESE (meq/l)		
COPPER (meq/l)		
IRON (meq/l)		
ZINC (meq/l)		
AMMONIA N (NH_3N meq/l)		
NITRITE N (NO_2N meq/l)		
TOTAL SUSSPENDED SOLIDS (TSS)		
TOTAL DISSOLVED SOLIDS (TDS)		
TOTAL ALKALINITY (as $CaCO_3$)		
TOTAL HARDNESS (as $CaCO_3$)		
TOTAL CATIONS (meq/l)	0.73	1.37
TOTAL ANIONS (meq/l)	0.74	1.34

Signed Stephen T. Jones

SOILTEST FARM CONSULTANTS, INC.

WATER ANALYSIS

Client: TCW Associates, Inc.
426 Ave West
Seattle, WA 98119

Date Received 7/12

Report No. 263-

SAMPLE I.D.	#3 Palmer Coking Coal Spring Upper	*4 Smoke N Joe House NE of Hyde Lake SE Sec 20
pH	7.6	7.5
SODIUM ABSORPTION RATIO	0.4	0.4
CLASSIFICATION OF WATER	Cl-Sl Low Sodium Hazard Low Salinity Hazard	Cl-Sl Low Sodium Hazard Low Salinity Hazard
CONDUCTIVITY (Ec X 103 at 25 C)	< 0.1	0.16
CALCIUM (Ca meq/l)	0.60 (12 ppm)	0.80 (16 ppm)
MAGNESIUM (Mg meq/l)	0.25 (3 ppm)	0.33 (4 ppm)
SODIUM (Na meq/l)	0.26 (6 ppm)	0.30 (7 ppm)
POTASSIUM (K meq/l)	(0 ppm)	0.03 (1 ppm)
CARBONATE (CO_3 meq/l)	—	—
BICARBONATE (HCO_3 meq/l)	0.8 (49 ppm)	1.1 (67 ppm)
SULFATE SULFUR (SO_4S meq/l)	0.19 (3 ppm) 9.0	0.22 (3.5 ppm) 10.5
CHLORIDE (Cl meq/l)	0.09 (3 ppm)	0.11 (4 ppm)
NITRATE NITROGEN (NO_3N meq/l)	0.06 (0.8 ppm) 3.5	0.04 (0.6 ppm) 2.7
ORTHO-PHOSPHATE PHOSPHORUS (PO_4P meq/l)		
MANGANESE (meq/l)		
COPPER (meq/l)		
IRON (meq/l)		
ZINC (meq/l)		
AMMONIA N (NH_3N meq/l)		
NITRITE N (NO_2N meq/l)		
TOTAL SUSSPENDED SOLIDS (TSS)		
TOTAL DISSOLVED SOLIDS (TDS)		
TOTAL ALKALINITY (as $CaCO_3$)		
TOTAL HARDNESS (as $CaCO_3$)		
TOTAL CATIONS (meq/l)	1.11	1.46
TOTAL ANIONS (meq/l)	1.14	1.47

Signed Stephen T. Jones

SOILTEST FARM CONSULTANTS, INC.

WATER ANALYSIS

Client: TCW Associates, Inc.
426 Ave West
Seattle, WA 98119

Date Received 7/12/88

Report No. 263-3

SAMPLE I.D.	#5 Green River at Black Diamond N. Bank, Near Air Shaft	#6 Palmer Coking Coal Spring Lower Palmer stream at picnic ground
pH	7.6	7.3
SODIUM ABSORPTION RATIO	0.3	2.0
CLASSIFICATION OF WATER	C1-S1 Low Sodium Hazard Low Salinity Hazard	C2-S1 Medium Sodium Hazard Low Salinity Hazard
CONDUCTIVITY (Ec X 103 at 25 C)	< 0.10	0.26
CALCIUM (Ca meq/l)	0.40 (8 ppm)	0.60 (12 ppm)
MAGNESIUM (Mg meq/l)	0.16 (2 ppm)	0.25 (3 ppm)
SODIUM (Na meq/l)	0.17 (4 ppm)	1.33 (31 ppm)
POTASSIUM (K meq/l)	(0 ppm)	0.03 (1 ppm)
CARBONATE (CO_3 meq/l)	—	—
BICARBONATE (HCO_3 meq/l)	0.6 (37 ppm)	1.0 (61 ppm)
SULFATE SULFUR (SO_4S meq/l)	0.09 (1.5 ppm) 4.5	0.38 (6 ppm) 18
CHLORIDE (Cl meq/l)	0.06 (2 ppm)	0.51 (18 ppm)
NITRATE NITROGEN (NO_3N meq/l)	(0.1 ppm) 0.3	0.02 (0.3 ppm) 1.3
ORTHO-PHOSPHATE PHOSPHORUS (PO_4P meq/l)		
MANGANESE (meq/l)		
COPPER (meq/l)		
IRON (meq/l)		
ZINC (meq/l)		
AMMONIA N (NH_3N meq/l)		
NITRITE N (NO_2N meq/l)		
TOTAL SUSSPENDED SOLIDS (TSS)		
TOTAL DISSOLVED SOLIDS (TDS)		
TOTAL ALKALINITY (as $CaCO_3$)		
TOTAL HARDNESS (as $CaCO_3$)		
TOTAL CATIONS (meq/l)	0.73	2.23
TOTAL ANIONS (meq/l)	0.75	1.91

Signed Stephen T. Jones

ANALYSIS OF WATER SAMPLES

BIOMED NOS. 10505-10509, 10529, 10530, & 10549-10551

SAMPLE ID	BIOMED NO.	pH	SPEC COND µmho/cm	TDS, ppm	Fe, ppm	Mn, ppm	Na, ppm	K, ppm	Mg, ppm	Ca, ppm	CO_3 ALK ppm as $CaCO_3$	HCO_3 ALK ppm as $CaCO_3$	Cl, ppm	NH_3-N, ppm	NO_3-N, ppm	SO_4, ppm
Deep Lake 5.0 #8802206	10505	7.06	71	46	0.20	<0.01	6	0.65	3.3	6.2	0	44	2.9	<0.003	0.1	7.2
Deep Lake 10.0 #8802207	10506	7.17	74	46	0.19	<0.01	6	0.63	2.7	6.3	0	88	2.2	<0.003	<0.1	7.2
Deep Lake 18.0 #8802208	10507	6.88	98	68	15	0.10	.6	0.99	3.6	8.6	0	28	2.0	1.2	<0.1	20
Fish Lake 3.0 #8802210	10508	7.31	47	50	0.07	<0.01	5	0.33	1.0	5.5	0	27	2.8	0.010	<0.1	3.4
Fish Lake 6.0 #8802211	10509	7.06	55	50	0.08	0.03	4	0.34	1.1	5.7	0	53	1.7	0.032	0.2	3.1
Well #1 #8802241 Cunningham, NW of Hyde Lake, SE Sec 20	10529	6.89	96	48	0.11	0.06	7	0.71	3.1	9.2	0	16	2.2	<0.003	<0.1	<0.5
Kanasket -Palmer #8802245 State Park well, SW 1/4 sec 10	10530	7.57	210	126	0.03	0.01	11	1.1	6.0	26	0	20	3.0	<0.003	0.1	22
B&C Fish Lake Strm	10549	7.32	51	104	0.05	<0.01	4	0.31	1.1	6.2	0	22	2.1	<0.003	0.1	1.6
B&C Deep Lake/Hyde Lake Strm	10550	7.53	70	124	0.16	<0.01	7	0.56	3.2	6.6	0	26	1.6	0.005	0.2	2.2
B&C Green River NW Sec 10	10551	7.37	36	84	0.02	0.01	3	0.24	0.87	5.0	0	8.0	1.5	<0.003	0.1	<0.5

NOTE: Samples were prefiltered through a 0.45 micron filter.

SECTION 16/20 HYDROGEOLOGIC STUDY
FINAL REPORT

Prepared for

Municipality of Metropolitan Seattle

Prepared by

CH2M Hill
and
Hong West & Associates

October 9, 1991

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SECTION 16/20 PROJECT
HYDROGEOLOGIC STUDY
FINAL REPORT

SECTION 0.0 EXECUTIVE SUMMARY

The Metro Section 16/20 project site is located approximately 35 miles southeast of Seattle, near the town of Cumberland. Hong West & Associates was contracted by CH2M Hill on the behalf of Metro to review existing hydrogeologic data, design and install nine new monitoring wells and perform a hydrogeologic evaluation of the site.

0.1 PHYSIOGRAPHY

The Section 16/20 project site is located in the Cascade Foothills physiographic area, which is characterized by high rainfall, surface soils with high infiltration capacity, increased local relief and bedrock exposure and decreased thickness of glacial deposits (as compared to lower elevation Drift Plain areas). The project site is situated within the Cumberland drainage basin, and occupies portions of the Green River Gorge and Deep Creek subbasins. The land surface is dominated by scattered hills with steep slopes composed primarily of bedrock, with intervening low relief glacial tablelands.

0.2 GEOLOGY

The geology of the project area is dominated by Pleistocene (1.5 million to 10,000 years before present) glacial deposits overlying Eocene (52 to 36 million years before present) bedrock units. The youngest exposed Pleistocene deposits in Puget Sound are recognized to be from the Vashon Stade of the Fraser Glaciation (approx. 20,000 to 10,000 years ago), which are typified by an upper recessional sand and gravel outwash, a middle lodgement till, and a lower advance sand and gravel outwash (simplified sequence). The Vashon deposits overlie a variable assortment of "pre-Vashon" sediments and bedrock. Thickness of unconsolidated materials decreases away from the lowland, due to increased elevation and rise of the upper bedrock surface.

Nine monitoring wells were constructed as part of the hydrogeologic investigations at the Metro Section 16/20 project site. Available data and field data collected during well installation were used to identify four major geologic units from top to bottom: Vashon Recessional Outwash, Vashon Till, Vashon Advance Outwash and Tertiary Bedrock. The ice-contact deposits and ablation till are lumped into the Recressional Outwash unit, because of the difficulty associated with defining contacts in highly variable materials and the genetic association of these deposits with glacial retreat. Variable spatial distribution of these four units results in complex hydrostratigraphy and ground water dynamics. No pre-Vashon unconsolidated sediments were identified during the field investigations.

Previous on-site investigations (Metro, 1989) suggested a continuous layer of glacial till underlies the Section 16/20 area. This study agrees with that finding insofar as much of the material encountered in borings MW-1 through MW-9 is glacial in origin. However, our analysis concludes that low permeability (i.e. less than 10^{-6} cm/sec) glacial lodgement till is absent or discontinuous beneath much of the project area; we interpret that much of the till is ablation till, which is also very dense but due to less fines and less compaction more permeable. The absence or discontinuous nature of lodgement till is explained by the position of the project site near the former margin of the continental ice sheet, where the dynamics of glacial erosion and deposition differ considerably from those areas in the Puge lowland. Features of the ice margin environment that result in discontinuous lodgement till include thinner ice (less overconsolidation), increase in subglacial meltwater erosion during retreat, irregular ice - to - ground contact and an increase in importance of ice-contact and ablation (melt-out) features.

0.3 HYDROGEOLOGY

Highly permeable recessional outwash and ice contact deposits cover the project area. These deposits are for the most part unsaturated. Perched water may be found locally above low permeability lodgement till layers, but not in sufficient quantity or extent to justify defining a separate aquifer requiring its own monitoring program. Highly permeable advance outwash deposits are continuous beneath the project area at depth and host the area's principal aquifer. Where low permeability till is absent, a 2 layer hydrostratigraphy results in an unconfined aquifer in glacial materials over bedrock. The depth to ground water averages 60 feet. The Section 16/20 project site is situated in an aquifer recharge area. A locally steep hydraulic gradient combined with overlying glacial lodgement till lenses produces local areas within the aquifer that are semi-confined.

Glacial lodgement till lenses also act as perching layers for ground water; it is suspected that these perched layers are not laterally extensive and probably discharge to the principal aquifer. The discontinuous nature of the glacial lodgement till and high infiltration capacity of the unsaturated soils suggest that ground water in Section 16/20 is in direct hydraulic connection with the land surface. Bedrock outcrops in the southeast quarter of Section 16 on Lizard Mountain and in the west half of Section 20. The bedrock structure limits recharge to the glacial aquifer and influences the direction of ground water flow. The prominent flow pattern is from east to west. The Section 16/20 site is located within a local ground water flow system where nearly all recharge to the aquifer is from direct infiltration of precipitation and nearly all discharge is to springs or the Green River. The degree of communication between the bedrock ground water regime (a fracture dominated turbulent flow system) and the glacial aquifer (a porous laminar flow system) is probably negligible, due to the differing permeabilities, recharge and flow mechanisms.

0.4 WATER QUALITY CONSIDERATIONS

At present, downgradient water use is limited to the Resort Spring, located in Section 17. Metro began one year of baseline water quality monitoring of the on-site monitoring wells and available off-site water wells in May, 1991. The additional off-site data has helped clarify flow directions in the southern half of Section 20. This was necessary because of the number of adjacent domestic wells in Sections 20 and 29. Ongoing monitoring will confirm whether any domestic water supply wells are downgradient from the Metro property in Section 20. Based on the initial monitoring, none of the wells appear to be downgradient from the Metro property in Section 20.

Mines in the vicinity of Section 16/20, including Lizard Mountain and Hyde Mine, are features excavated through bedrock. Bedrock does contain groundwater, but probably not in sufficient quantity or quality for drinking water purposes. The Hyde Mine drainage tunnel is mostly deep within bedrock; flow mechanisms in the upper glacial aquifer and the bedrock are sufficiently different so as to minimize the probability of water quality impacts resulting from the position of the mine workings.

SECTION 1.0 INTRODUCTION

This report provides an overview of the hydrogeologic characteristics of the Metro Section 16/20 project site located in Southeast King County, Washington. Hong West & Associates' hydrogeologic evaluation involved a review of available published and unpublished data regarding the project area and site-specific geologic and hydrogeologic field investigations. Provided in this report are overviews of previous studies and HWA's interpretations of site physiography, geology and hydrogeology. The primary objective of the project was to provide substantiating data for inclusion into Metro's draft and final EIS documents. For definitions of technical terms, the reader is referred to the glossary contained in the Appendix.

1.1 AUTHORIZATION

This project was authorized under CH2M Hill Standard Agreement for Professional Services, issued by Mr. David Peters of CH2M Hill, dated January, 2, 1991.

1.2 SCOPE OF WORK

Eight separate tasks were performed by Hong West & Associates:

Task 101	Review Existing Data
Task 301	Site Reconnaissance
Task 302	Well Construction
Task 305	Hydraulic Conductivity Testing
Task 306	Well Construction Report
Task 307	Data Analysis
Task 309	Final Report
Task 1500	Supplemental

The remainder of this report is based on data collected during performance of the eight tasks.

1.3 PREVIOUS INVESTIGATIONS

The Municipality of Metropolitan Seattle issued a report entitled *Geohydrology Studies of the Metro Section 16 Silvigrow Project* in March, 1989. This study was prepared by Metro, TCW Engineers and Brown and Caldwell and is referenced herein as Metro, 1989a. A second report entitled *Metro Section 16 Project Hydrogeology and Water Quality Evaluation* was issued in December, 1989 and is referenced herein as Metro 1989b. This study was prepared by TCW Associates, Inc., HLA/Harper Owes, The University of Washington College of Forest Resources and Metro. Both studies documented existing data relevant to site geology and hydrogeology and presented results of a 1988 test boring program that included installation of one monitoring well (shown as B-1 on Figure 2-1) and eight shallow borings. The pertinent hydrogeologic conclusions of both Metro (1989) studies include:

1. Ground water flow in Section 16 and 20 is probably to the north to northwest.

2. The chemical nature of spring, lake, stream and well waters are the same; spring and well water chemistry is consistent with local recharge to ground water.

3. Ground water in Section 16 is recharged by precipitation and discharges through springs and seeps along the Green River. The source of the Black Diamond springs and the Resort spring is groundwater; recharge enters the aquifer via lakes (Hyde Lake and Fish Lake) and precipitation.

4. The 1988 borings B-1 through B-9 penetrated glacial till, interpreted to be continuous beneath Sections 16 and 20 (reference Figure B-2 in the Metro, 1989b report), except where bedrock highs occur.

5. Mines in the vicinity will not contribute to any impact on ground water quality as a result of Silvigrow application.

1.4 SOURCES OF INFORMATION

Portions of this report are based on readily available published and unpublished data, with refinements added based on interpretation of such data and newly collected data obtained during construction of nine new monitoring wells (MW-1 through MW-9). Regional data sources include studies by the United States Geological Survey, the United States Department of Agriculture Soil Conservation Service and the Washington State Department of Natural Resources, Division of Geology and Earth Resources. Site specific and other data analyzed include the Metro 1989a and 1989b studies mentioned in Section 1.3, well logs collected by the Washington State Department of Ecology and aquifer analyses completed during this study. Additional data concerning the Lizard Mountain and Hyde Mines was obtained through an interview and site reconnaissance with Ernest Seliger, a longtime local resident and former mine worker. Water quality data and wellhead surveys were provided by Metro. The remaining hydrogeologic field work was performed by the CH2M Hill/Hong West & Associates team. A full list of references appears in Section 7.0.

SECTION 2.0 PROJECT AREA DESCRIPTION

The Metro Section 16/20 project site is located in Southeast King County, near the town of Cumberland, Washington. Access to the site may be gained from the west by the Kent-Kangley road and Cumberland-Kanaskat road. Access to the site from the south is via the Enumclaw-Cumberland road. Gravel roads with locking gates lead into Section 16 and Section 20 from 352nd Avenue SE (the Green River Gorge road).

2.1 LOCATION AND PHYSICAL SETTING

The project site is comprised of two square miles (Section 16 and Section 20, Township 21N and Range 7E of the Willamette Meridian) situated about 3 miles east of the City of Black Diamond in southeast King County, Washington. The project location is shown in Figure 2-1.

2.2 REGIONAL PHYSIOGRAPHY

Three distinct physiographic areas are relevant to evaluating ground water for the Section 16/20 project and were described by Robinson and Noble (1972) as follows:

2.2.1 Drift Plain

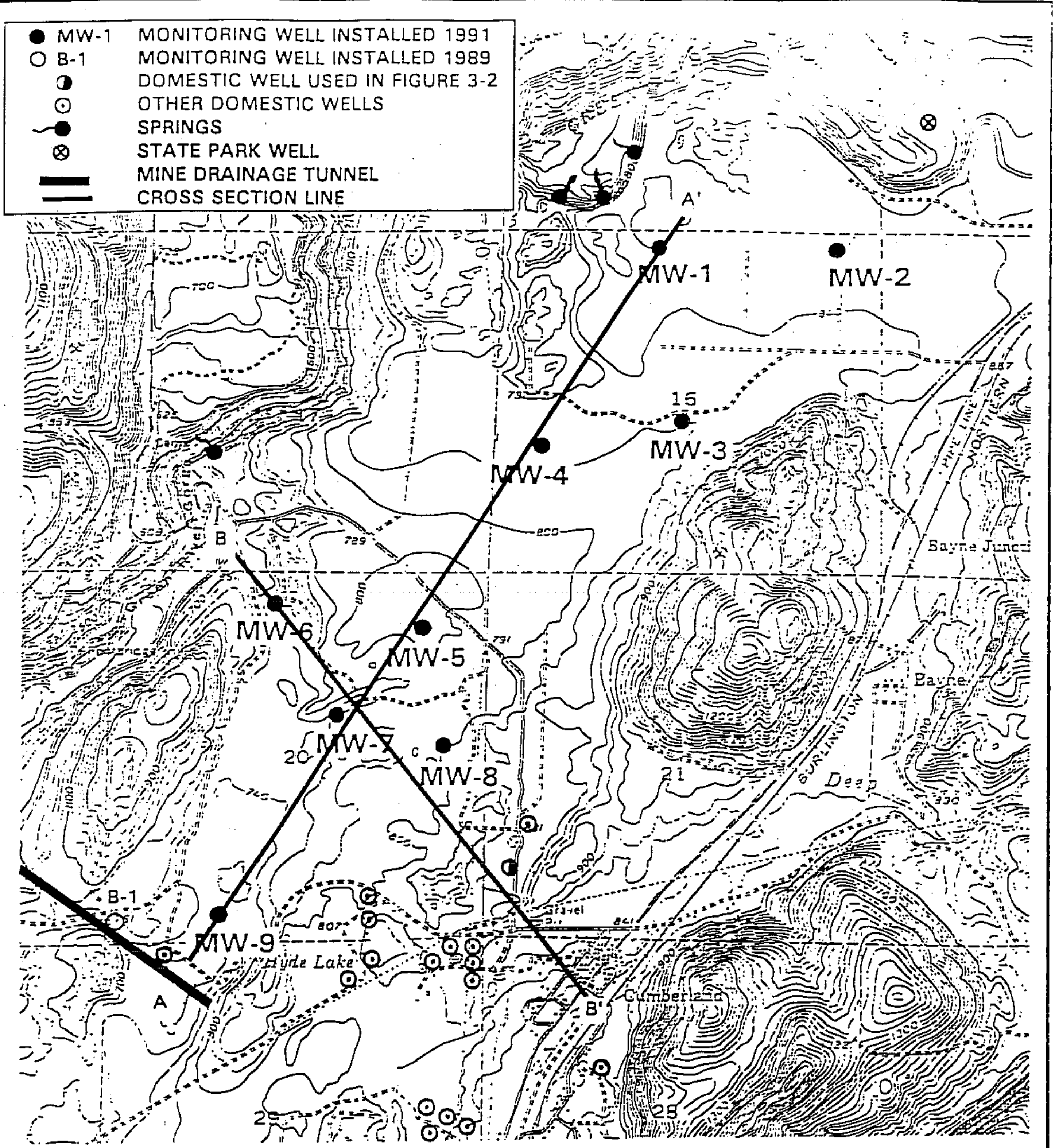
These are rolling lowlands with a topography dominated by the depositing and eroding actions of the last glaciation and a complex and thick sequence of geologic and hydrogeologic units. An example in the project area is the Covington Drift Plain located approximately,10 miles west of Section 16/20.

2.2.2 Major Valley Segments

These are major active river valleys that flow from the Cascades foothills through the glaciated lowlands to Puget Sound or Lake Washington that often contain locally important aquifers. An example in the project area is the Green-Duwamish valley located 15 miles west of Section 16/20.

2.2.3 Foothills Area

The foothills area is located between the drift plains and the high Cascade Mountains and is characterized by a rise in elevation, increase in relieft and bedrock exposure and decrease in thickness of glacial deposits. This area also contains locally important aquifers. The Section 16/20 project site is located within the Foothills physiographic area.



METRO SECTION 16/20 PROJECT

SITE AND WELL LOCATION MAP

HONG WEST & ASSOCIATES

FIGURE 2-1

2.3 PROJECT AREA PHYSIOGRAPHY

The topography of the northwestern two-thirds of Section 16 is nearly level, ranging from 800 to 840 feet above sea level. The ground rises to the southeast, where the bedrock of Lizard Mountain (Elev. 1,460) is exposed. There are two large rounded depressions in the northwest corner of Section 16 whose lowest elevations are 740 and 770 feet (Metro, 1989a). The topography of Section 20 is similar to Section 16, and includes the aforementioned bedrock highs and depressions. Overall, the topography of Section 20 is more irregular and hummocky. Slopes range from nearly level to about 5% over much of the project area. Local areas have slopes exceeding 10% - these usually coincide with bedrock exposures. The steepest slopes are found on Lizard Mountain in Section 16.

The Green River (which flows generally east to west) has carved a deep gorge, which is approximately 600 to 1000 feet north and west of the Section 16/20 project area. The surface of the project site has been somewhat modified by timber activities and associated gravel road building. There are several gravel quarries/pits scattered throughout Sections 16 and 20. The deepest of these excavations is about 20 feet. Maximum local relief throughout the project site is approximately 700 feet.

2.4 LOCAL DRAINAGE CHARACTERISTICS

The Section 16/20 project site is located in the Cumberland drainage basin (approximately 25 square miles) and occupies portions of two drainage subbasins identified in Metro (1989a). The northern two-thirds of Section 20 and all of Section 16 lie within the Green River Gorge subbasin and the remaining southern one-third of Section 20 lies within the Deep Creek subbasin (Refer to Figure 1-1 in the Metro 1989a study).

The Green River is the only perennial stream in the immediate vicinity of the Section 16/20 area. Previous studies (Metro, 1989b) identified two ephemeral streams on Lizard Mountain in Section 16. Metro staff traversed an ephemeral stream to its source in Section 20 in 1991. This stream is located just west of MW-6 (refer to Figure 2-1). It had substantial flow in May, 1991 but was dry by August, 1991. There are several topographic depressions scattered throughout the Section 16/20 area. These are probably glacial kettles. Where the bottom of the kettles are composed of relatively impermeable till, local seasonally wet areas are found. Two such depressions appear on the topographic map (Figure 2-1) in the southern portion of Section 20. Ponded or perched water in these depressions dissapates through slow percolation through the unsaturated zone and through evapotranspiration. The wet areas observed are not springs, which by definition are discharge points for flowing aquifers. Rather, the wet areas are recharge points for ground water. This is consistent with the observation that the entire Section 16/20 project site is situated in an area of aquifer recharge (refer to Section 4.2.3). Due to generally high infiltration rates, most of the drainage appears to be internal.

SECTION 3.0 GEOLOGY

The distribution of geologic materials governs existing ground water recharge, discharge and flow mechanisms and is an important factor in consideration of the hydrogeologic system at the Section 16/20 project site.

3.1 REGIONAL GEOLOGY

The geology of the Puget Sound region consists of thick (up to 3,000 feet) complex sequences of glacial and non-glacial unconsolidated silt, sand and gravel overlying thick sequences of consolidated bedrock all deposited in a major structural trough. During the Pleistocene Epoch (approximately 1,500,000 to 10,000 years ago) the Cordilleran Ice Sheet advanced and retreated through the Puget lowland forming deposits generally referred to as drift, till and outwash. During periods between the glacial advances, the Puget lowland was filled with alluvial sediments deposited by rivers draining the western slopes of the Cascades and the eastern slopes of the Olympics. Hall and Othberg (1974) estimate the sediment pile is as much as 3,600 feet thick in the Seattle area and about 2,000 feet thick near Tacoma. Sediment thickness decreases in general away from the central axis of the Puget lowland, except along the northeast portion of the Olympic Peninsula, near Sequim, where thicknesses exceed 3,000 feet (Noble, 1960). The most recently published "concensus" geologic/stratigraphic column for the region (Galster and Laprade, 1991) is provided for reference as Figure 3-1. Only a small portion of the sequence are found at Section 16/20. Project-relevant units are described below from youngest to oldest:

3.1.1 Fraser-Age Glacial and Post-Fraser Non-Glacial Deposits

The youngest Pleistocene sediments in the Puget lowland are referred to as Vashon drift. The Vashon glaciation was the most recent stade of the Fraser Glaciation to affect the area. Post-glacial deposits (Holocene, <10,000 years in age) overlie glacial deposits, usually in active stream and river valleys eroded down through the older glacial deposits. Other post-glacial deposits include peat, which is found in valleys and depressions and is formed by organic accumulations in marshes and bogs, and locally significant landslide deposits.

The Vashon drift (approximately 20,000 to 10,000 years in age) is subdivided in the literature into three principal units. The upper unit is a somewhat discontinuous, weakly stratified sand and gravel deposit termed Vashon Recessional Outwash. The middle unit is a non-stratified assortment of clay, silt, sand, gravel and boulders termed Vashon Till. The bottom unit is a moderately stratified sand and gravel deposit termed Vashon Advance Outwash. Sub-units occur in local

PERIOD	AGE (Ka)		GEOLOGIC/CLIMATIC UNITS		TIME/STRATIGRAPHIC UNITS	
Quaternary	Holocene		Winthrop Creek glacial		Alluvium, colluvium marine deposits, lahars, volcanic ash	
		3	"Hypsithermal interval"			
	Pleistocene	10 13.5	Fraser Glacial	Vashon Stade	Vashon Drift	Recessional deposits
						Vashon Till
						Esperance Sand Advance outwash
						Lawton Clay
		20	Olympia non-glacial		Discovery formation	
		60	Possession glacial		Possession Drift	
		80	Whidbey non-glacial		Whidbey Formation	
		100	Double Bluff.glacial		Double Bluff Drift*	
		250	▨	▨	▨	▨
		730	Salmon Springs Glacial	Upper glacial	Upper Salmon Springs Drift*	
				Non-glacial	Non-glacial sediments, tephra*	
		840		Lower glacial	Lower Salmon Springs Drift*	
			Puyallup non-glacial		Puyallup Formation*	
			Stuck glacial		Stuck Drift*	
			Alderton non-glacial		Alderton Formation*	
		2.000	Orting glacial		Orting Drift*	
Tertiary	Pliocene		▨	▨	▨	▨
	Miocene		Continental		Hammer Bluff Formation*	
	Oligocene		Marine/estuarine		Blakeley Formation	
	Eocene		Continental - volcanic		Puget Group	Renton Formation
						Tukwila Formation
						Tiger Mountain Fm.*
			Marine		Raging River Formation*	

GENERALIZED GEOLOGIC/STRATIGRAPHIC COLUMN FOR SEATTLE/PUGET SOUND AREA
from: Galster and LaPrade, 1991

FIGURE 3-1

areas where drift and outwash were deposited against the receding glacier front (ice-contact deposits) and along the margins of the Vashon ice sheet (morainal embankments), (Booth, 1984). These deposits tend to display rapid lateral changes in grain size. Vashon Till and Recessional Outwash commonly outcrop at the surface; Advance Outwash is widely recognized through well log interpretation and sparse exposures in deep river gorges and gravel quarries.

3.1.2 Pre-Fraser Deposits

Older Pleistocene deposits (pre-Fraser) appear in the literature under various nomenclature depending on the type locality (i.e. Salmon Springs drift, Auburn Gravel, Soos Clay). These deposits attain great thicknesses (over 1000 feet) in Central Puget Sound, and are thin or absent in marginal areas. However, a lack of deep drilling data combined with complex geology has rendered the task of regional pre-Vashon stratigraphic correlation problematic. Booth (1984) attributes the absence of pre-Vashon deposits in upland, marginal areas to similar processes responsible for stripping pre-Wisconsin glacial drift in the midwestern and northeastern U.S. In the Foothills area near former glacial margins, isolated pre-Vashon deposits remain in locations topographically higher than the inferred Vashon glacial maximum.

3.1.3 Tertiary Bedrock

The most widespread pre-Pleistocene bedrock was formed during the Tertiary Period (66.4 to 1.5 million years in age) and includes siltstone, sandstone and volcaniclastic deposits. The rock is commonly folded and deeply eroded units lie under the thick Pleistocene deposits while relatively resistant units form bedrock highs or ridges that are the erosional remnants of the large folds. Tertiary age rocks host the coal deposits mined in the region during the early to mid 1900s. Thicknesses of the sedimentary rock in the Green River area exceed 6000 feet (Vine, 1962).

3.2 SECTION 16/20 GEOLOGY

Based on the known distribution of glacial deposits (e.g. Hall and Othberg, 1974), the project site is located within two miles of the former eastern lateral margin of Fraser glacier ice and contains geologic and topographic features of the ice margin environment. Section 16/20 geology is characterized by two northeast-trending bedrock highs (1600+ ft Lizard Mountain in Section 16 and an unnamed 900+ ft hill in Section 20) that enclose a relatively level upland area of glacial deposits averaging 100 feet in thickness. Based on our interpretation of the literature and field data, only Fraser-age glacial deposits overlie bedrock beneath the study area. Pre-Fraser deposits were presumably removed during Vashon glaciation, thus simplifying correlation of stratigraphic units. The Pleistocene geology of this area, however, is unique and will be described below and summarized further in Section 3.3.

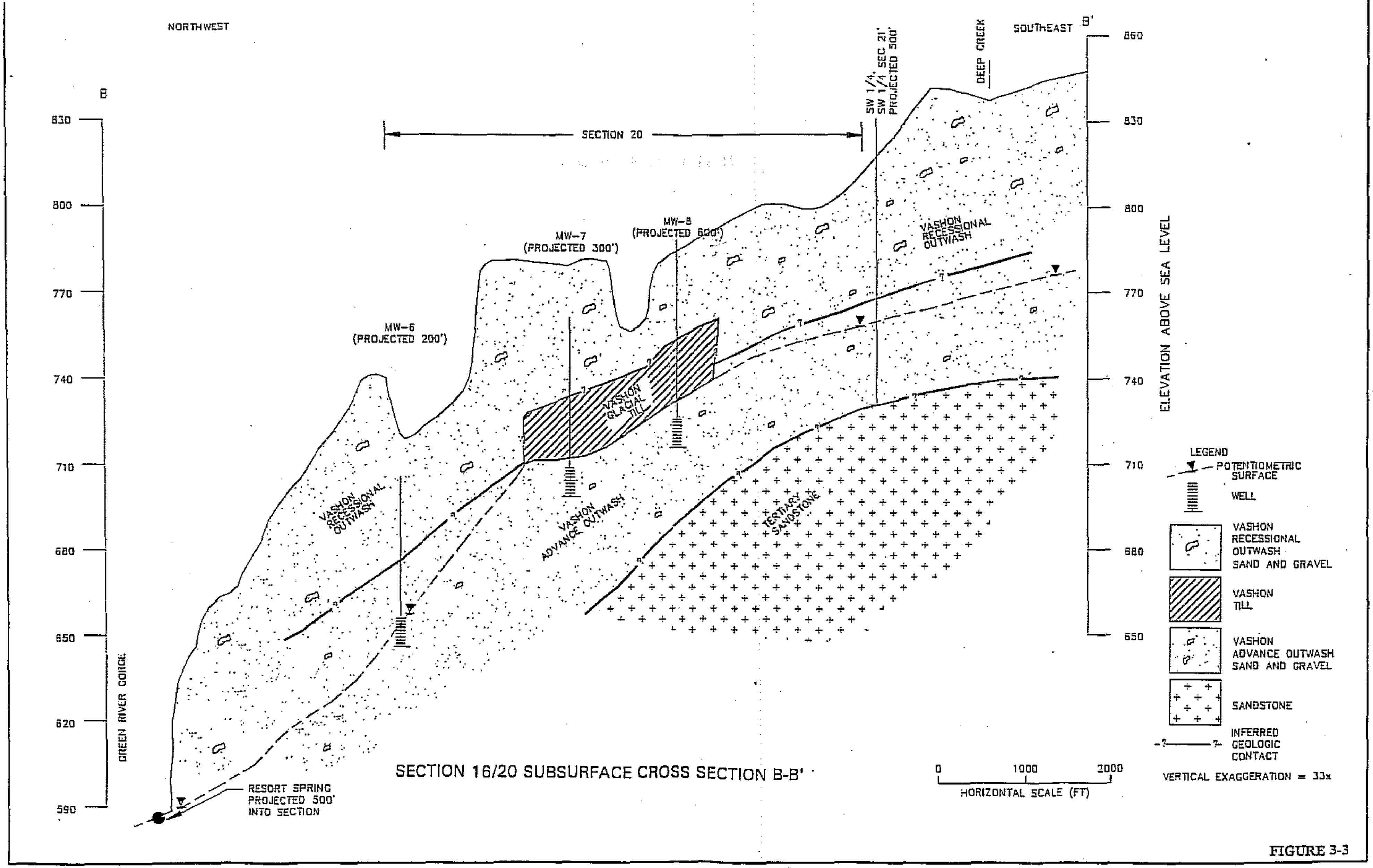
Four separate geologic units were identified in the borings, plus an additional "transitional" zone, described below from top to bottom Refer to Figures 3-2 and 3-3 for generalized subsurface cross sections based on correlation/interpretation of boring logs and note that wells not located directly on the section line are "projected" into the section. Glacial deposits are known to vary widely over distances measured in tens of feet. The complexity of glacial deposits and relatively large distance between borings (at least 1,000 feet) makes absolute correlation of distinct units problematic; hence, only major units that are most relevant to hydrogeology are differentiated. Details of the borings are contained within the Appendix. Each geologic unit displays a range of grain size variation between the interpreted contacts, as evidenced by the various descriptions in the boring logs. Inferred geologic contacts between boreholes are dashed and labeled with question marks on Figures 3-2 and 3-3.

3.2.1 Recessional Outwash/Ice Contact Deposits

These are generally equivalent to the "terrace gravel and stratified drift" described in the Metro (1989a, 1989b) reports. This unit covers much of the land surface in Sections 16/20. These deposits are characteristically less stratified, more boulder/moraine-like than commonly observed recessional outwash units. The hummocky topography in the northwest corner of Section 16 and much of Section 20 suggests a preponderance of ice contact features. Hummocky morainal topography is a characteristic feature of "dead ice" - non flowing ice remnants separated from the retreating glacier (Embleton and King, 1971). Melt-out of glacial ice "dumped" bouldery debris in some areas, remnant ice blocks formed kettles and sporadic meltwater streams deposited a thin veneer of recessional outwash. This geomorphology suggests a fundamentally different depositional regime than drift plain recessional outwash, i.e. classic recessional outwash (with successive stages of deglaciation producing outwash channels that cut into older, more extensive expanses of coarse sediment). The boulder-strewn, chaotic nature of the deposits suggests rapid glacial thinning and retreat in the vicinity of the project area, where ice-contact and subglacial deposition predominated. Thickness of the recessional/ice contact units ranged from approximately 30 to 75 feet.

3.2.2 Glacial Till

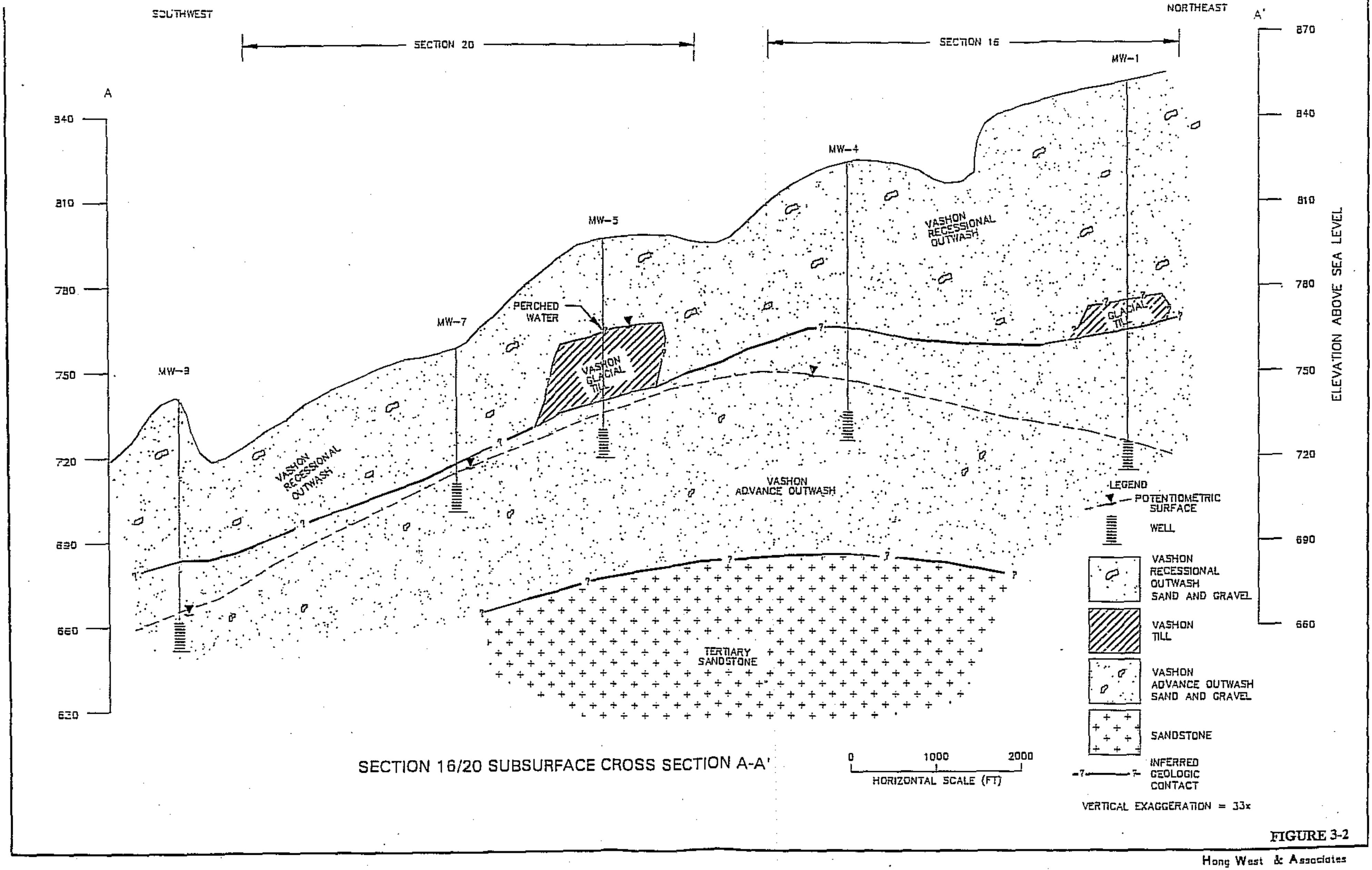
Glacial till is present as lodgement till remnants (either deposited sporadically or eroded by subglacial meltwater) or as the variety commonly referred to as ablation till. The lack of overconsolidation structures may imply that the ice only rarely grounded against these sediments (Booth, 1984) in the Section 16/20 area. The fall-out of debris released from the base of melting ice produces ablation till, and this process is consistent with the features observed. Isolated, lodgement till-like bodies were observed in four of the nine boreholes (refer to Figures 3-2 and 3-3 and the Appendix for detailed description of units encountered). These deposits resembled the classic Vashon lodgement till in terms of relative stratigraphic position; however, overall, the deposits encountered were a coarser-grained, less dense ablation till as opposed to the classic fine grained "concrete like" lodgement



SECTION 16/20 SUBSURFACE CROSS SECTION B-B'

FIGURE 3-3

Hong West & Associates



SECTION 16/20 SUBSURFACE CROSS SECTION A-A'

FIGURE 3-2

Hong West & Associates

till. Thickness of the till units ranged from approximately 0 to 24 feet.

3.2.3 Transitional Zone

A transitional zone, possibly representing a gradational contact between till and advance outwash was observed in Section 20 (MW-5). This unit may be a reworked advance outwash deposit with silty layers, capable of locally perching ground water. Thickness observed in MW-5 was 10 feet. The transitional zone was also observed in Section 16 (MW-2), where the advance outwash was unusually silty.

3.2.4 Advance Outwash

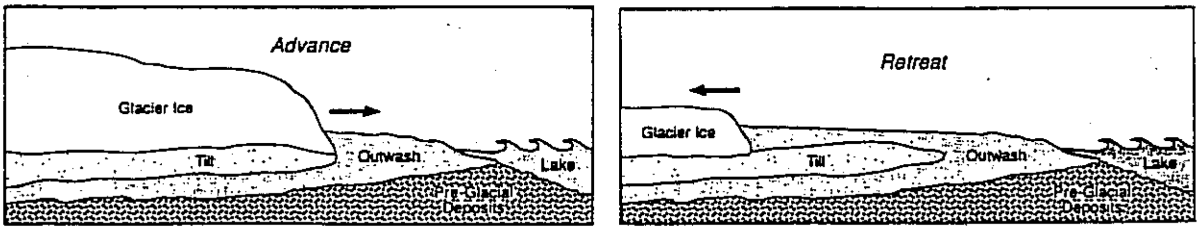
All nine boreholes penetrated this unit. Advance outwash is typically a very coarse, highly permeable and unweathered sandy gravel deposited by meltwater streams emanating from the advancing glacial front. Thickness ranged from 25 to at least 50 feet beneath much of the project area. The bottom of this unit was not fully penetrated, except in MW-2. Aquifers in advance outwash are highly transmissive and are a regionally important source of underground water supply, capable of well yields in excess of 1000 gpm. This unit is discussed further in Section 4.0 GROUND WATER.

3.2.5 Bedrock

Tertiary age bedrock of the Puget Group (30 to 60 million years in age) consisting of andesitic volcanic rocks and arkosic sandstone was observed in MW-2 and at the surface on Lizard Mountain in Section 16. The bedrock contains generally north-trending folds (anticlines and synclines) and northwest - trending faults. In the vicinity of Lizard Mountain, the bedrock dips to the southeast and contains numerous coal seams ranging from a few inches to a few tens of feet in thickness.

SECTION 3.3 SECTION 16/20 GEOLOGY SUMMARY

A classical model for the genesis of glacial deposits in Puget Sound was described in the Metro (1989a, 1989b) reports (Figures 2-4 and A-4, respectively) and is duplicated below:



This model is generally valid for the Drift Plain physiographic area described in Section 2.2. However, the Foothills area represents a transition between an ice margin environment and a drift plain environment, so the processes of erosion and deposition were quite different than the above model.

Our interpretation (observed in other upland areas away from the central axis of Puget Sound) is that during Vashon glaciation the Section 16/20 project area had the following glacial features:

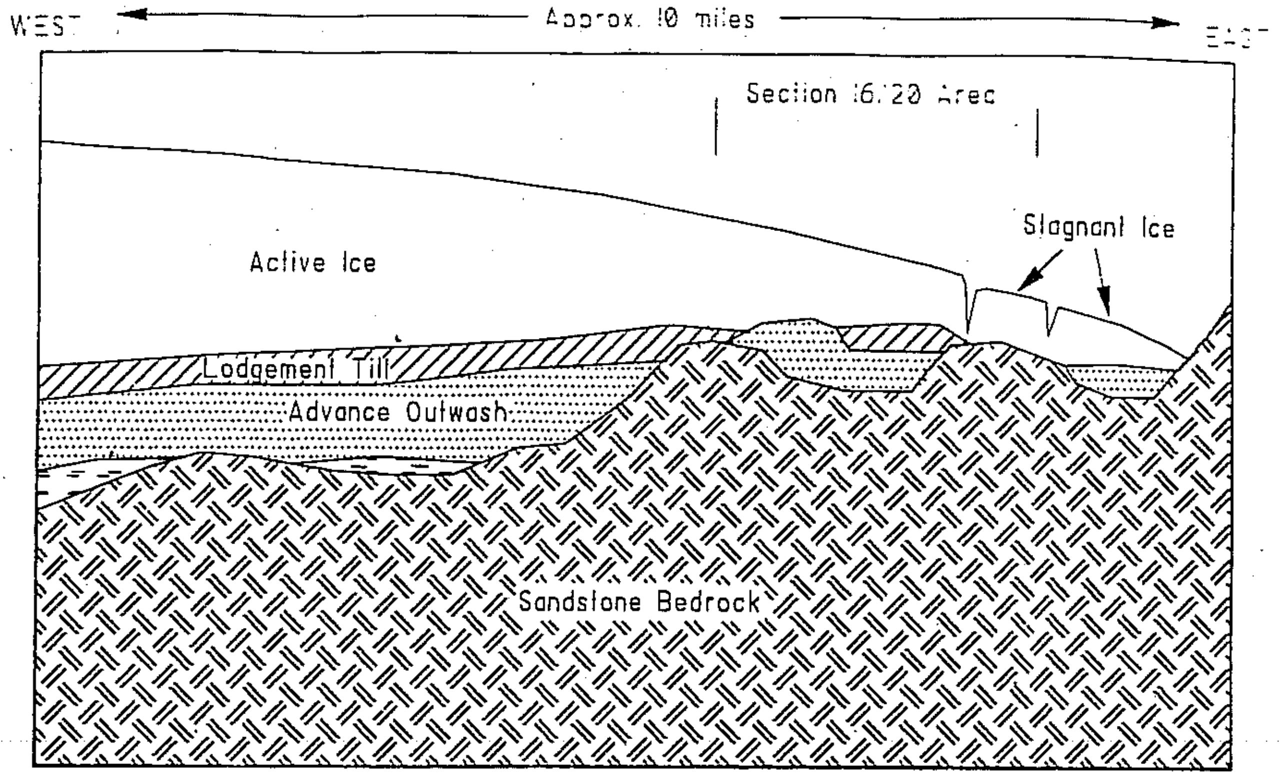
1. Ice thickness near the glacial margins was not great enough to erode and deposit a continuous sheet of lodgment till.

2. The bottom of the Vashon glacier margin was honeycombed by a network of subglacial streams that eroded and reworked the till, leaving isolated lodgement till remnants and/or stratified till-like deposits after glacial retreat.

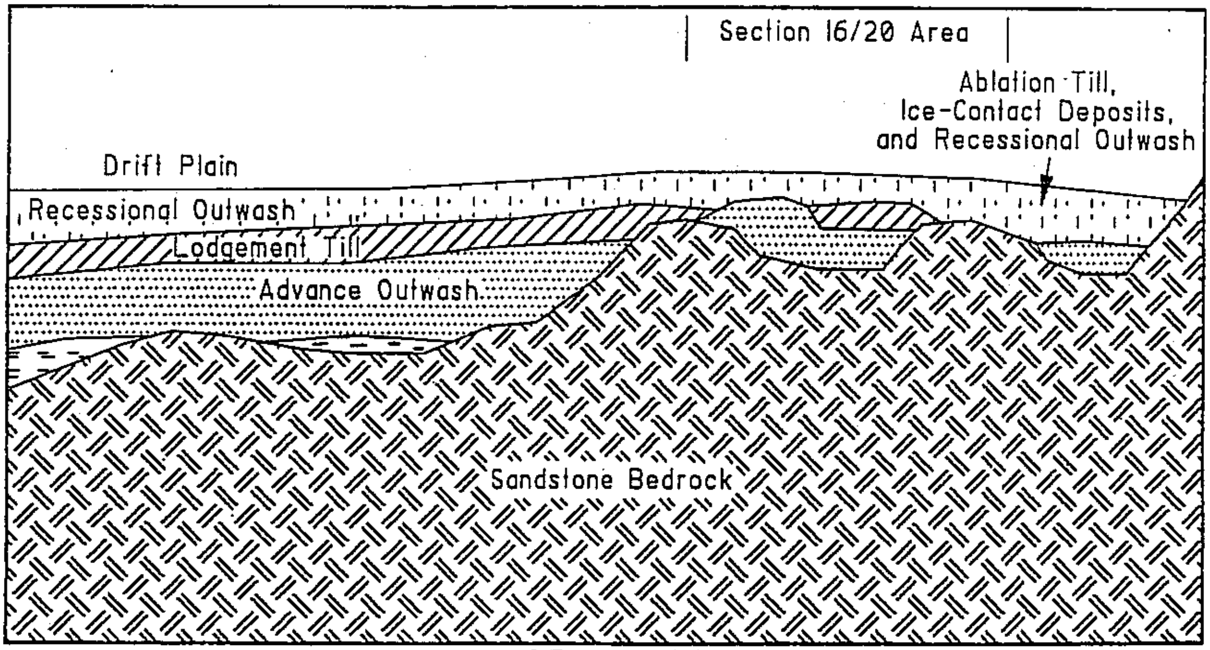
3. The Vashon glacier was not in full contact with the ground, especially during ice retreat (nearly full contact required for continuous lodgement till formation).

4. As ice retreated, large stagnant ice blocks separated from the moving glacier, producing highly variable ice-contact deposits and till remnants. Rapid melt-out left significant volumes of ablation till.

In summary, the model for glacial erosion and deposition in Foothills areas includes the advance and retreat of the glacier as illustrated above; however, the foothills areas have the added influence of pre-existing topography (i.e. the bedrock hills) and a decreased thickness of glacial ice and glacial deposits. The Figure A-4 from the Metro 1989b report duplicated above is essentially a north-to-south profile. Below is a west-to-east schematic profile illustrating our interpretation of some of the glacial features of the foothills area and glacial margin environment during glacial advance and retreat (Figure 3-4).



MAXIMUM GLACIAL ADVANCE



DEGLACIATION

▤ Pre-Vashon Deposits

NOT TO SCALE

METRO SECTION 16/20 PROJECT

MODEL FOR GLACIAL MARGIN-FOOTHILLS AREA

HONG WEST & ASSOCIATES

FIGURE 3-4

Project #: 98031

SECTION 4.0 GROUND WATER

An understanding of regional and site-specific ground water conditions is critical to evaluating land application impacts and developing a credible monitoring program. Ground water is a major source of drinking water in the project area - both as a direct source via drilled wells and indirectly through discharge to various springs such as Black Diamond Springs and the Resort Spring. This section provides an overview of the Section 16/20 ground water conditions as a basis for evaluating the extent of potential water quality impacts and designing a ground water monitoring program to detect any such impacts.

4.1 REGIONAL HYDROGEOLOGY

The Puget lowland has a varied and complex hydrogeologic system. Multiple aquifers occur in areas underlain by thick sequences of glacial and nonglacial deposits. Some areas in central Puget Sound have more than three hydraulically separate aquifers. The most widespread aquifers occur within (from top to bottom) Vashon Recessional Outwash, Vashon Advance Outwash and pre-Vashon gravels (such as Auburn Gravel in southern King County). Major aquitards include the Vashon Till and pre-Vashon silts and clays (such as the Soos Clay in southern King County).

4.1.1 Ground Water Occurrence and Hydrostratigraphy

The South King County Ground Water Management Plan (GWMP) describes several aquifers. One of these aquifers is present throughout the Section 16/20 area based on our interpretation of previous data (Metro, 1989a, 1989b; Ecology Well logs) and newly-collected field data obtained during this study. Previous studies (Robinson and Noble, 1972) identified this aquifer and named it the Cumberland aquifer. Based on examination of regional data, there are four major hydrostratigraphic layers that are pertinent to the study area. These layers are defined as groupings of sediment or rock (geologic units) that exhibit similar physical and hydrologic characteristics, both vertically and horizontally. The four hydrostratigraphic units listed below consist of upper and lower aquifer systems and upper and lower aquitards. The on-site significance of each layer is discussed in Section 4.2

LAYER 1 Upper Perched Aquifer (Vashon Recessional Outwash)
LAYER 2 Upper Aquitard (Vashon Till)
LAYER 3 Principal Aquifer (Vashon Advance Outwash)
LAYER 4 Lower Aquitard (Bedrock)

4.1.2 Recharge/Discharge Characteristics

Regional recharge to all aquifers is achieved through three principal mechanisms:

1. Direct infiltration of precipitation
2. Infiltration of surface water from lakes, streams and swamps
3. Inter-aquifer exchange

Secondary recharge mechanisms include irrigation, infiltration from septic drainfields and stormwater runoff from manmade impervious surfaces.

Annual precipitation averages 65 inches per year in the study area and is considered the major contributor to aquifer recharge. Lakes such as Hyde Lake and Deep Lake are important local sources of aquifer recharge. Aquitard permeability, thickness and continuity in combination with the vertical distribution of aquifer hydraulic heads governs the degree of inter-aquifer exchange.

Regional discharge occurs through interaquifer exchange, discharge to surface water and evapotranspiration.

4.1.3 Ground Water Flow

The complex distribution of aquifer and aquitard materials and recharge/discharge conditions results in complex regional ground water flow patterns.

Regional ground water flow patterns are influenced by numerous geologic, hydrologic and topographic factors. The glacial sediments are discontinuous and heterogeneous, incised by streams and rivers and isolated by bedrock highs. In south King County, most ground water flow is toward the major discharge points (Green River and White River). The hydraulic gradient steepens in aquifer recharge zones and tends to flatten out in discharge zones (except near major springs).

Ground water flow in the upper, unconfined aquifer is generally controlled by topography and the configuration of the upper aquitard (till) surface. Ground water flow in the lower, principal water supply aquifer is controlled by recharge/discharge relationships and confining pressure. Those portions of aquifers within the zone of influence of major wellfields exhibit the characteristic radial flow pattern produced by well pumping and drawdown. Lakes produce ground water mounding effects, while bedrock barriers produce divergent flow conditions.

4.1.4 Regional Ground Water Development

Ground water is an important source of drinking water in the Puget Sound region. In south King County, water wells are developed in the unconfined (upper) aquifers and in deeper aquifers. Most wells produce from 5 to 500 gpm and are generally less than 200 feet deep. There are several high yielding wells and wellfields developed by Municipal water districts and other water purveyors, for example the City of Kent's and King County Water District's wellfields in Covington and Ravensdale. Drinking water supply in the region is from a combination of surface and ground water sources.

4.1.5 Regional Ground Water Quality

Ground water quality in the region is typically excellent. Routine water quality monitoring of public water supply wells indicates that the ground water quality in the principal water supply aquifer (wells placed in Advance Outwash) of the area is excellent and suitable for public water supply. Insufficient data are available at this time to adequately characterize water quality in the shallow aquifer where it exists. Areas with recessional outwash gravel exposed at the surface and shallow ground water are susceptible to water quality degradation, particularly where there is a high density of septic tank drainfield systems or uncontrolled application of pesticides and fertilizers.

The Metro (1989b) study described the results from 24 samples taken from streams, lakes, wells (including B-1 in Section 20) and springs (including Black Diamond Springs). The composition of the water samples, relative to major ions, was plotted on trilinear diagrams for the purpose of evaluating the chemical character of water. Almost all of the water samples analyzed were of the calcium bicarbonate character (Metro, 1989) and had low total dissolved solids, indicating local recharge and short ground water residence time.

Insufficient data exist to characterize water quality in bedrock. Verbal reports from residents with bedrock wells indicate the water often has an unpleasant taste and odor; this may be related to the carbonaceous nature of the bedrock in the area.

4.2 SECTION 16/20 HYDROGEOLOGY

Site-specific characterization of Section 16/20 hydrogeology is critical to the evaluation of project water quality and potential land use impacts. Factors such as depth to ground water, rates and directions of ground water flow, aquifer recharge and discharge characteristics and water quality are used to describe the existing ground water conditions at the site. The following discussion is based on a review of the Metro reports (1989a, 1989b) and new findings resulting from HWA's 1991 field investigation and monitoring well installations. For a detailed discussion of field investigations, please refer to the Technical Appendix attached to this report.

4.2.1 Ground Water Occurrence and Hydrostratigraphy

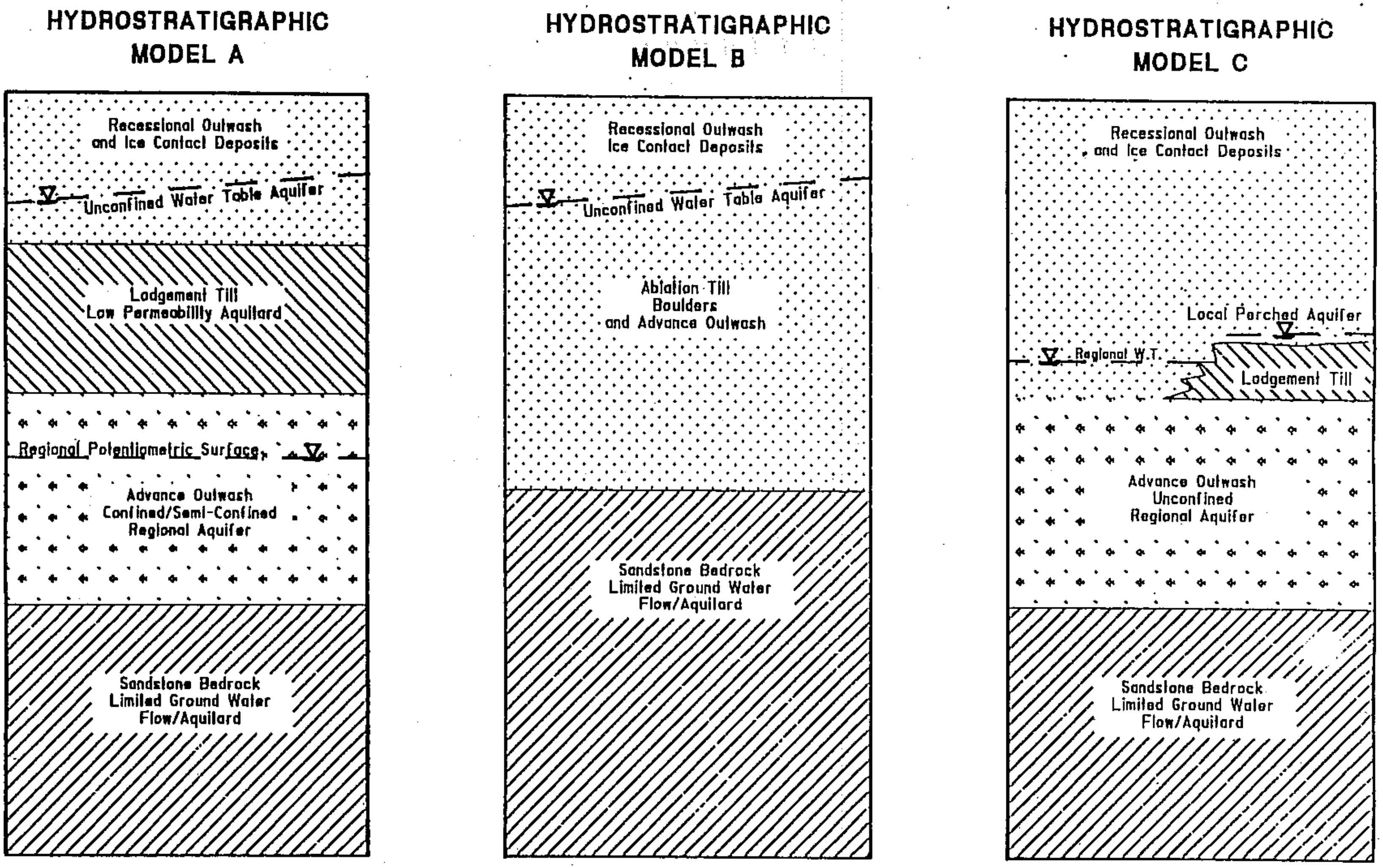
Based on examination of previous reports, and our field data, three conceptual models of ground water conditions have been developed for Section 16/20. This model includes basic ground water characteristics and variants of the four major hydrostratigraphic units introduced in Section 4.1. Refer to Figure 4-1, Hydrostratigraphic Models which illustrate the relationship between the hydrostratigraphic layers, in particular the role of glacial lodgement till on hydrostratigraphy and ground water dynamics. The four layers described do not occur everywhere in vertical succession.

LAYER 1 Upper Aquifer (recessional outwash): This hydrostratigraphic unit is either absent or discontinuous over much of Section 16/20, due to the discontinuous nature of the underlying aquitard (see Layer 2) and the complex distribution of recessional outwash and moraine deposits. It is most recognizable in Section 20, where perched water was observed at the surface in several depressions and in MW-5. Layer 1 is more common in Drift Plain environments.

LAYER 2 Upper Aquitard (Vashon Lodgement Till): Where present, this unit serves as the base of the upper aquifer and confines ground water in the underlying aquifer(s). The unit is very dense and compact with a significant proportion of fine grained sediment, thus forming a significant barrier to ground water flow. Permeability of lodgement till typically ranges from 10^{-6} to 10^{-8} cm/sec. Low permeability lodgement till was observed in wells MW-5, in the northeast corner of Section ,20 MW-7 and MW-8 in Section 20 and possibly in Section 16 in MW-1 and MW-2. Layer 2 may also be present in the northwestern one third of Section 16 at considerable depth. Where lodgement till is absent, a mixture of ablation till and very coarse recessional and ice contact deposits is observed. Ablation till and associated deposits are relatively permeable. Therefore, perched ground water in Layer 1 is uncommon. A falling head permeability test (refer to Appendix) of ablation till taken from MW-3 indicated a vertical permeability of approximately $5X10^{-3}$ cm/sec ($1X10^{-2}$ feet/minute).

LAYER 3 Principal Aquifer (Vashon Advance Outwash): This unit underlies nearly the entire Section 16/20 area, with the exception being those areas where the glacial deposits pinch out against bedrock. Thickness of this unit varies from several tens of feet in the northwestern quarter of Section 16 to less than five to zero feet in the eastern one half of Section 16. Permeability (as estimated utilizing slug tests and grain size distribution data) ranges from $1.8X10^{-3}$ to >.5 cm/sec ($3.6X10^{-3}$ to 1 ft/min; refer to Appendix). Where glacial till is discontinuous or absent, this unit is in direct hydraulic connection with the land surface (Figure 4-1, Model B, single-aquifer system).

LAYER 4 Lower Aquitard (Tertiary Bedrock): This unit serves as the lower confining unit for the Principal Aquifer (when under confining conditions) or as a perching layer under water table conditions. Pre-Vashon silts and clays are absent in the study area. Tertiary bedrock is generally considered an aquitard with permeabilities below $1x10^{-4}$ cm/sec ($2X10^{-4}$ ft/min) and ground water flow controlled by the nature and orientation of fractures in the rock. Regional recharge is generally through surface exposures of fractures, faults and mine workings. Residence time for ground water in Layer 4 is probably



4 LAYER SYSTEM
LATERALLY CONTINUOUS
LODGEMENT TILL
2 AQUIFER SYSTEM

ENVIRONMENT: DRIFT PLAIN AREA

2 LAYER SYSTEM
LODGEMENT TILL ABSENT
SINGLE AQUIFER SYSTEM

ENVIRONMENT: FOOTHILLS AREA

TRANSITIONAL SYSTEM
LODGEMENT TILL REMNANTS ACT
AS LOCAL PERCHING LAYER
MODIFIED SINGLE AQUIFER SYSTEM

ENVIRONMENT: FOOTHILLS AREA

NOT TO SCALE

METRO SECTION 16/20 PROJECT

HYDROSTRATIGRAPHIC MODELS

HONG WEST & ASSOCIATES

FIGURE 4-1

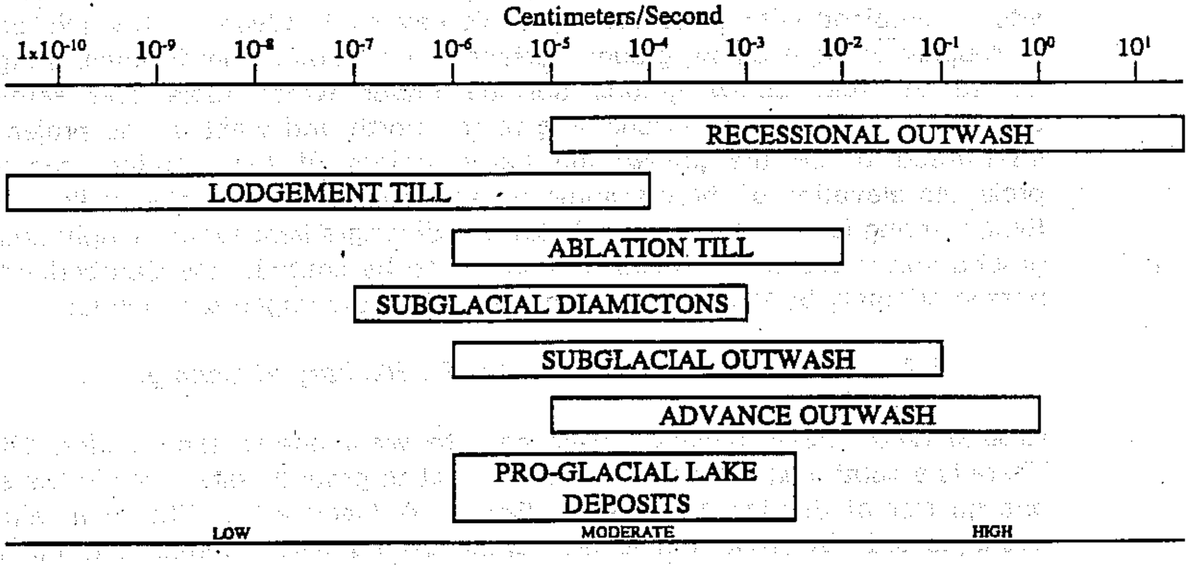
Project #: 90131

greater than that of the glacial aquifer, which is reflective of a regional flow system.

Due to the differing hydraulic properties of the bedrock and advance outwash, hydraulic communication between the two layers is probably negligible.

Table 4-1 below illustrates the typical range for hydraulic conductivity (permeability) which might be expected in glacial deposits of the Pacific Northwest. Table 4-1 was developed from published data (e.g. Freeze and Cherry, 1979) and in-situ and laboratory tests of aquifer materials conducted by Hong West & Associates staff. As the table indicates, the hydraulic conductivity and/or permeability of glacial deposits will vary over a wide range. Till, including the lodgement and ablation subtypes can vary over 8 orders of magnitude.

TABLE 4-1 TYPICAL RANGES FOR HYDRAULIC CONDUCTIVITY IN NORTHWEST GLACIAL DEPOSITS



4.2.2 Definition of Uppermost Aquifer For Monitoring

Washington State regulations require definition of uppermost aquifer prior to design of a monitoring program. "Monitorable" ground water should ideally have the following characteristics:

1. Continuous beneath area of concern

2. Hydraulic gradient is measurable beneath area of concern

3. Ground water samples may be taken from conventional monitoring wells during most of the year

Another important consideration should be that the aquifer to be monitored is an important aquifer in terms of water supply, or clearly connected to such an aquifer.

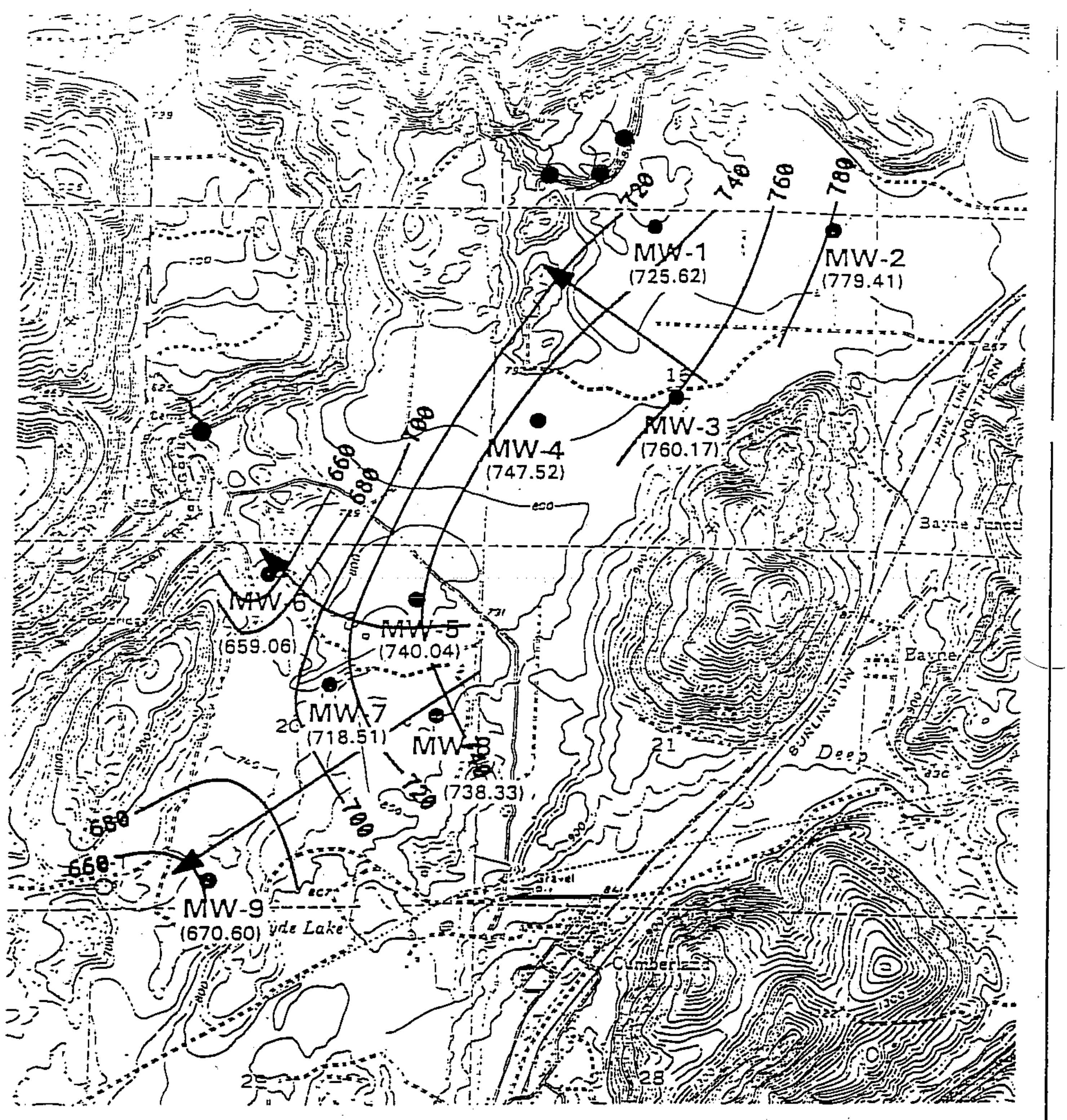
Ground water was encountered in all nine borings at depths roughly corresponding to the upper contact of the advance outwash with overlying glacial till/transitional zone or ice-contact deposits (refer to Figures 3-2 and 3-3 for the relationship between geologic contacts and water levels). This water level corresponds to seasonal high conditions and probably varies seasonally on the order of 10-15 feet (Refer to Figures 4-2 and 4-3 for a comparison of winter and summer water levels). Shallow or perched ground water was encountered in one boring (MW-5), and the lateral and vertical extent of shallow ground water appears to be limited.

Based on our interpretations, the upper aquifer beneath the Section 16/20 project site is contained within Hydrostratigraphic Layer 3 - Advance Outwash, and occurs at roughly 60 feet below ground surface, with potentiometric levels ranging from 50 to 75 feet below ground surface under water table and semi-confined conditions. The springs discharging to the north and west of the project site are interpreted to be the primary discharge points of this aquifer, based on the projected elevation of the measured potentiometric levels in the wells. Since the Resort spring is at present the only known downgradient water supply and perched ground water above lodgement till appears to be limited, the Cumberland Aquifer, hosted primarily by Vashon Advance outwash is the uppermost aquifer.

4.2.3 Ground Water Flow and Aquifer Recharge/Discharge

Ground water flows generally from east to west across the Section 16/20 site. There is a southeast to northwest component to ground water flow in the southeast one quarter of Section 16 (refer to Figures 4-2 and 4-3). The hydraulic gradient averages .02 feet/foot, but is less steep during late summer and fall (Refer to Figures 3-2 and 3-3 for a graphical representation of the hydraulic gradient). Depth to ground water averages 60 feet. Water levels dropped approximately 3 feet between late March and mid-May, 1991 but flow directions remained the same. Additional data collected in August, 1991 indicated a further drop in water levels.

The bedrock barrier of Lizard Mountain defines the local upgradient flow and recharge boundary. Aquifer recharge is almost entirely from direct infiltration of precipitation. Unusually low conductivity levels observed during well development (refer to Technical Appendix) are indicative of recharge conditions, high hydraulic

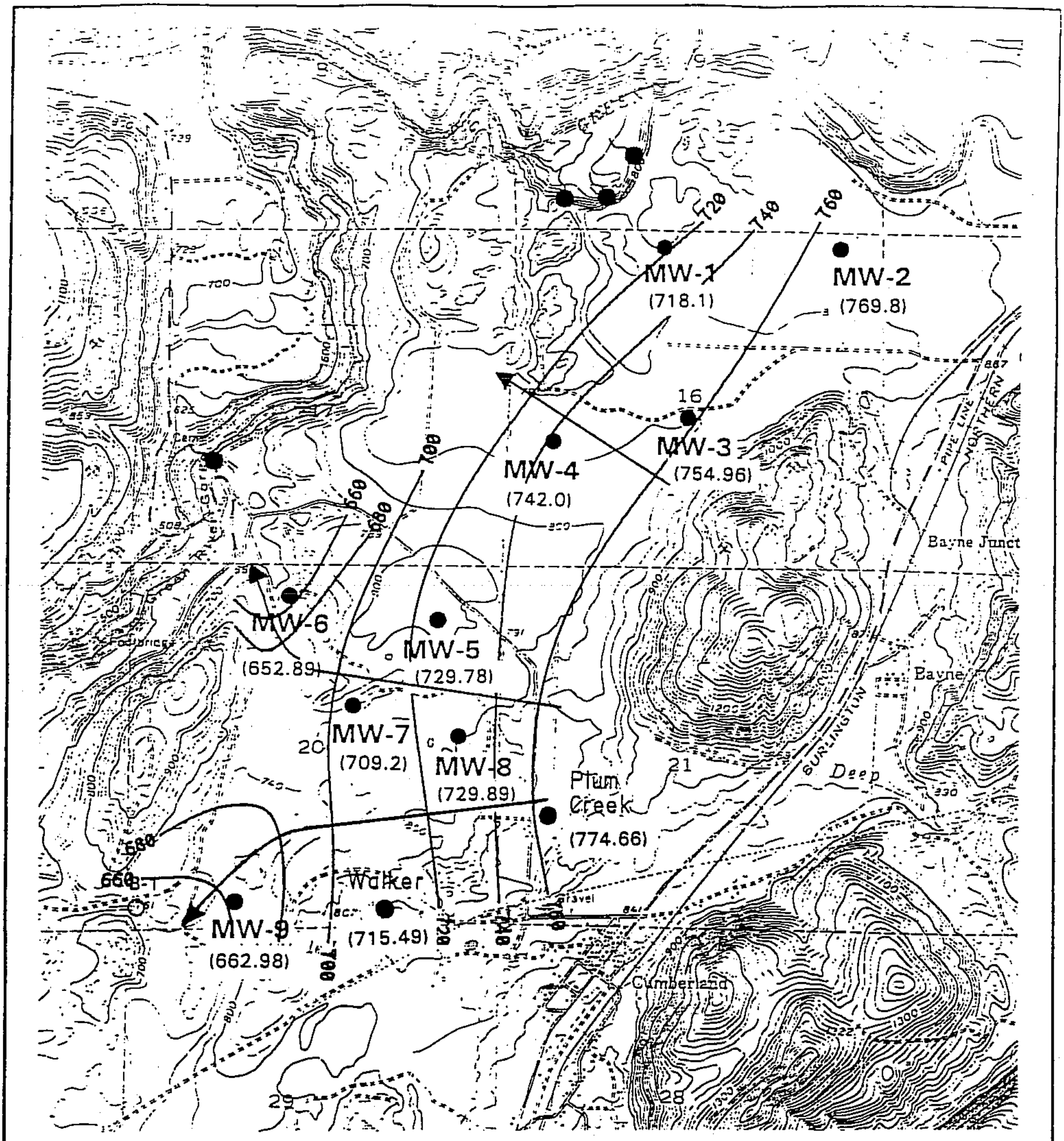


METRO SECTION 16/20 PROJECT

POTENTIOMETRIC MAP - 3/91

HONG WEST & ASSOCIATES

FIGURE 4-2



METRO SECTION 16/20 PROJECT

POTENTIOMETRIC MAP - 8/91

HONG WEST & ASSOCIATES

FIGURE 4-3

conductivity and short ground water residence time, characteristics that are consistent with the findings of Metro (1989b). Ground water is present under unconfined to semi-confined conditions.

Ground water in Section 20 flows generally from east to west until it approaches the bedrock barrier where flow apparently diverges to the southwest and northwest (refer to Figures 4-2 and 4-3). Refined ground water contours for the southern portion of Section 20 were obtained by surveying and measuring water levels in two domestic water supply wells (refer to Figure 4-3). Note that the contours in Section 20 illustrated in Figure 4-2 do not continue beyond a line drawn between wells MW-9 and MW-8 due to a lack of data for the southeastern quarter of the Section. With the collection of additional data from off-site domestic wells, the contours were continued further south with more confidence. The orientation of water level contours may vary slightly with seasonal fluctuations in gradient and water levels. Further data will confirm the observation, illustrated in Figure 4-3 that flow is from east to west across Section 20.

Ground water discharges to the surface from a series of springs located south of the Green River. Due to the varying proximity and elevation of the discharge points, hydraulic gradient is variable: in the northern half of the section it is .04 feet/foot, in the south half it averages .015 to .02 feet/foot. Ground water is present under unconfined conditions. Recharge to Section 20 ground water is primarily from direct infiltration of precipitation and infiltration of run-off in the vicinity of Lizard Mountain in Section 21. A map depicting the depth to the upper surface of Advance Outwash is shown in Figure 4-4.

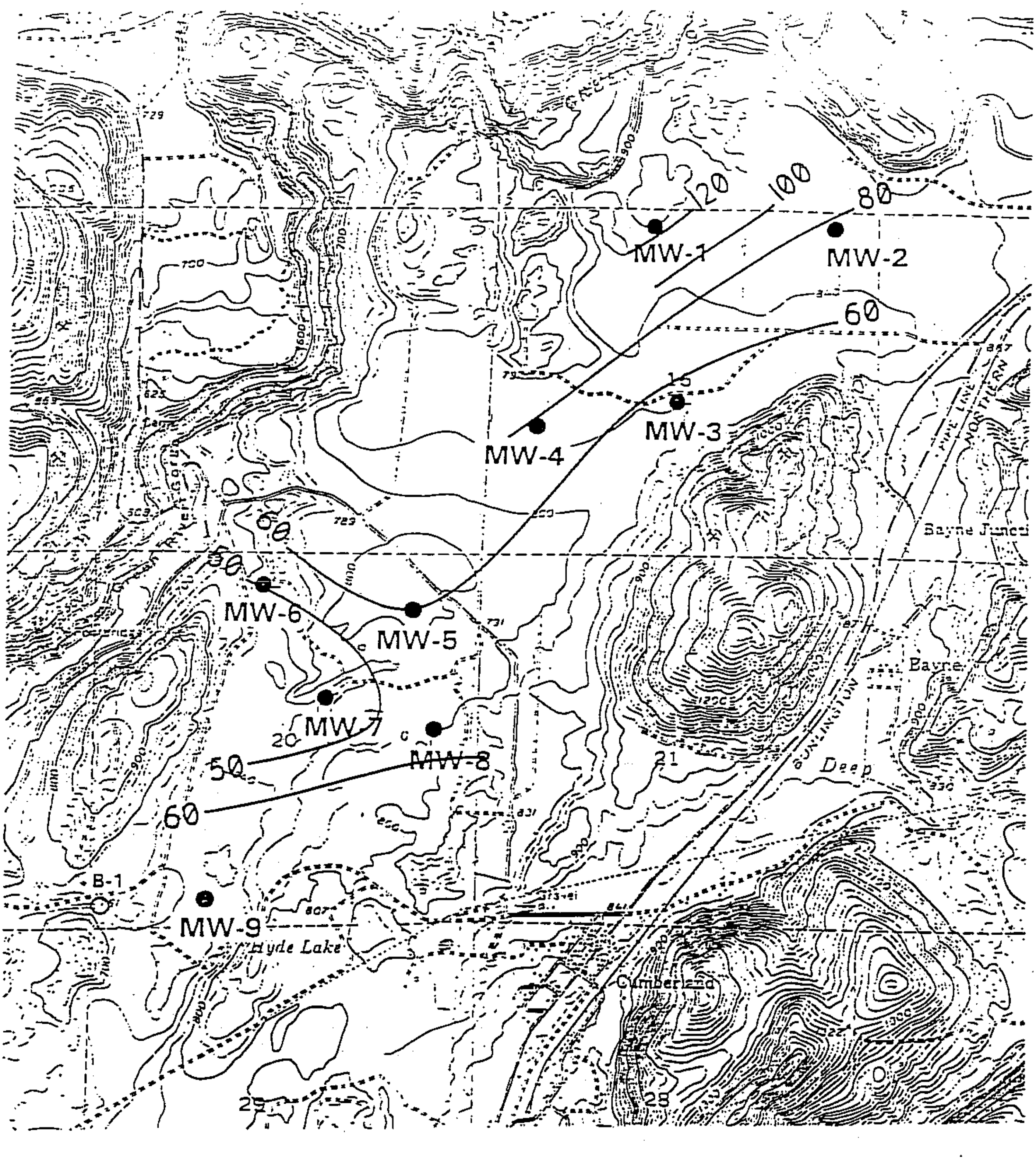
An estimate of ground water flow velocity within the principal aquifer beneath Sections 16/20 may be obtained using the following equation:

$$v = \frac{K\,i}{n}$$

using K = average hydraulic conductivity = .049 cm/sec
i = average hydraulic gradient = .02
n = assumed porosity = 40%

v = 127 meters/day = 416 feet/day

Water level measurements and well elevations are summarized below in Table 4-2.



METRO SECTION 16/20 PROJECT

DEPTH TO TOP OF PRINCIPAL AQUIFER

HONG WEST & ASSOCIATES

FIGURE 4-4

TABLE 4-2
MONITORING WELL WATER LEVEL SUMMARY
(elevations in feet)

	MW-1	MW-2	MW-3	MW-4	MW-5	MW-6	MW-7	MW-8	MW-9
Top PVC	854.65	842.19	813.74	827.88	799.35	707.90	760.60	791.04	744.54
3-24-91	725.62	779.41	760.17	747.52	740.04	659.06	718.51	738.33	670.60
5-15-91	724.49	777.28	757.86	742.36	737.02	657.34	715.73	737.07	665.79
8-8-91 *	718.10	769.80	754.96	742.00	729.78	652.89	709.20	729.89	662.98

DOMESTIC WELLS: (8-8-91): Plum Creek - 774.66; Walker - 715.49

NOTE: Well elevations surveyed by METRO

* Well cap for dedicated pump (.25') added

4.2.4 Adjacent Ground Water Development

Well logs on file at the Washington Department of Ecology were reviewed during this study and the Metro (1989a, 1989b) studies. There are no water wells recorded in Section 16, and five wells are recorded in the southeastern quarter of Section 20. There are several wells located in Sections 28 and 29, south of the project area. The Plum Creek well located in the southwest quarter of Section 21 was used to gain additional water level data. The Kanasket-Palmer State Park well is located in Section 10, northeast of the project area. Approximate locations of nearby wells, based on the most recent well logs available from Ecology (May, 1991) are shown on Figure 2-1. Water use is generally for domestic purposes; some of the wells may be used for irrigation purposes. The Walker property located near Hyde Lake contains two wells. One well is drilled into the glacial aquifer and generally goes dry each summer. A second well is drilled into the Puget Group bedrock and, according to its owner, is not suitable for drinking water supply, but is used for irrigation.

The Resort Spring (shown on Figure 2-1) serves as a water supply. Based on measured potentiometric levels and ground water flow direction, this spring is hydraulically downgradient from Sections 16/20. Based on initial well surveys, the wells in the southeast quarter of Section 20 and northeast quarter of Section 29 are not downgradient from the Metro Section 16/20 project site. As mentioned in Section 4.2.3, additional water level data collected from these water wells and the on-site wells will confirm the observation of ground water flow directions in this area.

4.3 SECTION 16/20 GROUND WATER QUALITY

Metro began a year-long baseline water quality evaluation of the on-site wells by taking its first quarterly groundwater samples from the nine new on-site wells in May, 1991. Samples were obtained by Metro staff by using dedicated Geoguard pumps utilizing industry-standard techniques for sample containers, preservation and analysis. Samples were analyzed for conventional, bacteriological, total and dissolved metals and organic parameters. The baseline data will build upon the data collected during the Metro (1989b) study and will be used during subsequent hydrochemical characterization of the Section 16/20 project site aquifer and will also provide the basis for scoping future monitoring efforts.

4.4 POTENTIAL IMPACT/AFFECTS OF MINING

The coal mining history of the Section 16/20 area dates back to the early 1900s. Vine (1969) describes the stratiform coal deposits of the South King County area. Two major mining operations existed during the early to mid 1900s in the project area: Lizard Mountain in Section 16 and Hyde Mine, just south of Section 20, in Section 29. Coal ore was extracted using tunneling and open pit excavations on the east and west side of Lizard Mountain. Two haulage slopes and one air ventilation shaft were excavated into the northwest side of Lizard Mountain. These structures are collapsed and obscured by vegetation. There are also scattered collapse features along the toe of Lizard Mountain. It is assumed that the excavations were in the direction of the southeast-dipping coal veins. There is no evidence to suggest underground tunnels, shafts or adits northwest of Lizard Mountain in Section 16. A small collapse feature was discovered approximately 600 feet east of MW-3. This is interpreted as a collapsed prospect hole. A map showing the extent of mine workings appears as Figure 2-5 in the Metro (1989b) report.

A former mine drainage tunnel passes beneath the southwest corner of Section 20, in the vicinity of B-1. This tunnel was excavated to remove excess water from the Hyde Mine workings in the north central portion of Section 29. The former tunnel in this area is probably 150 to 250 feet below the contact between the upper bedrock surface and overlying glacial deposits (the approximate plan view location of the tunnel is shown on Figure 2-1). Much of the water draining through the tunnel and discharging near its mouth above the Green River (at elevation 411; Metro, 1989b) is probably derived from ground water seepage in the bedrock fractures. The bedrock ground water regime probably operates on a regional scale. Recharge is primarily through surface exposures of fractures, faults and mine workings in the project area.

Direct observation of the hydrologic interaction between bedrock and overlying glacial deposits is not feasible in the Hyde Mine drainage tunnel area due to the excessive depth of the former tunnel (ranging up to several hundred feet below ground surface). However, some generalizations concerning this relationship are in order. Figure 4-5 is a schematic of the former Hyde Mine drainage tunnel, based on the information cited in the Metro (1989b) report. Groundwater flow in the glacial aquifer is predominantly sub-horizontal laminar flow with a relatively steep hydraulic gradient due to recharge/discharge conditions. Groundwater flow in the bedrock is structurally controlled by the position and orientation of fracture systems and is at least in part turbulent flow. The bulk permeability of the glacial deposits probably exceeds the whole-rock permeability of the bedrock on a macro scale by several orders of magnitude.

What this means, qualitatively, is that the amount of hydraulic connection between the two ground water regimes is probably negligible. The fact that the former mine drainage tunnel passes well beneath the bedrock/glacial deposit contact decreases the chances of the tunnel being a major conduit for principal aquifer ground water discharge. The hypothesis of hydraulic separation can be supported in part by comparing the hydrochemistry of the glacial (principal) aquifer to that of the former tunnel discharge water above the Green River.

In summary, it is unlikely that the mine excavations in the Section 16/20 area would provide major conduits for principal aquifer ground water flow or contaminant transport. There are no obvious deflections of ground water contours in Section 20 (Refer to Figure 4-2 and 4-3) that would suggest that the former tunnel (or the hypothetical "ancestral" Green River channel) act as underground conduits for ground water flow. If this was the case, the contours would bend in the "downstream" direction along the axis of the conduit. Measured potentiometric levels in monitoring wells do not indicate any such anomalous flow patterns caused by the influence of mine tunnels or other subsurface irregularities.

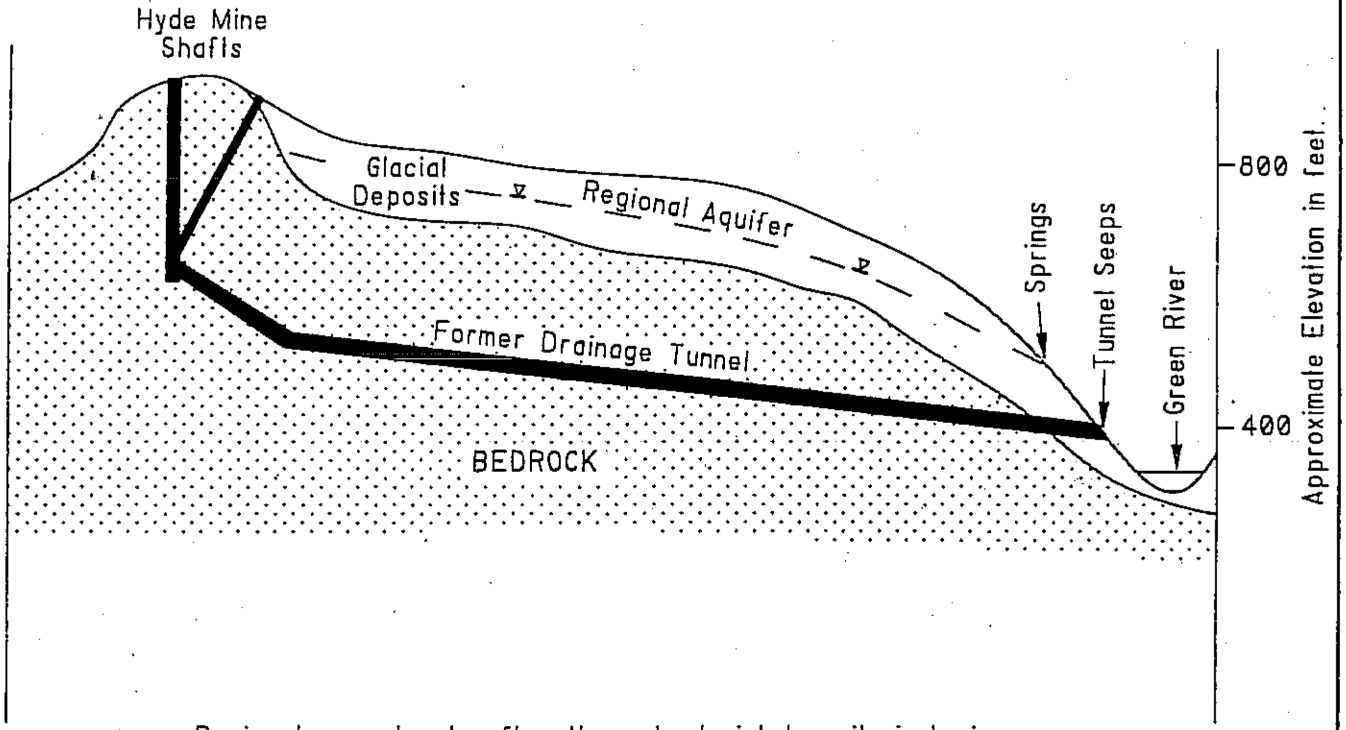
SECTION 5.0 FINDINGS AND CONCLUSIONS

Based on review of available data and new data collected during installation of nine monitoring wells, the following general conclusions are presented relative to the hydrogeology of the Metro Section 16/20 project. The following statements summarize the Section 16/20 project ground water system:

1. Highly permeable recessional outwash and ice contact deposits cover the project area. These deposits are for the most part unsaturated. Perched water may be found locally above low permeability lodgement glacial till layers, or silty "transistional" advance outwash.

2. Moderate to low permeability glacial lodgement till is absent or discontinuous beneath the project area.

3. Highly permeable advance outwash deposits are continuous beneath the project area and host the area's principal aquifer. Depth to groundwater averages 60 feet.



Regional ground water flow through glacial deposits is laminar, sub-horizonatal flow, discharging to the Green river via springs, above bedrock. Regional ground water flow through bedrock is through fractures; mostly turbulent flow. Vertical exchange of ground water between the two systems is negligible.

NOT TO SCALE

METRO SECTION 16/20 PROJECT

HYDE MINE DRAINAGE TUNNEL
SCHEMATIC CROSS-SECTION

HONG WEST & ASSOCIATES

FIGURE 4-5

Project #: 90131

4. Where glacial till is absent or discontinuous, the principal aquifer behaves as a water table aquifer. A steep hydraulic gradient combined with overlying glacial till produces local areas within the aquifer that are semi-confined.

5. The Section 16/20 project area is within a local ground water flow system, where nearly all recharge to the aquifer is from direct infiltration of precipitation and nearly all discharge is to springs or the Green River.

6. Ground water flows generally from east to west across the project site. A bedrock high creates a north and south divergence in the flow pattern in Section 20.

7. The generally high infiltration capacity of the surface sediments, the high permeability of the advance outwash and the relatively large local relief between recharge and discharge areas causes the area's ground water system to have a steep hydraulic gradient and a resultant high rate of flow.

8. Former mine workings at Lizard Mountain in Section 16 and the Hyde Mine drainage tunnel in Section 20 do not appear to significantly impact the rate or direction or ground water flow in the overlying glacial aquifer.

SECTION 6.0 RECOMMENDATIONS

Based on our investigation, several data gaps were identified which are important in evaluating the hydrogeology of the Section 16/20 project site and developing a credible monitoring program.

1. Ongoing ground water level data utilizing existing on-site monitoring wells and off-site domestic water supply wells should be evaluated by a hydrogeologist to confirm that wells in the southeast quarter of Section 20 and the northeast quarter of Section 29 are not downgradient (under any seasonal flow regimes) from the Metro Section 20 property.

2. The "perched" aquifer tentatively identified in MW-5, Section 20 is not known. If glacial till is areally limited. Low permeability glacial till is discontinuous, perched water from Layer 1 discharges to Layer 3 and therefore will not require a separate monitoring system.

3. The benefits of additional field data collection to determine the extent of perched ground water in Section 20 may not be justified, given the remote likelihood of hydraulic separation beyond the limits of the project site. Vadose zone monitoring and principal aquifer monitoring will provide early detection of changes in groundwater quality.

4. The discharge from the former Hyde Mine drainage tunnel should be sampled and the hydrochemistry should be evaluated.

5. The baseline water quality data and water level data from ongoing monitoring should be evaluated periodically by a hydrogeologist.

6. Following the initial year's worth of monitoring, the baseline water quality and hydrochemistry should be described and evaluated by a hydrogeologist prior to design and planning of the project water quality monitoring program.

SECTION 7.0 REFERENCES

Bates, R.L. and Jackson, J.A., Editors, Dictionary of Geologic Terms, 3rd edition; American Geological Institute, 1984.

Booth, D.B. , 1984, *Glacier Dynamics and the Development of Glacial Landforms in the Eastern Puget Lowlands, Washington*, PhD. Thesis, University of Washington, 191 p.

- - - - - , 1988, *Geologic Map of Southeast King County*, King County Surface Water Management Group, unpublished.

Economic and Engineering Services, Inc. *South King County Ground Water Management Plan, Grant No. 1, Background Data Collection and Management Issues;* report to South King County Ground Water Advisory Committee, Volumes I and II, 1989.

Embleton, C. and King. C.A. Glacial and Periglacial Geomorphology, Macmillan of Canada, Toronto, 1971, 608p.

Flint, R.F. Glacial and Pleistocene Geology , John Wiley and Sons, New York, 1971.

Freeze, R.A. and Cherry, J.A., Groundwater, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1979, 588p

Galster, R.W. and Laprade, W.T., 1991, *Geology of Seattle, Washington, United States of America:* Bulletin of the Association of Engineering Geologists, Vol. XXVIII, No. 3, p 235-302.

Hall, J.B. and Othberg, K.L., 1974, *Thickness of Unconsolidated Sediments, Puget Lowland, Washington;* Washington Department of Natural Resources Geologic Map GM-12.

Hvorslev, M.J. , 1951, *Time-Lag and Soil Permeability in Groundwater Observations:* U.S. Army Corps of Engineers Waterways Experiment Station, Bulletin No. 36.

Luzier, J.E., 1969, *Geology and Ground Water Resources of Southwestern King County, Washington;* U.S. Geological Survey Water Supply Bulletin 28.

Municipality of Metropolitan Seattle, 1989a, *Geohydrology Studies of the Metro Section 16 Silvigrow Project;* Metro publication.

Municipality of Metropolitan Seattle, 1989b, *Metro Section 16 Silvigrow Project Hydrogeology and Water Quality Evaluation;* Metro publication 337.

Noble, J.W., 1960, *A Preliminary Report on the Geology and Ground Water of the Sequim-Dungeness Area, Clallam County, Washington;* Washington Department of Conservation Division of Water Resources Water Supply Bulletin 11.

Robinson, J.B. and Noble, J.W., 1974, *Water Resource Management Study,* City of Seattle; Appendix A.

Soil Conservation Service, 1973, *Soil Survey of King County, Washington;* United States Department of Agriculture

Vine, J.D. , 1962, *Geology and Coal Resources of the Cumberland, Hobart and Maple Valley Quadrangles, King County, Washington;* U.S. Geological Survey Professional Paper 624, 67 p.

Washington State Department of Ecology, 1990, 1991 *Water Well Reports Files*

Wylie, A. and Wood, T. (1990); *A Program to Calculate Hydraulic Conductivity Using Slug Test Data;* Ground Water, vol. 28, No. 5 Sept.-Oct., 1990. pp 783-786.

APPENDICES

APPENDIX A
TECHNICAL GLOSSARY

Ablation Till -- Nonsorted, nonlayered, extremely heterogeneous sediment deposited at the nose or lateral margin of a retreating glacier.

Adit -- A nearly horizontal mine passage from the surface in a mine.

Aquifer -- A subsurface waterbearing soil or rock unit capable of yielding water.

Aquitard -- A soil or rock unit not capable (or relatively incapable) of transmitting ground water.

Confined Aquifer -- A soil or rock aquifer unit that is isolated from the atmosphere at the point of discharge by a low permeable unit. Confined ground water is generally subject to pressure greater than atmosphere.

Diamicton -- Nonsorted terrigenous sediments and rocks containing a wide range of particle sizes, regardless of origin.

Discharge -- The water flowing in a stream or through an aquifer past a specific point in a given period of time.

Drift -- A collective term for all the rock, sand, and clay that is deposited by a glacier either as till or outwash.

Epoch - Used informally to designate a relatively short interval of geologic time, e.g. a glacial epoch.

Hydraulic Conductivity -- The ease with which a porous material allows the flow of liquid or gaseous fluids.

Hydraulic Connection -- Two or more hydrostratigraphic units which allow water to pass between them.

Hydraulic Gradient -- The rate of change in total head per unit distance of flow in a given direction, i.e. the slope of the water table or potentiometric surface.

Hydrostratigraphic Unit -- A body of rock/soil having considerable lateral extent and composing a geologic framework for a reasonably distinct hydrogeologic system.

Hydrostatic Pressure - Force exerted on a liquid by surrounding solid.

Ice-Contact Deposits - Geomorphic features that include moraines, kames, kettles, drumlins and eskers; generally composed of nonstratified or stratified drift deposited in contact with melting or stagnant glacial ice. Numerous small coalescing kettles produce hummocky topography.

Laminar -- Water flow in which the stream lines remain distinct and in which the flow direction at every point remains unchanged with time. It is characteristic of the movement of ground water.

Lodgement Till -- Nonsorted, nonlayered sediment deposited beneath a moving glacier; generally very dense and compact.

Moraine -- A mound, ridge, or other distinct accumulation of unsorted, unlayered glacial debris deposited chiefly by direct action of glacier ice.

Outwash -- Primarily sand and gravel washed out from a glacier by meltwater streams and deposited in front of or beyond an active glacier.

Overconsolidation (glacial) - A high degree of compaction (and associated structures) of subglacial sediments resulting from the forces exerted by the weight of glacier ice.

Perched Aquifer -- Ground water separated from an underlying main body of ground water by an unsaturated zone. May be seasonal and limited in lateral extent.

Potentiometric Surface/Level -- Surface to which water in an aquifer would rise under hydrostatic pressure.

Recharge -- The processes involved in the absorption and addition of water to the zone of saturation or water body.

Stade - A substage of a glacial stage marked by a glacial readvance.

Stage - A time term for a major subdivision of a glacial epoch; it includes glacial stage and interglacial stage

Stratigraphic Unit -- Unit consisting of layered, mainly sedimentary rocks, grouped for description, mapping, or correlation purposes.

Turbulent -- Water flow in which the flow lines are confused and heterogeneously mixed. It is typical of flow in surface-water bodies and bedrock cavities and fractures.

Vadose Zone -- (Unsaturated Zone) A subsurface zone containing water under pressure less than that of the atmosphere. The zone is limited above by the land surface and below by the water table.

Water Balance -- A sum of all the sources of supply and the corresponding discharges with respect to an aquifer or a drainage basin.

Water Table Aquifer -- (Unconfined Aquifer) A soil or rock aquifer unit which is under atmospheric pressure. The aquifer is not overlain by a low permeable unit.

Zone of Saturation - That part of a geologic formation in which soil or rock pores are filled with water and the pressure of that water is equal to or greater than atmospheric pressure.

APPENDIX B
TECHNICAL REPORT-FIELD INVESTIGATIONS
METRO SECTION 16/20 PROJECT

I. SUMMARY

Hong West & Associates (HWA) installed nine 2" PVC monitoring wells at the Metro Section 16/20 site near Cumberland, Washington between December 13, 1990 and March 24, 1991. Initially, drilling was hampered somewhat by the unusually severe winter weather and some large boulders which were successfully bypassed by deploying a downhole hammer on an air rotary rig. However, the incidence of nested boulders increased. The CH2M Hill/Hong West & Associates team elected to suspend drilling operations after installation of MW-3 and MW-5 due to the very high incidence of large boulders encountered and the inability of the air rotary rig to successfully advance the 6" steel casing. After a period of technical and comparitive evaluations of available drilling methods, dual wall reverse circulation was selected over air rotary and cable tool as the method best suited to the Section 16./20 geologic conditions. A shift in drilling technology from conventional air rotary to dual wall reverse circulation required execution of a new drilling contract. After mobilizing the reverse circulation rig on-site, the remaining 7 wells were completed within a week's time.

Figure 2-1 (in text of report) shows the locations of all monitoring wells at the project site. Monitoring wells MW-3 and MW-5 were installed by Ramlo Well Drilling, Graham, Washington. Monitoring wells MW-1, MW-2, MW-4, MW-6 thru 9 were installed by Layne Environmental Drilling of Tacoma, Washington. Wellhead horizontal locations (to the nearest .1 ft) and elevations (to the nearest .01 ft) were surveyed by Metro staff. All drilling, well construction and development was supervised and inspected by Hong West & Associates' hydrogeologists. Boring logs were prepared on site by the geologist during well drilling and construction and modified accordingly after reviewing samples in the geotechnical laboratory. Table 1 presents a summary of the Section 16/20 project monitoring well construction details. Refer to the accompanying well logs for lithologic and well construction details. Upon well completion, water levels were measured periodically to provide data for construction of potentiometric maps. Boring logs were examined to evaluate site geology and aquifer thickness. Hydraulic conductivity testing was performed on several monitoring wells to provide for an estimate of saturated hydraulic conductivity of the aquifer materials. Geotechnical laboratory testing was carried out on selected soil samples to provide further geologic/hydrogeologic data for characterization. After the initial construction, development and water level monitoring was complete, Metro installed dedicated Geoguard sampling pumps in each well and commenced with water quality monitoring in May, 1991.

TABLE 1
Monitoring Well Summary

Well Number	Ground Surface Elevation (feet)*	Top of PVC Casing Elevation (feet) **	Drill Depth (feet)	Screen Depth (feet)	Screen Elevation (feet)
MW-1	853.32	854.65	139	127-137	726.32-716.32
MW-2	840.81	842.19	90	78-88	762.81-752.81
MW-3	812.27	813.74	76	63-73	749.27-739.27
MW-4	825.92	827.88	99	86-96	739.92-729.92
MW-5	797.94	799.35	77	65-75	732.94-722.94
MW-6	705.46	707.90	59	47-57	658.46-648.46
MW-7	758.91	760.60	59	47-57	711.91-701.91
MW-8	788.53	791.04	72	59-69	729.53-719.53
MW-9	741.80	744.54	90	79-89	662.80-652.80

NOTES: * Elevations surveyed by Metro
** Add .25' to these elevations to allow for addition of Geoguard cap

II. EQUIPMENT/DECONTAMINATION

Drilling for wells MW-3 and MW-5 was performed with air rotary drill rig owned and operated by Tacoma Pump & Drilling Company (d/b/a Ramlo Well Drilling) of Graham, Washington. The remainder of the drilling was performed with a dual-wall reverse-circulation drill rig owned and operated by Layne Environmental Services of Tacoma, Washington.

All drilling equipment was pressurized-hot water washed/steamed cleaned prior to entering and after leaving each borehole site. In addition, all downhole drilling tools were pressurized-hot water washed/steam cleaned between borings.

III. DRILLING

The air rotary drill rig used a "drill and drive" method. A 6" diameter tricone bit was advanced two to five feet below the the 6" steel drill casing after which the casing was hammer driven to the drilled depth. A 6" diameter drive shoe was welded to the bottom of the initial length of 6" drill casing. A twenty foot, 5" diameter stabilizer and twenty foot, 4-1/2" diameter drill rods were used to advance the boring. Cuttings (up to about 3" in diameter) were removed from the hole by compressed air pumped down the drill string and released through the bit.

The dual wall reverse-circulation rig utilized a pile drive method. The dual-wall pipe, 9" outside diameter, 6" inside diameter was driven into the ground with a pile driver built into the rig. Air was blown down the annular space between the two casings, forcing the cuttings up the inner 6" diameter pipe. Removal of material ranging from silt to 6" cobbles or rock fragments was possible using this method.

IV. SAMPLING

Samples were collected from a cyclone attached to the end of the 6" diameter air discharge tube (cyclone was not used on MW-3 or MW-5). Sampling intervals were typically every five feet or less. After field inspection by the HWA geologist, samples were sealed and labeled in air-tight containers for transportation to HWA's soils laboratory for analysis.

V. WELL COMPLETION

All monitoring wells were completed using threaded 2-inch schedule 40 PVC pipe as a riser and a 10-foot section of screen with 0.010-inch slot widths. A filter pack of Colorado 10-20 silica sand was placed around each screen and bentonite grout was used to seal and backfill the annular space. Bentonite chips were used to complete the seal where the grout settled in the borehole. As the pipe and backfill were placed, the drill casing was withdrawn from the hole. An inner 6-inch and outer 12-inch diameter security casing was installed at the surface and embedded in concrete. See the attached well logs for details of individual well completions.

VI. WELL DEVELOPMENT

Monitoring wells were developed using either a single pipe airlift technique or by bailing. The airlift technique used 100 CFM compressed air, filtered for liquid, particulate and organic matter using a three-phase filter, which was conducted to the screened zone through a 1 inch continuous PVC pipe. A separate length of 1" diameter PVC development pipe was dedicated to each well. The pipe was systematically raised and lowered over the screen during development. The bailing method used a 5' long 1" diameter PVC tube with a "foot valve" attached to the bottom end. The bailer was lowered on nylon rope into the water until filled, then manually lifted back to the surface and dumped. Samples of the water lifted during development were tested at regular intervals for pH and conductivity. Development was continued until discharge water was relatively clear and pH and conductivity stabilized. The volume of well development water varied from approximately 10 to 75 gallons depending on the technique used.

VII. MONITORING WELL SUMMARIES

Following is a well-by-well description of drilling and well construction activities, based on field logs and notes. For well details, refer to Exhibit A, Monitoring Well Logs. Note on the logs that the open symbol for ground water indicates the level at which ground water was first encountered and the closed symbol represents the stabilized water level after well installation.

MONITORING WELL MW-1

This well was drilled, installed, and developed between March 20, and April 1 1991.

Drilling originally began on MW-1 on December 29, 1990 with the air-rotary drill rig, but was abandoned due to boulders encountered. The borehole was backfilled with bentonite chips as per WAC 173-160. Drilling began again utilizing the dual-wall reverse-circulation drill rig and was completed on March 20, 1991. Boulders were again encountered at a depth of 27 to 32 feet, but were successfully drilled through. Ground water was originally encountered at a depth of 127 feet b.g.s., with a static level after installation of 127.7 feet. The well screen interval was from a depth of 137 to 127 feet. Screen elevations relative to the Metro survey are contained in Table 1.

Well MW-1 was developed on April 1, 1991 for a period of 2.5 hours using a bailer until stable pH and conductivity readings were obtained. A pH of 8.11 and a conductivity of 2000 uS were recorded. The conductivity readings seemed abnormally high and may have been the result of a malfunctioning instrument on April 1, 1991 (see also MW-6). Approximately 11 gallons of water were removed during development.

MONITORING WELL MW-2

This well was drilled, installed, and developed between March 21, and April 2, 1991.

Drilling began and was completed on March 20, 1991, utilizing the dual-wall reverse-circulation drill rig. Ground water was originally encountered at a depth of 78 feet b.g.s., with a static level after installation of 61.4 feet. The well screen interval was from a depth of 88 to 78 feet.

Well MW-2 was developed on April 2, 1991 for a period of 50 minutes using the air-lift technique until stable pH and conductivity readings were obtained. A pH of 8.5 and a conductivity of 148 uS were recorded. Approximately 75 gallons of water were removed during development.

MONITORING WELL MW-3

This well was drilled, installed, and developed between December 13 and December 27, 1990.

Drilling began on December 13, 1990 utilizing the air-rotary drill rig and was completed on December 27, 1990. Ground water was originally encountered at a depth of 53 feet b.g.s., with a static level after installation of 53 feet. The well screen interval was from a depth of 73 to 63 feet.

Well MW-3 was developed on December 27, 1990, for a period of 1 hour using the air-lift technique until water flowed clear.

MONITORING WELL MW-4

This well was drilled, installed, and developed between March 21, and April 2, 1991.

Drilling began on March 21, 1991 and was completed on March 22, 1991, utilizing the dual-wall reverse-circulation drill rig. A boulder was encountered at a depth of 39 feet. After pounding on the boulder unsuccessfully for the last 2.5 hours of March 21 the rig was moved to an alternate location approximately 50 feet away. The new hole encountered a boulder at 5 feet. The driller then decided to return to the original hole, with the casing still in at 40 feet, and use a downhole hammer. The abandoned borehole was sealed with bentonite chips in accordance with WAC 173-160. The downhole hammer successfully drilled through the boulder in about 10 minutes. The dual wall pipe was then driven through the boulder and on to the final depth. Ground water was originally encountered at a depth of 79 feet b.g.s., with a static level after installation of 78.4 feet. The well screen interval was from a depth of 96 to 86 feet.

Well MW-4 was developed on April 2, 1991 for a period of 2 hours using the air-lift technique until stable pH and conductivity readings were obtained. A pH of 7.9 and a conductivity of 81.6 uS were recorded. Approximately 40 gallons of water were removed during development.

MONITORING WELL MW-5

This well was drilled, installed, and developed between January 1, and April 3, 1991.

Drilling began on January 1, and was completed on January 7, 1991, utilizing the air-rotary drill rig. Perched ground water was originally encountered from a depth of 38 to 42 feet b.g.s. Ground water was encountered at a depth of 68 feet with a static level after installation of 56.5 feet. The well screen interval was from a depth of 75 to 65 feet.

Well MW-5 was developed on April 3, 1991 for a period of 40 minutes using a bailer until stable pH and conductivity readings were obtained. A pH of 7.8 and a conductivity of 112 uS were recorded. Approximately 10 gallons of water were removed during development.

MONITORING WELL MW-6

This well was drilled, installed, and developed between March 22, and April 1, 1991.

Drilling began on March 22, and was completed on March 23, 1991, utilizing the reverse-circulation drill rig. Ground water was encountered at a depth of 49 feet with a static level after installation of 46.4 feet. The well screen interval was from a depth of 57 to 47 feet.

Well MW-6 was developed on April 1, 1991 for a period of twp hours using a bailer until the water cleared and stable pH and conductivity readings were obtained. A pH of 7.71 and a conductivity of 1970 uS were recorded. The conductivity readings seemed abnormally high and may have been the result of a malfunctioning instrument. Approximately 20 gallons of water were removed during development.

MONITORING WELL MW-7

This well was drilled, installed, and developed between March 23, and April 2, 1991.

Drilling began on and was completed on March 23, 1991, utilizing the reverse-circulation drill rig. Ground water was encountered at a depth of 43 feet with a static level after installation of 40.4 feet. The well screen interval was from a depth of 57 to 47 feet.

Well MW-7 was developed on April 2, 1991 for a period of 26 minutes using the air-surge method until the water cleared and stable pH and conductivity readings were obtained. A pH of 7.8 and a conductivity of 199 uS were recorded. Approximately 15 gallons of water were removed during development.

MONITORING WELL MW-8

This well was drilled, installed, and developed between March 23, and April 3, 1991.

Drilling began and was completed on March 23, 1991, utilizing the reverse-circulation drill rig. Ground water was encountered at a depth of 57 feet with a static level after installation of 50.2 feet. The well screen interval was from a depth of 69 to 59 feet.

Well MW-8 was developed on April 3, 1991 for a period of 25 minutes using the air-surge method until the water cleared and stable pH and conductivity readings were obtained. A pH of 7.67 and a conductivity of 256 uS were recorded. Approximately 15 gallons of water were removed during development.

MONITORING WELL MW-9

This well was drilled, installed, and developed between March 24, and April 3, 1991.

Drilling began on and was completed on March 24, 1991, utilizing the reverse-circulation drill rig. Ground water was encountered at a depth of 77 feet with a static level after installation of 71.2 feet. The well screen interval was from a depth of 89 to 79 feet.

Well MW-9 was developed on April 3, 1991 for a period of 50 minutes using the bailer method until the bailer broke and was lost down the hole. The bailer was subsequently removed from the hole and development completed on May 25, 1991. An initial pH of 6.61 and a conductivity of 103 uS were recorded. Approximately 10 gallons of water were removed during development.

VIII. HYDRAULIC CONDUCTIVITY TESTING AND ANALYSIS

Single-well hydraulic conductivity testing was used to further define the aquifer parameters for the Section 16/20 project site. Rate-of-fall and rate-of-rise slug tests were performed on April 15th and May 1st, 1991, for six monitoring wells (MW-1, MW-2, MW-4, MW-5, MW-7, and MW-9). The rate-of-fall was initiated by placing a solid "slug" made of solid PVC below the water table and measuring the well response over time. After the well recovered to static conditions, the slug was removed instantaneously and the rate-of-rise was measured. Water level response was measured using a pressure tranducer and Hermit Datalogger (manufactured by In-Situ Inc.).

Permeability estimates were obtained using the methods of Hvorslev (1951) and Bouwer and Rice (1976), and checked using the computer program, SLUGTEST (Wylie and Wood, 1990).

Methodology

The Hvorslev analysis assumes a homogeneous, isotropic, and infinite medium. The equation used is one of many presented by Hvorslev for differing well geometry and aquifer conditions. The equation which follows can be applied to unconfined aquifer conditions for most well designs where the length of the well screen is considerably greater than the radius of the well screen, L/R > 8, (Fetter, 1988). The equation for hydraulic conductivity is:

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

where

K is the hydraulic conductivity in ft/min
r is the radius of the well casing (0.167 ft for all wells)
L is the length of the well screen (10 ft for all wells)
R is the radius of the well filter pack (0.75 ft for all wells, except MW-5 = 0.5 ft)
T_0 is the basic time lag (Read from graph in minutes)

T_0, the basic time lag, is determined graphically from a semilogarithmic plot of the head ratio (h/h_0) vs time (t). The distance the water level responds immediately upon removal (or injection) of the slug is h_0. The water level response at some time, t, after the slug is removed (or injected), is h. The head ratio is plotted on the logarithmic axis. The time is plotted on the arithmetic axis. A best fit line is plotted through the data. T_0 is the time value where the best fit line intersects the 0.37 h/h_0 line.

The Bouwer and Rice method also assumes a homogeneous, isotropic, infinite medium. It can be used for "slug tests on partially or completely penetrating wells in unconfined aquifers for a wide range of geometry conditions" (Bouwer and Rice, 1976). The equation used is:

$$K = \frac{r_c^2 \ln(R_e/r_w)}{2L} \; \frac{1}{t} \ln\frac{y_0}{y_t}$$

where

K is the hydraulic conductivity in feet/minute
r_c is the radius of the casing (0.167 ft for all wells)
R_e is the effective radius of the well (obtained from type curves)
r_w is the radius of the borehole (0.75 ft for all wells, except MW-5; $r_w = 0.5$)
y_0 is the initial drop in head
L is the length of the screen (10 ft for all wells)
t is an arbitrary time
y_t is the depth below static water level at time t

The term y_t is determined graphically from a semilogarithmic plot of y (well response) vs time. The reponse, y, is plotted on the logarithmic axis. The time is plotted on the arithmetic axis. From the best fit line through the data y_t is taken at any arbitrarily selected t.

The term $\ln(R_e/r_w)$ is determined by the equation:

$$\ln(R_e/r_w) = \left| \frac{1.1}{\ln(H/r_w)} + \frac{A + B\ln[(D - H)/r_w]}{L/r_w} \right|^{-1}$$

where:

H is the distance from the water table to the bottom of the well screen
D is the distance from the water table to the bottom of the aquifer
A, B are values taken from type curves

The value $\ln[(D - H)/r_w]$ has an effective upper limit value of 6. If $\ln[(D - H)/r_w]$ is greater than 6, a value of 6 should be used for the term $\ln[(D - H)/r_w]$ in the above equation (Bouwer and Rice, 1976). The value of D is unknown for all wells, except MW-2, therefore we used a value of 4 for $\ln[(D - H)/r_w]$ in our calculations, which equates to an aquifer thickness of 50 to 70 feet.

If D = H, as it does for MW-2, the term $\ln[(D - H)/r_w]$ cannot be used. In this case the above equation should be changed to:

$$\ln(R_e/r_w) = \left| \frac{1.1}{\ln(H/r_w)} + \frac{C}{L/r_w} \right|^{-1}$$

This equation is valid for wells fully penetrating the aquifer.

The terms A, B and C are dimensionless coefficients that are functions of $L/r_{w\ \text{if}\ D>>H}$. The values of A, B and C are taken from type curves that can be found in Bouwer and Rice, 1976, p. 425.

Results and Discussion

The results of the slug tests performed are summarized in Table 2 Aquifer Parameter Summary.

TABLE 2
Aquifer Parameter Summary

	Hydraulic Conductivity (cm/sec)			
Well Number andTest Method	Hvorslev	Slugtst Program	Bouwer & Rice	Average (by well)
MW-1 Falling Head	0.12	0.068	NA	
MW-1 Rising Head	0.06	0.09	0.058	0.079
MW-2 Falling Head	0.009	0.0024	0.0035	
MW-2 Rising Head	0.018	0.0018	NA	0.0069
MW-4 Falling Head	0.05	0.035	NA	
MW-4 Rising Head	0.04	0.05	0.04	0.043
MW-5 Falling Head	0.085	0.04	NA	
MW-5 Rising Head	0.039	NA	NA	0.055
MW-7 Falling Head	0.073	0.038	NA	
MW-7 Rising Head	0.092	NA	0.099	0.075
MW-9 Falling Head	0.12	NA	NA	
MW-9 Rising Head	NA	NA	NA	0.12

NA = Not Analyzed; insufficient data

Due to the high hydraulic conductivity, some extremely fast recovery rates were experienced during the slug tests. This resulted in sparse data making the analysis slightly more subjective, but repeatable and not significantly less accurate.

Note that for both methods (Hvorslev, 1951; Bouwer and Rice, 1976) the time-drawdown data "should plot on a straight line." Clearly, the graphs presented in Exhibit C indicate that test conditions were not ideal and that the linear relationship is only observed for very early time (in this case, the rising head data look better). Since the subject aquifer is composed of glacial outwash it is presumed to be highly permeable, perhaps too permeable to estimate K using slug tests. Multiple well pumping tests are far more precise methods under these conditions.

Bouwer and Rice (1976) is probably the more valid test because Hvorslev assumes an ellipsoidal well screen and infinite vertical extent of the flow system. Further, Hvorslev equates Re to L (to use Bouwer and Rice variables), which is not the case. Actually Re is less than L and this leads to an overestimation of K.

With the exception of MW-2 (completed in silty gravel), the estimated hydraulic conductivity values were in the range of .04 to .12 cm/sec. An average value for the advance outwash of .08 cm/sec (.16 ft/minute) may be used to estimate rate and velocity of ground water flow.

The slug test data, graphs and calculations used in the analysis are presented in Exhibit C.

IX. GEOTECHNICAL LABORATORY TESTING

Eight samples were selected for geotechnical analysis. Grain size distribution was determined for the following:

MW-1 -- 135 foot sample
MW-2 -- 50 + 55 foot composite sample
MW-3 -- 38-39 undisturbed (Dames & Moore) sample
MW-4 -- 90 foot sample
MW-6 -- 20 foot sample
MW-6 -- 55 foot sample
MW-7 -- 55 foot sample
MW-8 -- 5 foot sample

Samples analyzed ranged from poorly graded gravel with sand (GP) to silty gravel with sand (GM). Permeability calculations were performed using the method outlined in Powers (1981). However, due to either very high uniformity coefficients or high D50 grain size, analysis could only be done for three of the samples. All estimates for permeability based on grain size distribution were greater than .05 cm/sec (.1 ft/minute).

A falling head permeability test was performed on the MW-3 38-39 foot undisturbed sample, logged as glacial till. The calculated K value was 5.6 X 10 -3 cm/sec. Refer to Exhibit B for all geotechnical analyses.

EXHIBIT A

MONITORING WELL LOGS

HONG WEST & ASSOCIATES

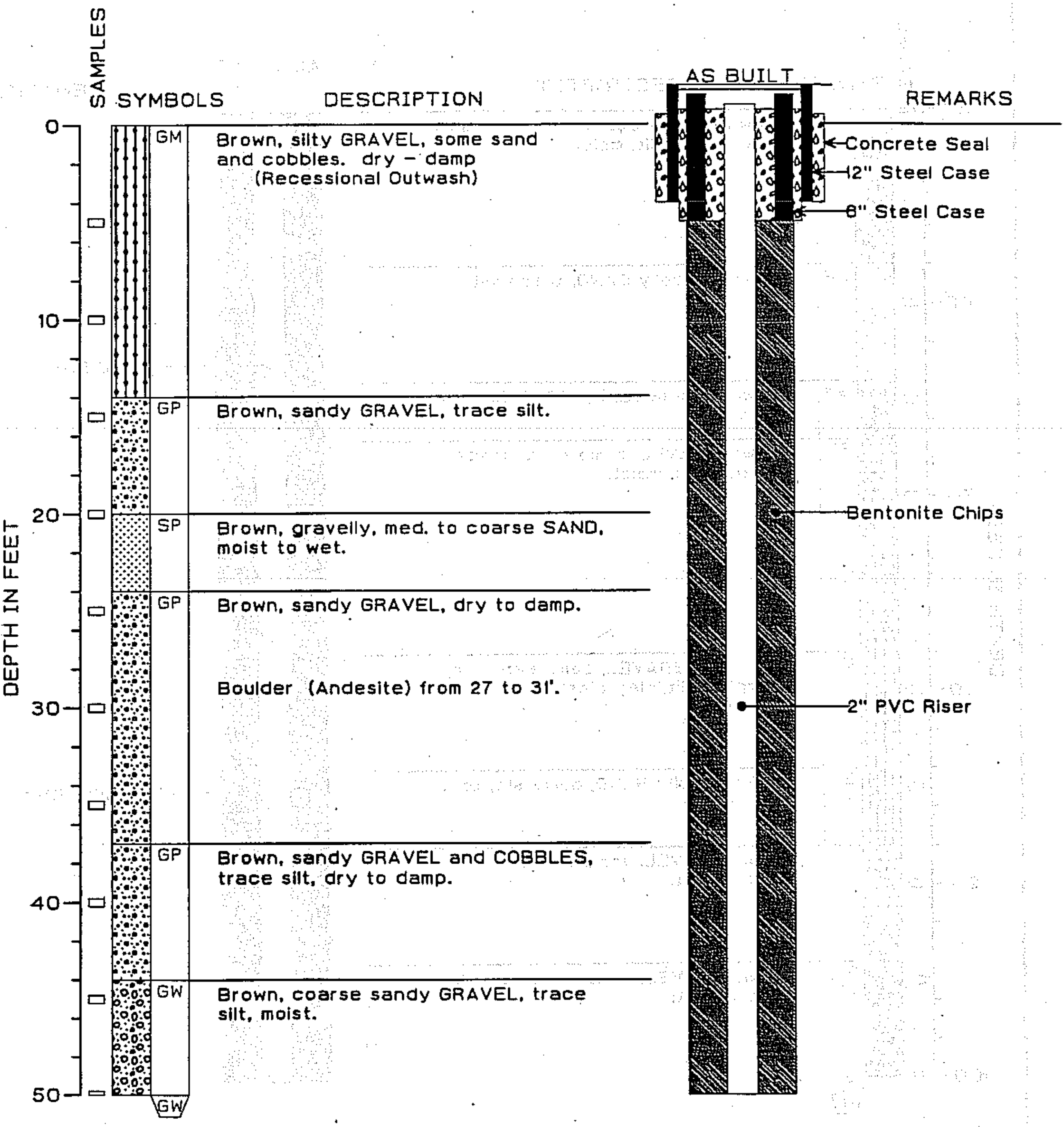
P.O. BOX 596, LYNNWOOD, WASHINGTON 98046, (206)774-0106

DRILLING COMPANY: Layne Environmental Services
DRILLING METHOD: Dual Wall Reverse Circulation
SAMPLING METHOD: Grab sample from cyclone.

WELL LOG

LOGGED BY: Dan Howard

TOTAL DEPTH: 139 FEET
DATE STARTED: 3-20-91
DATE FINISHED: 3-20-91



GM Brown, silty GRAVEL, some sand and cobbles. dry - damp (Recessional Outwash)

GP Brown, sandy GRAVEL, trace silt.

SP Brown, gravelly, med. to coarse SAND, moist to wet.

GP Brown, sandy GRAVEL, dry to damp.

Boulder (Andesite) from 27 to 31'.

GP Brown, sandy GRAVEL and COBBLES, trace silt, dry to damp.

GW Brown, coarse sandy GRAVEL, trace silt, moist.

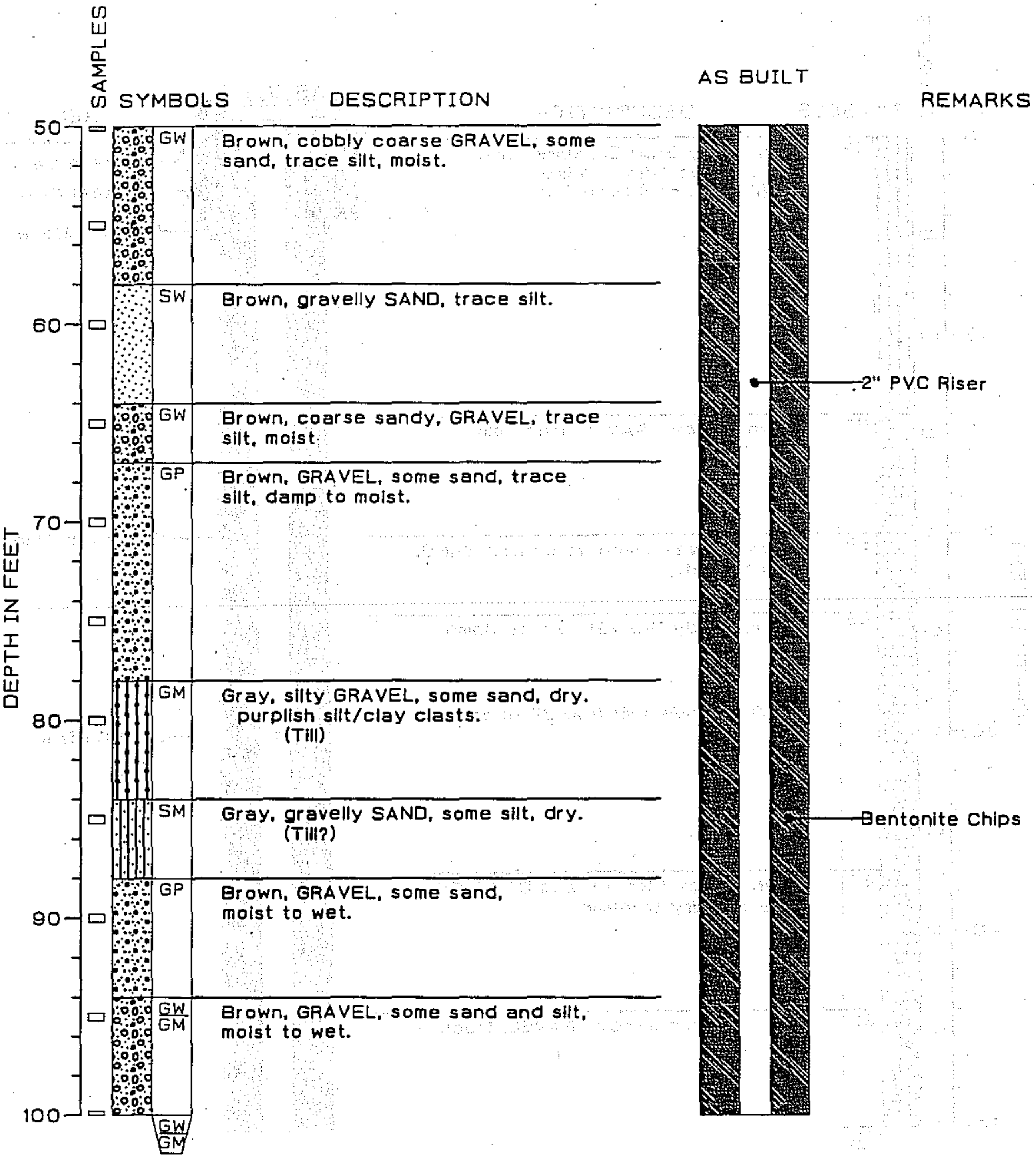
PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 853.32 ft.
MEASURING POINT EL.: 854.65 ft.

WELL MW-1

PROJECT NUMBER: 90131

PAGE: 1 OF 3

HONG WEST & ASSOCIATES
WELL LOG



SYMBOLS	DESCRIPTION
GW	Brown, cobbly coarse GRAVEL, some sand, trace silt, moist.
SW	Brown, gravelly SAND, trace silt.
GW	Brown, coarse sandy, GRAVEL, trace silt, moist
GP	Brown, GRAVEL, some sand, trace silt, damp to moist.
GM	Gray, silty GRAVEL, some sand, dry. purplish silt/clay clasts. (Till)
SM	Gray, gravelly SAND, some silt, dry. (Till?)
GP	Brown, GRAVEL, some sand, moist to wet.
GW/GM	Brown, GRAVEL, some sand and silt, moist to wet.

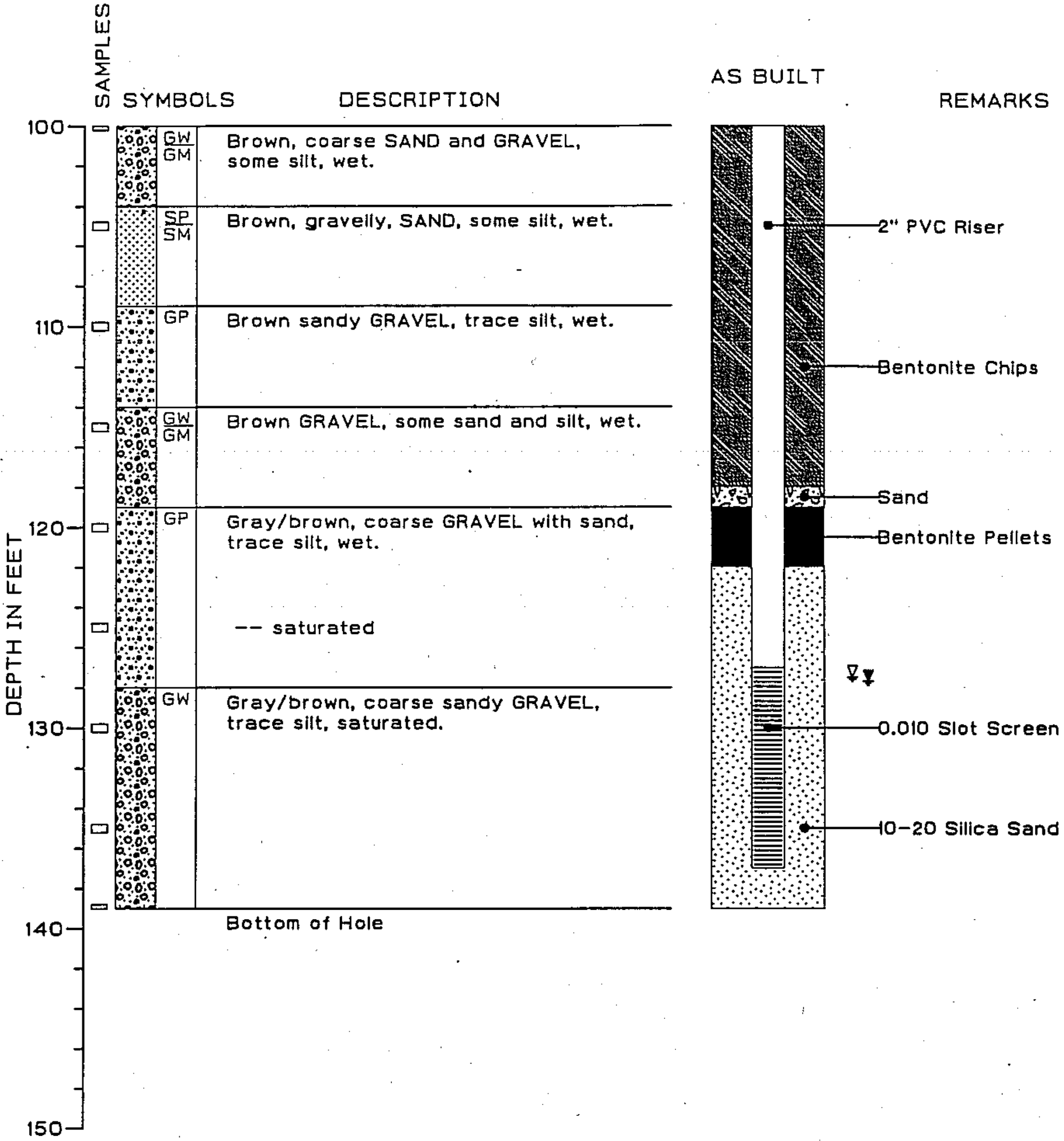
PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 853.32 ft.
MEASURING POINT EL.: 854.85 ft.

WELL MW-1

PROJECT NUMBER: 90131

PAGE: 2 OF 3

HONG WEST & ASSOCIATES
WELL LOG



GW/GM Brown, coarse SAND and GRAVEL, some silt, wet.

SP/SM Brown, gravelly, SAND, some silt, wet.

GP Brown sandy GRAVEL, trace silt, wet.

GW/GM Brown GRAVEL, some sand and silt, wet.

GP Gray/brown, coarse GRAVEL with sand, trace silt, wet.

-- saturated

GW Gray/brown, coarse sandy GRAVEL, trace silt, saturated.

Bottom of Hole

PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 853.32 ft.
MEASURING POINT EL.: 854.65 ft.

WELL MW-1

PROJECT NUMBER: 90131

PAGE: 3 OF 3

HONG WEST & ASSOCIATES

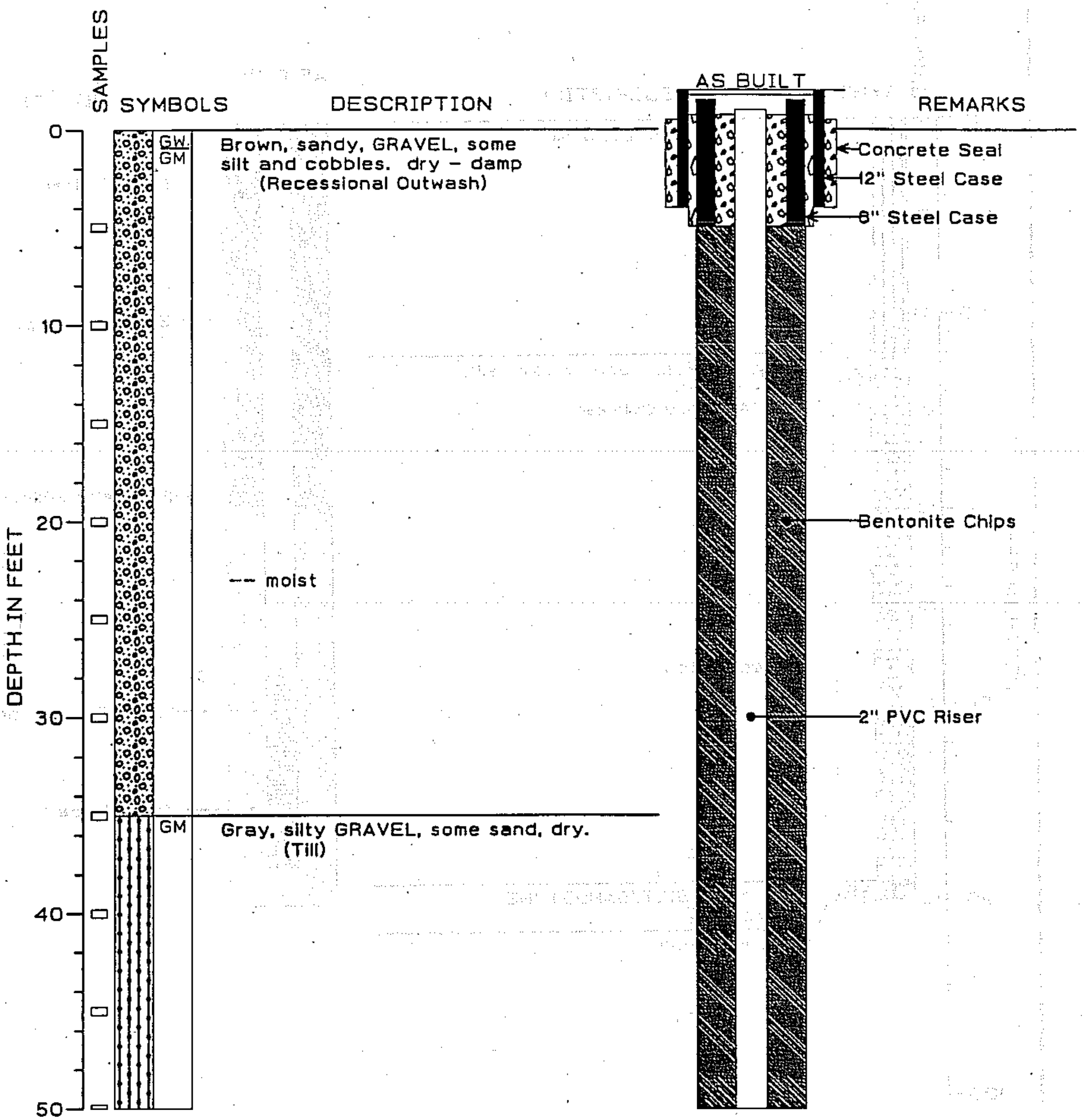
P.O. BOX 596, LYNNWOOD, WASHINGTON 98046, (206)774-0106

DRILLING COMPANY: Layne Environmental Services
DRILLING METHOD: Dual Wall Reverse Circulation
SAMPLING METHOD: Grab sample from cyclone.

WELL LOG

LOGGED BY: Dan Howard

TOTAL DEPTH: 90 FEET
DATE STARTED: 3-21-91
DATE FINISHED: 3-21-91



Brown, sandy, GRAVEL, some silt and cobbles. dry - damp
(Recessional Outwash)

-- moist

Gray, silty GRAVEL, some sand, dry.
(Till)

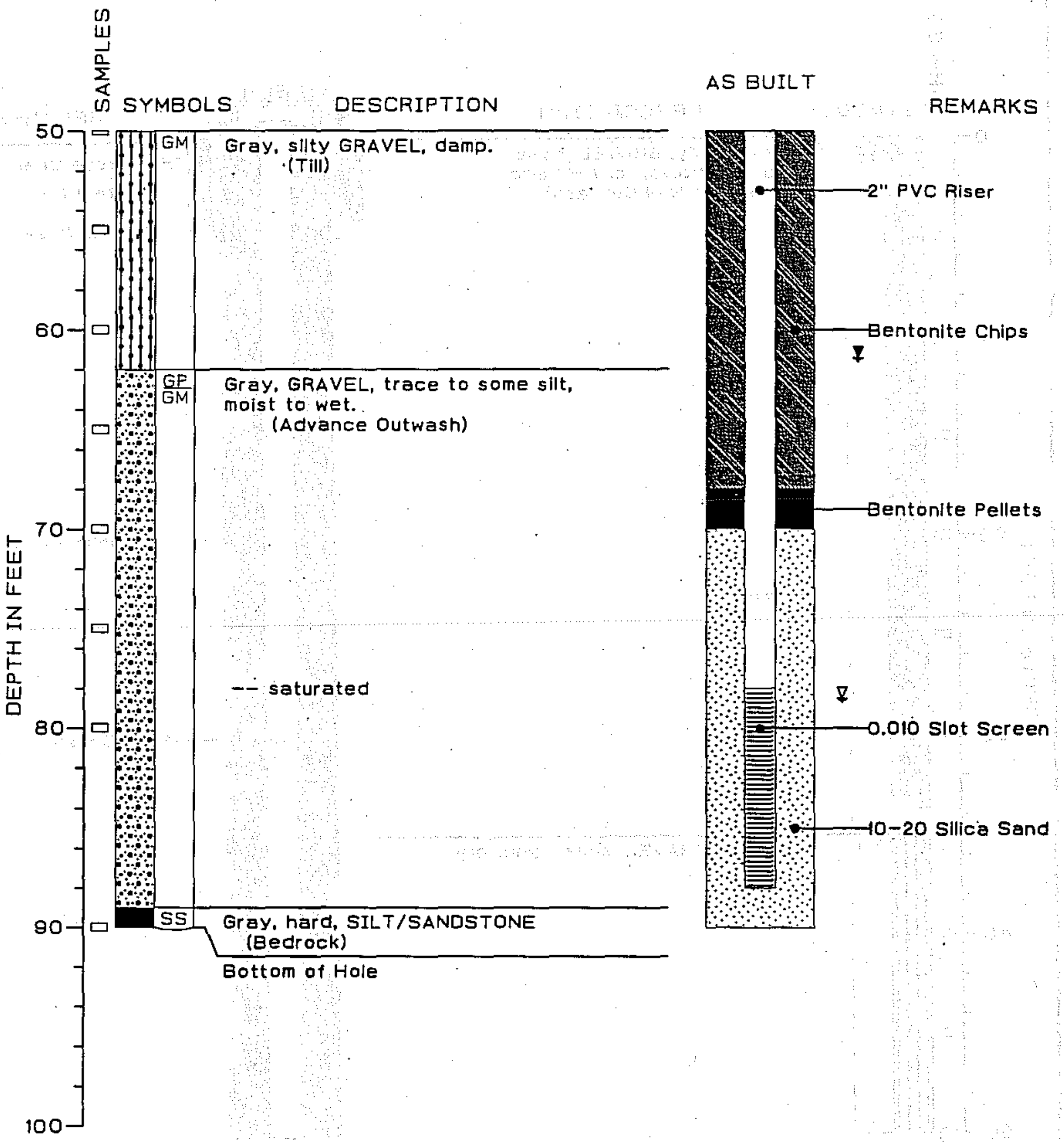
PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 840.81 ft.
MEASURING POINT EL.: 842.19 ft.

WELL MW-2

PROJECT NUMBER: 90131

PAGE: 1 OF 2

HONG WEST & ASSOCIATES
WELL LOG



PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 840.81 ft.
MEASURING POINT EL.: 842.19 ft.

WELL MW-2

PROJECT NUMBER: 90131

HONG WEST & ASSOCIATES

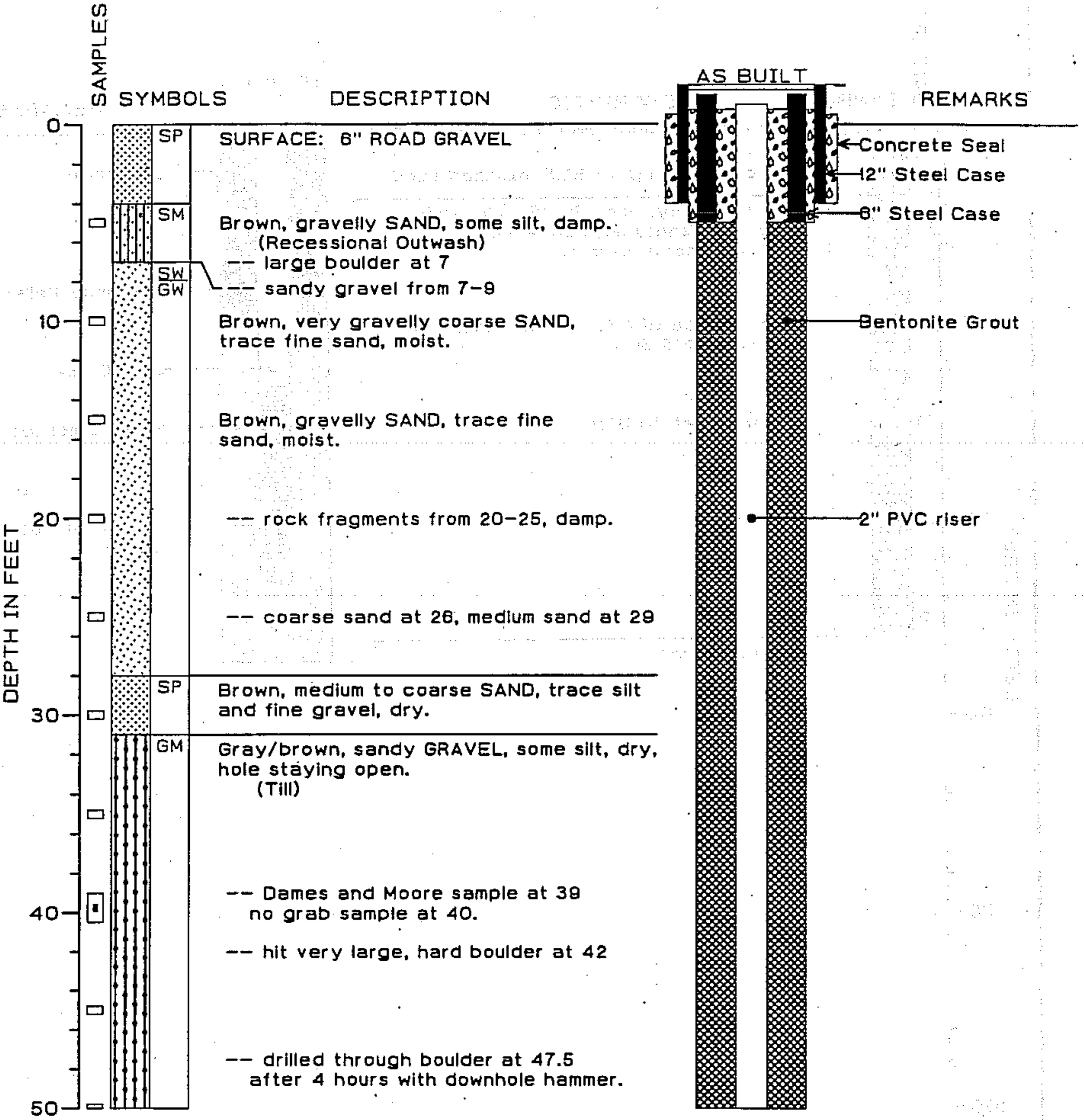
P.O. BOX 596, LYNNWOOD, WASHINGTON 98046, (206)774-0106

DRILLING COMPANY: Tacoma Pump and Drilling
DRILLING METHOD: Air Rotary – 6" Tricone
SAMPLING METHOD: Grab sample from air discharge tube

WELL LOG

LOGGED BY: Doug Geller

TOTAL DEPTH: 76 FEET
DATE STARTED: 12-13-90
DATE FINISHED: 12-27-90



SURFACE: 6" ROAD GRAVEL

Brown, gravelly SAND, some silt, damp.
(Recessional Outwash)
-- large boulder at 7
-- sandy gravel from 7-9

Brown, very gravelly coarse SAND, trace fine sand, moist.

Brown, gravelly SAND, trace fine sand, moist.

-- rock fragments from 20-25, damp.

-- coarse sand at 26, medium sand at 29

Brown, medium to coarse SAND, trace silt and fine gravel, dry.

Gray/brown, sandy GRAVEL, some silt, dry, hole staying open.
(Till)

-- Dames and Moore sample at 39 no grab sample at 40.

-- hit very large, hard boulder at 42

-- drilled through boulder at 47.5 after 4 hours with downhole hammer.

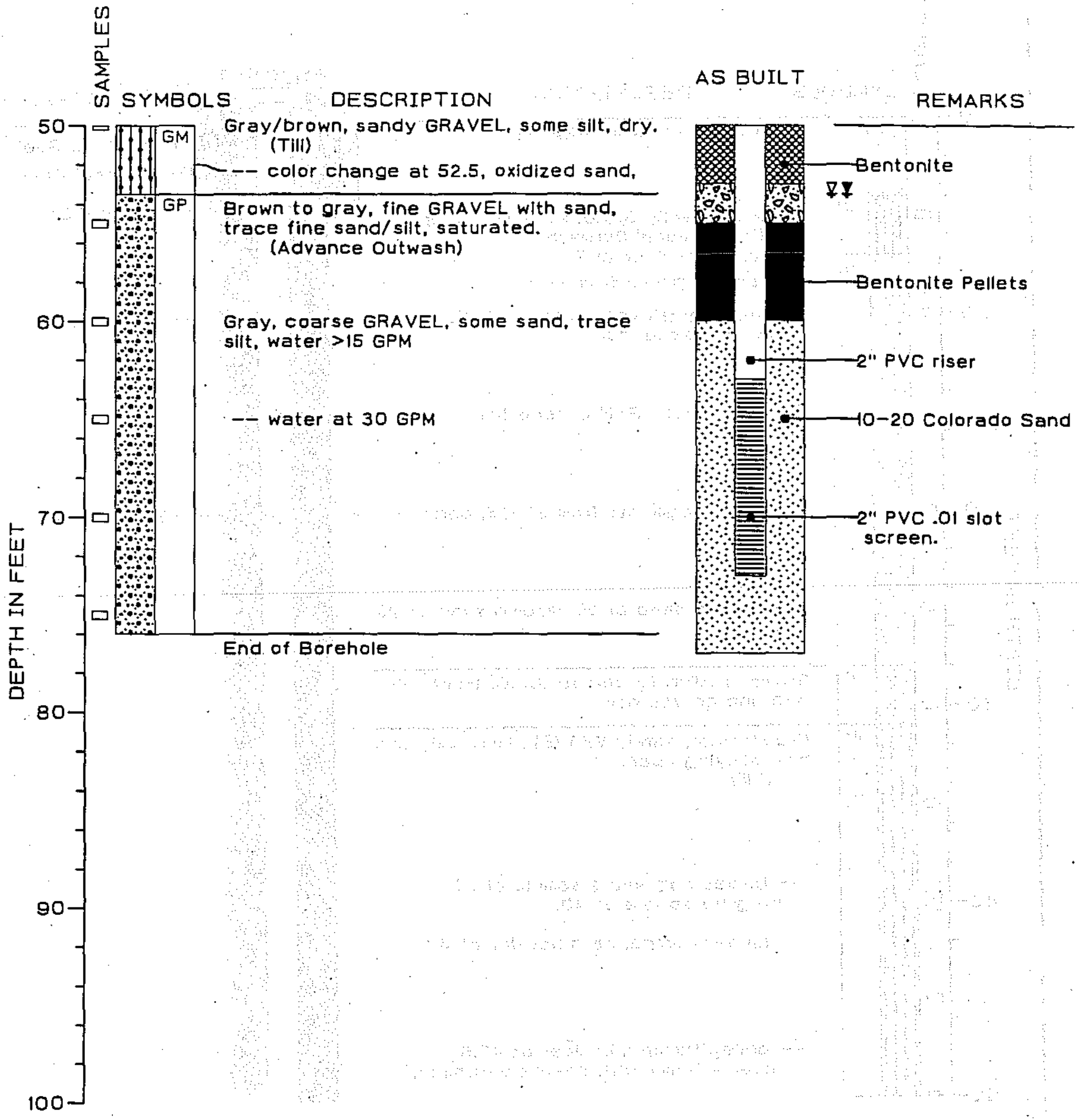
PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 812.27 ft.
MEASURING POINT EL.: 813.74 ft.

WELL MW-3

PROJECT NUMBER: 90131

PAGE: 1 OF 2

HONG WEST & ASSOCIATES
WELL LOG



Gray/brown, sandy GRAVEL, some silt, dry. (Till)

-- color change at 52.5, oxidized sand,

Brown to gray, fine GRAVEL with sand, trace fine sand/silt, saturated. (Advance Outwash)

Gray, coarse GRAVEL, some sand, trace silt, water >15 GPM

-- water at 30 GPM

End of Borehole

PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 812.27 ft.
MEASURING POINT EL.: 813.74 ft.

WELL MW-3

PROJECT NUMBER: 90131

PAGE: 2 OF 2

HONG WEST & ASSOCIATES

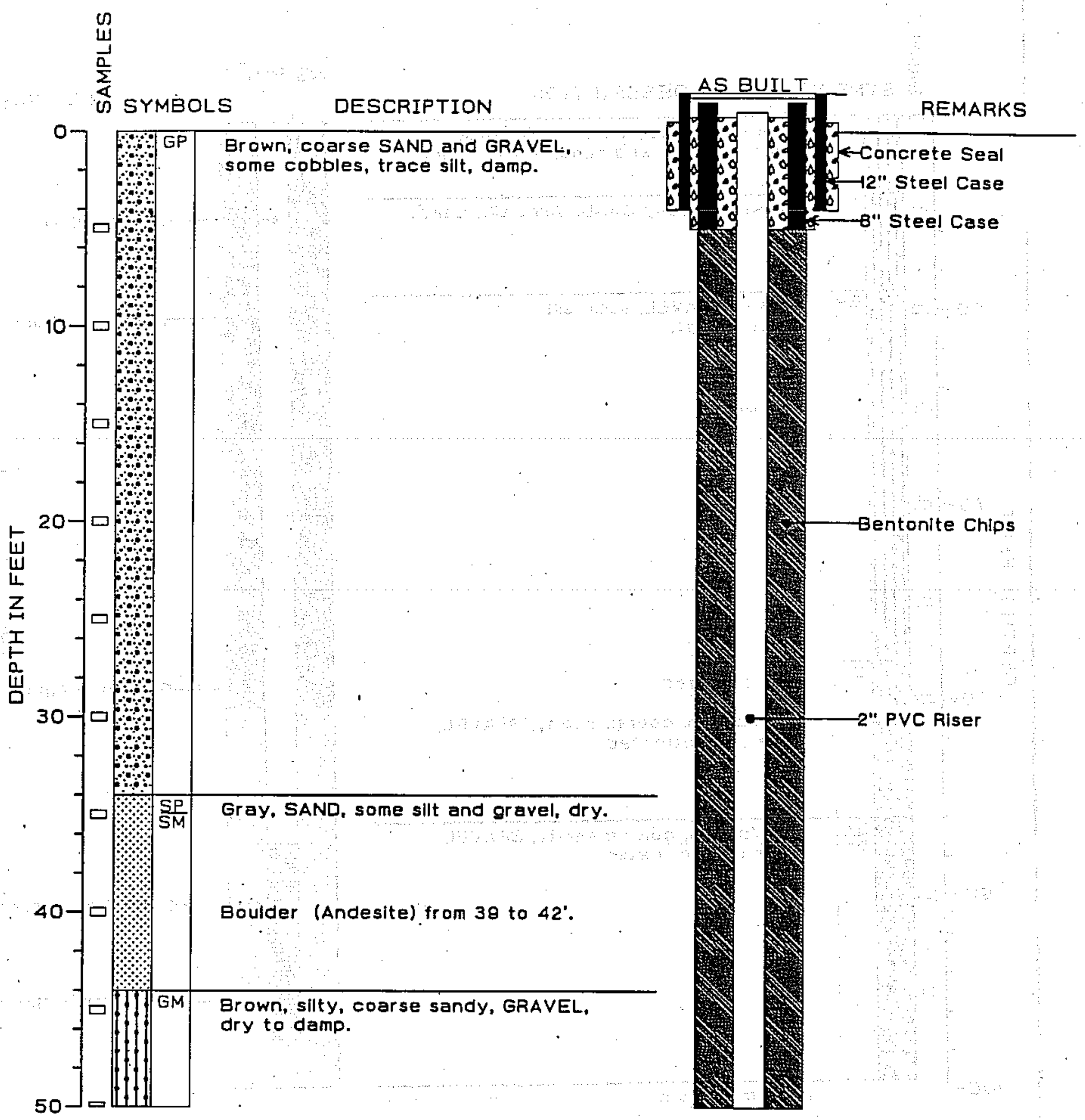
P.O. BOX 596, LYNNWOOD, WASHINGTON 98046, (206)774-0106

DRILLING COMPANY: Layne Environmental Services
DRILLING METHOD: Dual Wall Reverse Circulation
SAMPLING METHOD: Grab sample from cyclone.

WELL LOG

LOGGED BY: Dan Howard

TOTAL DEPTH: 99.5 FEET
DATE STARTED: 3-21-91
DATE FINISHED: 3-22-91



GP — Brown, coarse SAND and GRAVEL, some cobbles, trace silt, damp.

SP/SM — Gray, SAND, some silt and gravel, dry.

Boulder (Andesite) from 39 to 42'.

GM — Brown, silty, coarse sandy, GRAVEL, dry to damp.

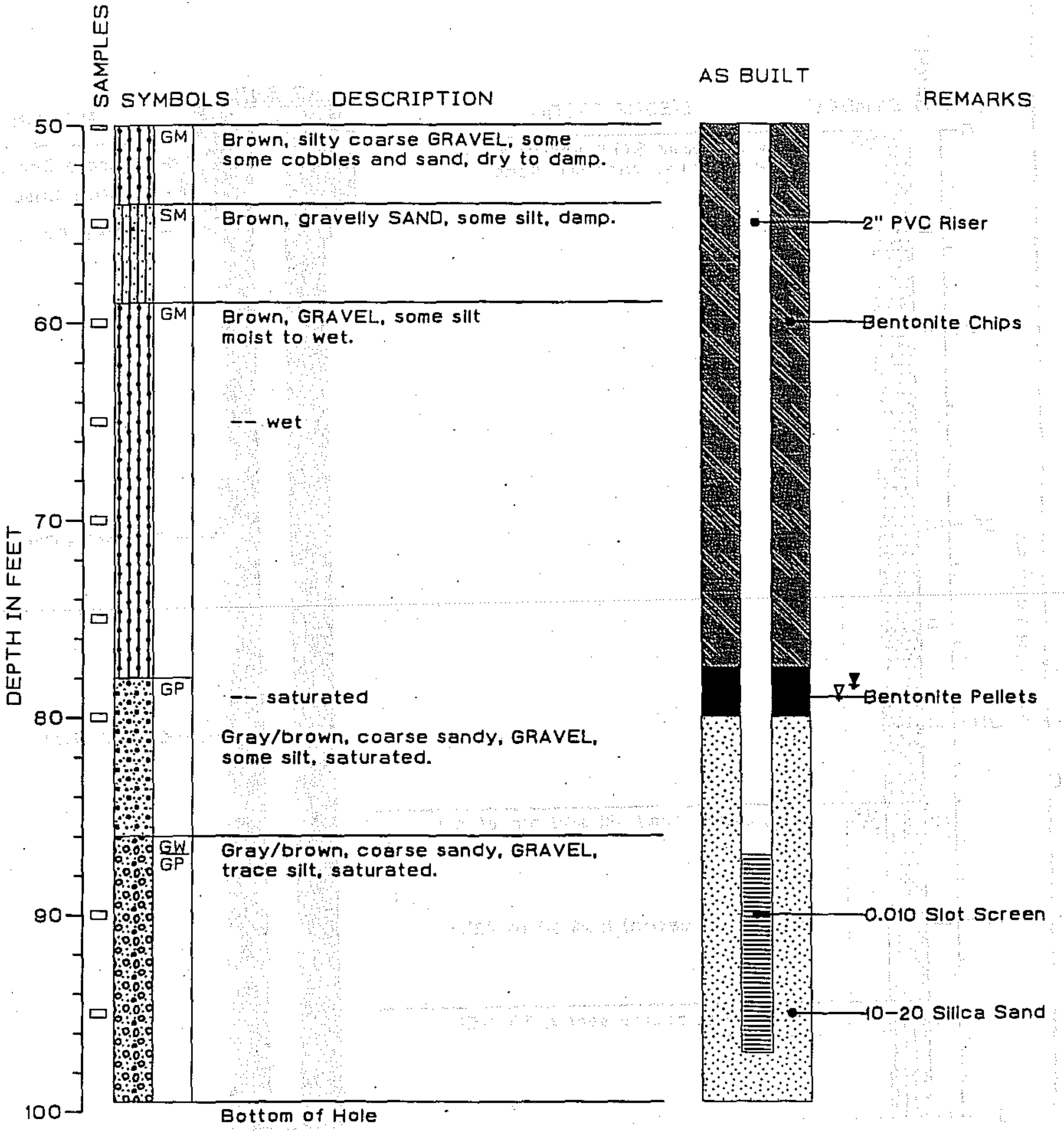
PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 825.92 ft.
MEASURING POINT EL.: 827.88 ft.

WELL MW-4

PROJECT NUMBER: 90131

PAGE: 1 OF 2

HONG WEST & ASSOCIATES
WELL LOG



Brown, silty coarse GRAVEL, some some cobbles and sand, dry to damp.

Brown, gravelly SAND, some silt, damp.

Brown, GRAVEL, some silt moist to wet.

-- wet

-- saturated

Gray/brown, coarse sandy, GRAVEL, some silt, saturated.

Gray/brown, coarse sandy, GRAVEL, trace silt, saturated.

Bottom of Hole

PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 825.92 ft.
MEASURING POINT EL.: 827.88 ft.

WELL MW-4

PROJECT NUMBER: 90131

PAGE: 2 OF 2

HONG WEST & ASSOCIATES

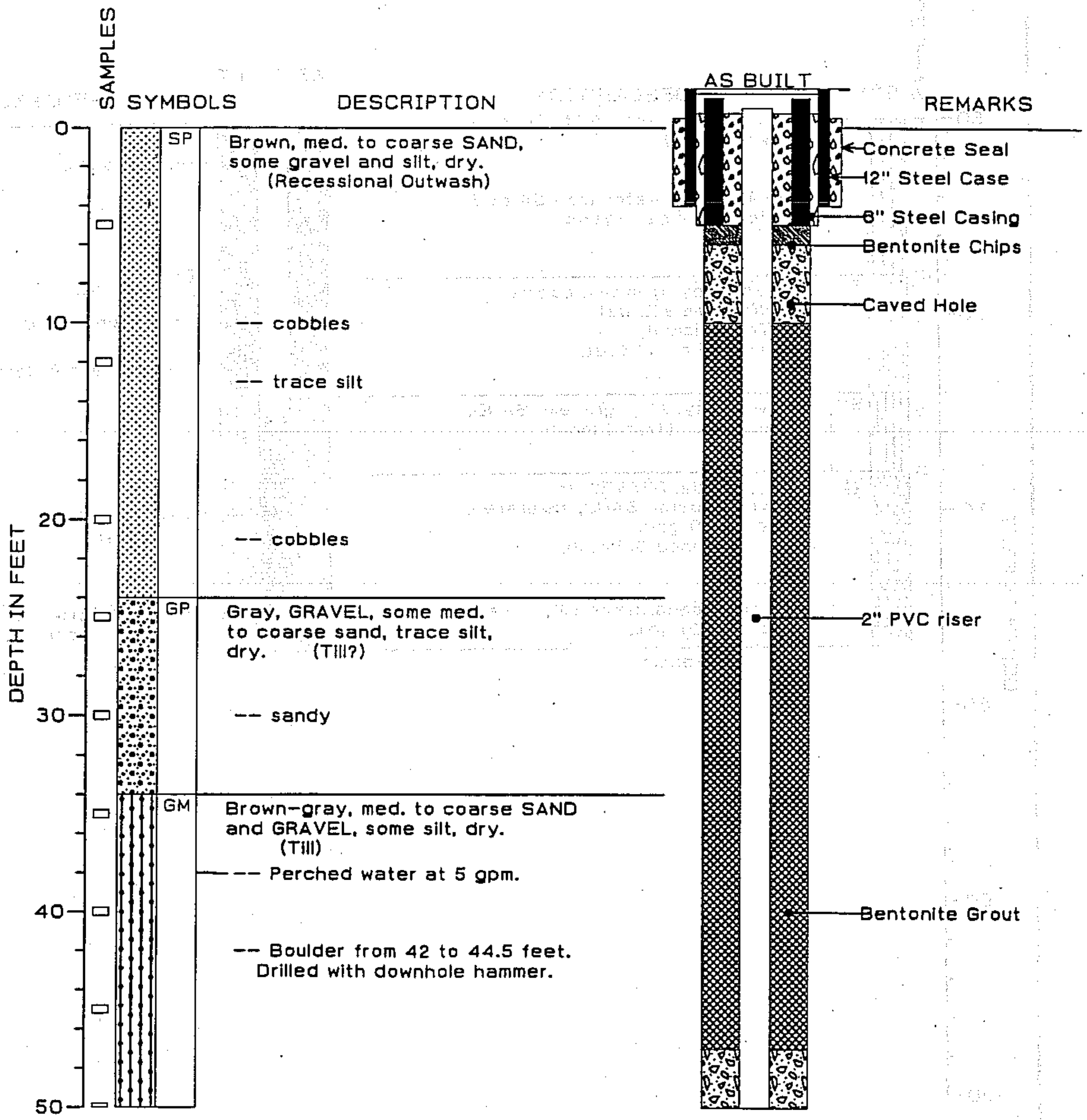
P.O. BOX 596, LYNNWOOD, WASHINGTON 98046, (206)774-0106

DRILLING COMPANY: Tacoma Pump and Drilling
DRILLING METHOD: Air Rotary – 6" Tricone
SAMPLING METHOD: Grab sample from air discharge tube

WELL LOG

LOGGED BY: Howard/Dunn

TOTAL DEPTH: 77 FEET
DATE STARTED: 1-3-91
DATE FINISHED: 1-8-91



Brown, med. to coarse SAND, some gravel and silt, dry. (Recessional Outwash)

-- cobbles

-- trace silt

-- cobbles

Gray, GRAVEL, some med. to coarse sand, trace silt, dry. (Till?)

-- sandy

Brown-gray, med. to coarse SAND and GRAVEL, some silt, dry. (Till)

-- Perched water at 5 gpm.

-- Boulder from 42 to 44.5 feet. Drilled with downhole hammer.

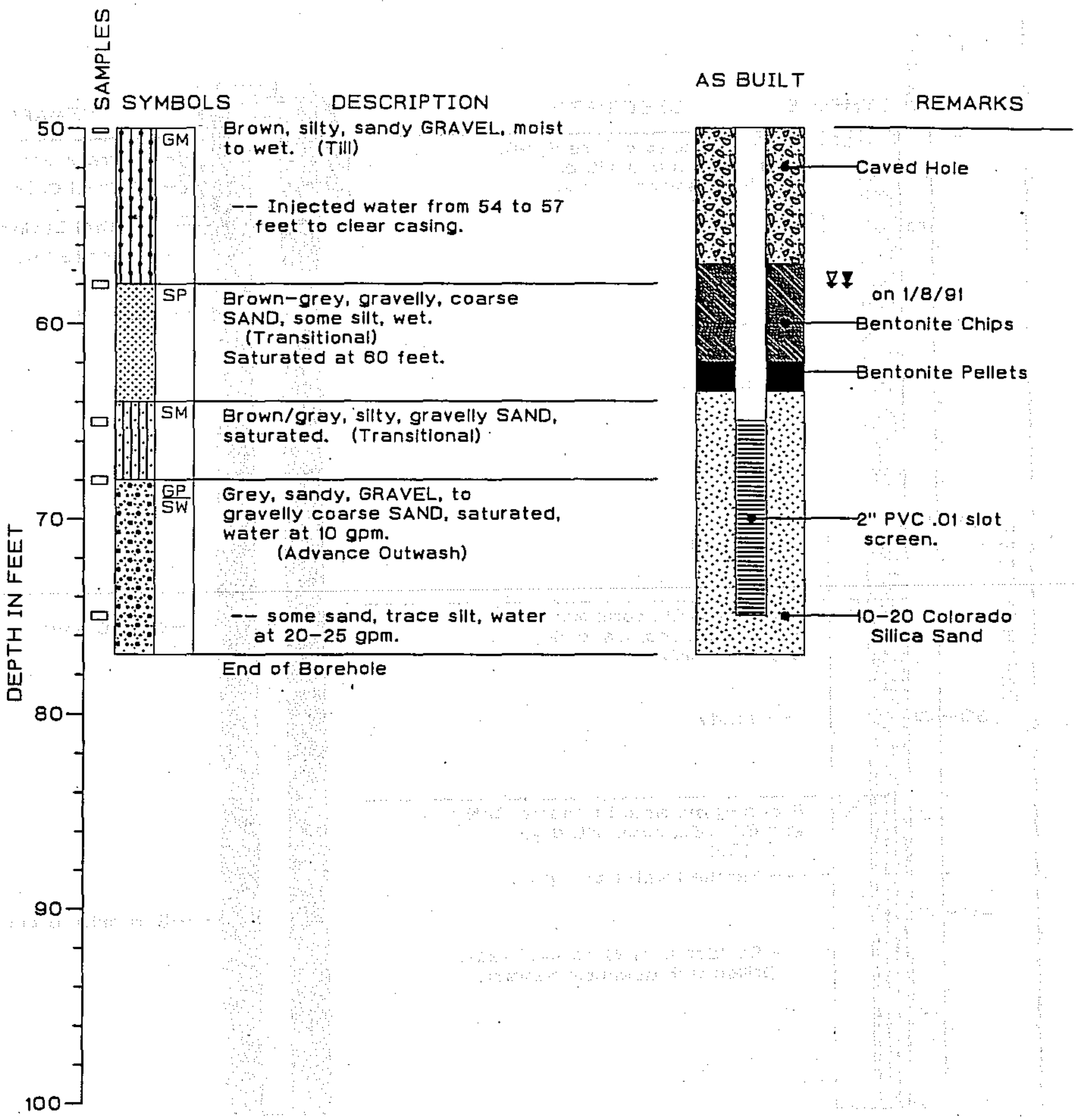
PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 797.94 ft.
MEASURING POINT EL.: 799.35 ft.

WELL MW-5

PROJECT NUMBER: 90131

PAGE: 1 OF 2

HONG WEST & ASSOCIATES
WELL LOG



Brown, silty, sandy GRAVEL, moist to wet. (Till)

-- Injected water from 54 to 57 feet to clear casing.

Brown-grey, gravelly, coarse SAND, some silt, wet. (Transitional)
Saturated at 60 feet.

Brown/gray, silty, gravelly SAND, saturated. (Transitional)

Grey, sandy, GRAVEL, to gravelly coarse SAND, saturated, water at 10 gpm. (Advance Outwash)

-- some sand, trace silt, water at 20-25 gpm.

End of Borehole

PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 797.94 ft.
MEASURING POINT EL.: 799.35 ft.

WELL MW-5

PROJECT NUMBER: 90131

PAGE: 2 OF 2

HONG WEST & ASSOCIATES

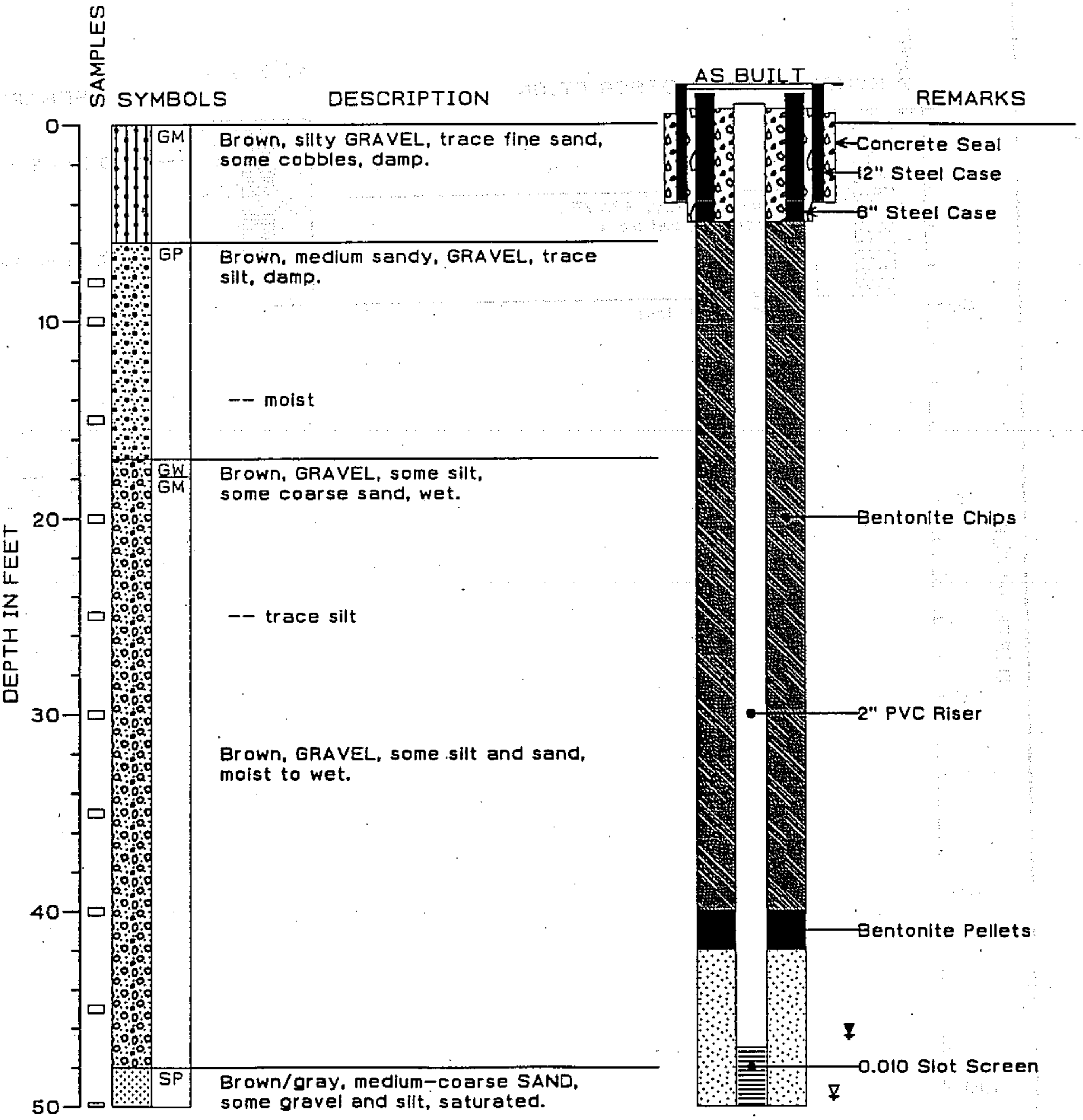
P.O. BOX 596, LYNNWOOD, WASHINGTON 98046, (206)774-0106

DRILLING COMPANY: Layne Environmental Services
DRILLING METHOD: Dual Wall Reverse Circulation
SAMPLING METHOD: Grab sample from cyclone.

WELL LOG

LOGGED BY: Dan Howard

TOTAL DEPTH: 59.5 FEET
DATE STARTED: 3-22-91
DATE FINISHED: 3-23-91



Brown, silty GRAVEL, trace fine sand, some cobbles, damp.

Brown, medium sandy, GRAVEL, trace silt, damp.

-- moist

Brown, GRAVEL, some silt, some coarse sand, wet.

-- trace silt

Brown, GRAVEL, some silt and sand, moist to wet.

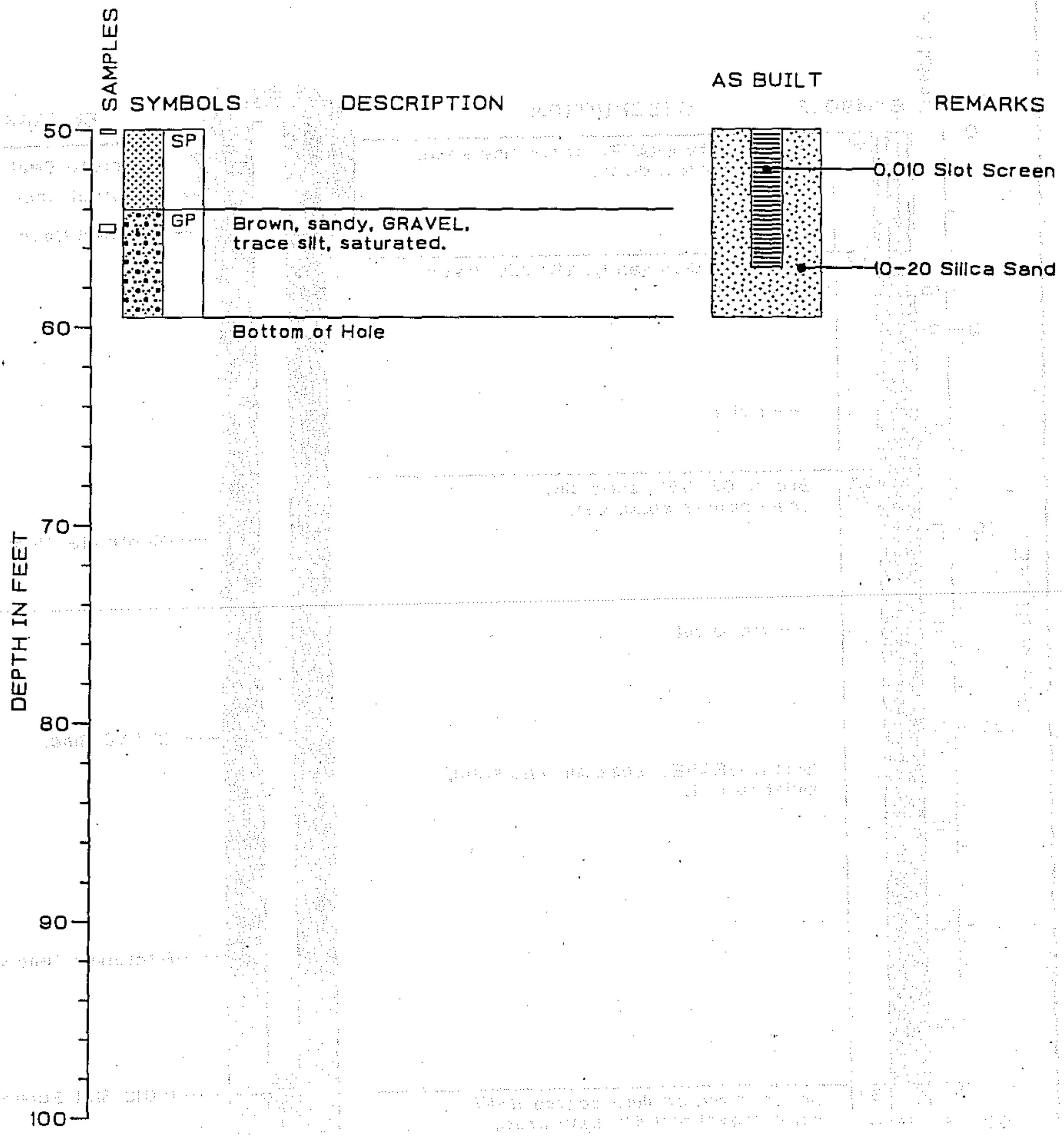
Brown/gray, medium-coarse SAND, some gravel and silt, saturated.

PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 705.46 ft.
MEASURING POINT EL.: 707.90 ft.

WELL MW-6

PROJECT NUMBER: 90131

HONG WEST & ASSOCIATES
WELL LOG



PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 705.46 ft.
MEASURING POINT EL.: 707.90 ft.

WELL MW-6

PROJECT NUMBER: 90131

PAGE: 2 OF 2

HONG WEST & ASSOCIATES

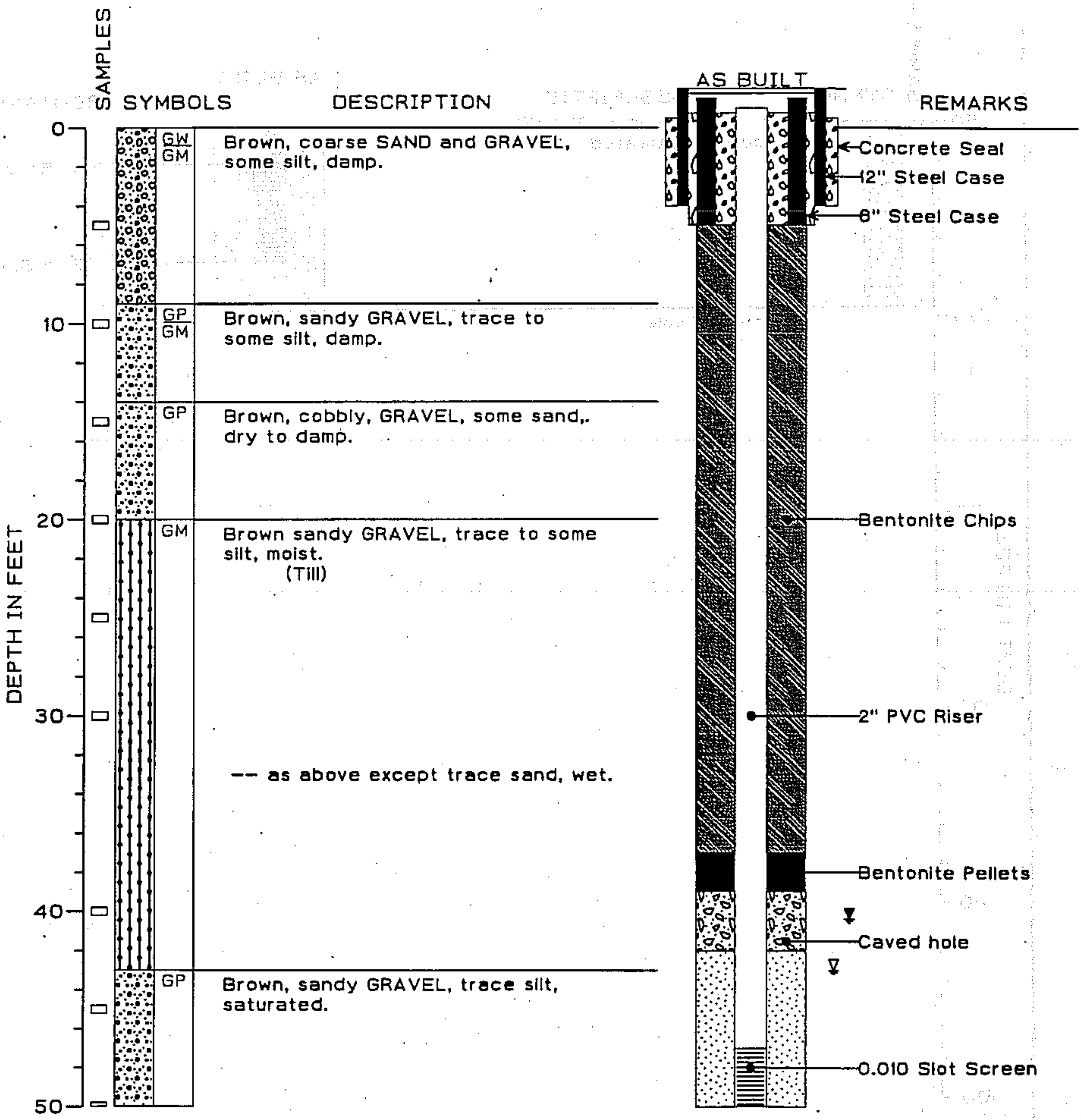
P.O. BOX 596, LYNNWOOD, WASHINGTON 98046, (206)774-0106

DRILLING COMPANY: Layne Environmental Services
DRILLING METHOD: Dual Wall Reverse Circulation
SAMPLING METHOD: Grab sample from cyclone.

WELL LOG

LOGGED BY: Dan Howard

TOTAL DEPTH: 59.5 FEET
DATE STARTED: 3-23-91
DATE FINISHED: 3-23-91



Brown, coarse SAND and GRAVEL, some silt, damp.

Brown, sandy GRAVEL, trace to some silt, damp.

Brown, cobbly, GRAVEL, some sand,. dry to damp.

Brown sandy GRAVEL, trace to some silt, moist.
(Till)

-- as above except trace sand, wet.

Brown, sandy GRAVEL, trace silt, saturated.

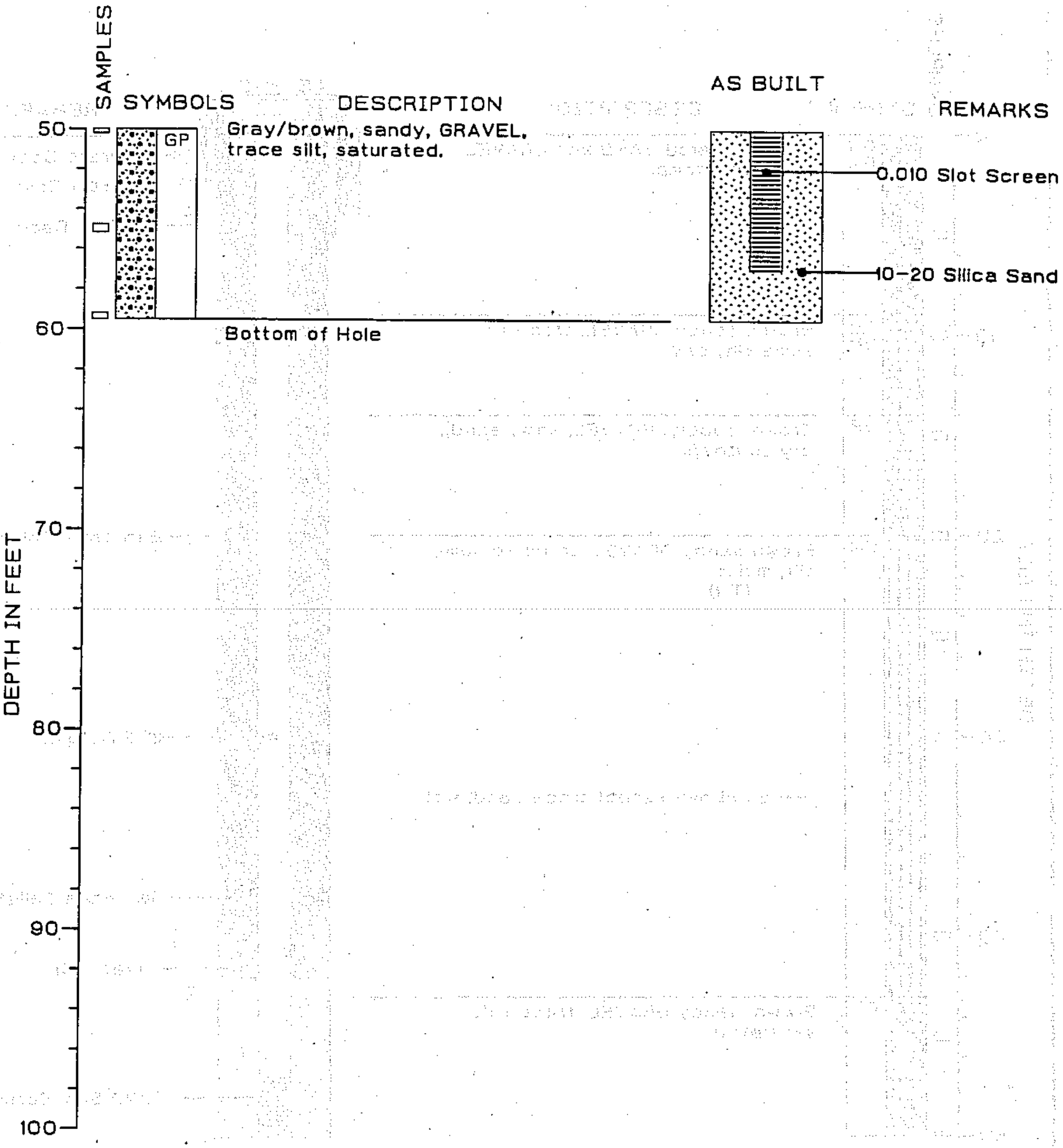
PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 758.91 ft.
MEASURING POINT EL.: 760.60 ft.

WELL MW-7

PROJECT NUMBER: 90131

PAGE: 1 OF 2

HONG WEST & ASSOCIATES
WELL LOG



Gray/brown, sandy, GRAVEL, trace silt, saturated.

Bottom of Hole

PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 758.91 ft.
MEASURING POINT EL.: 760.80 ft.

WELL MW-7

PROJECT NUMBER: 90131

PAGE: 2 OF 2

HONG WEST & ASSOCIATES

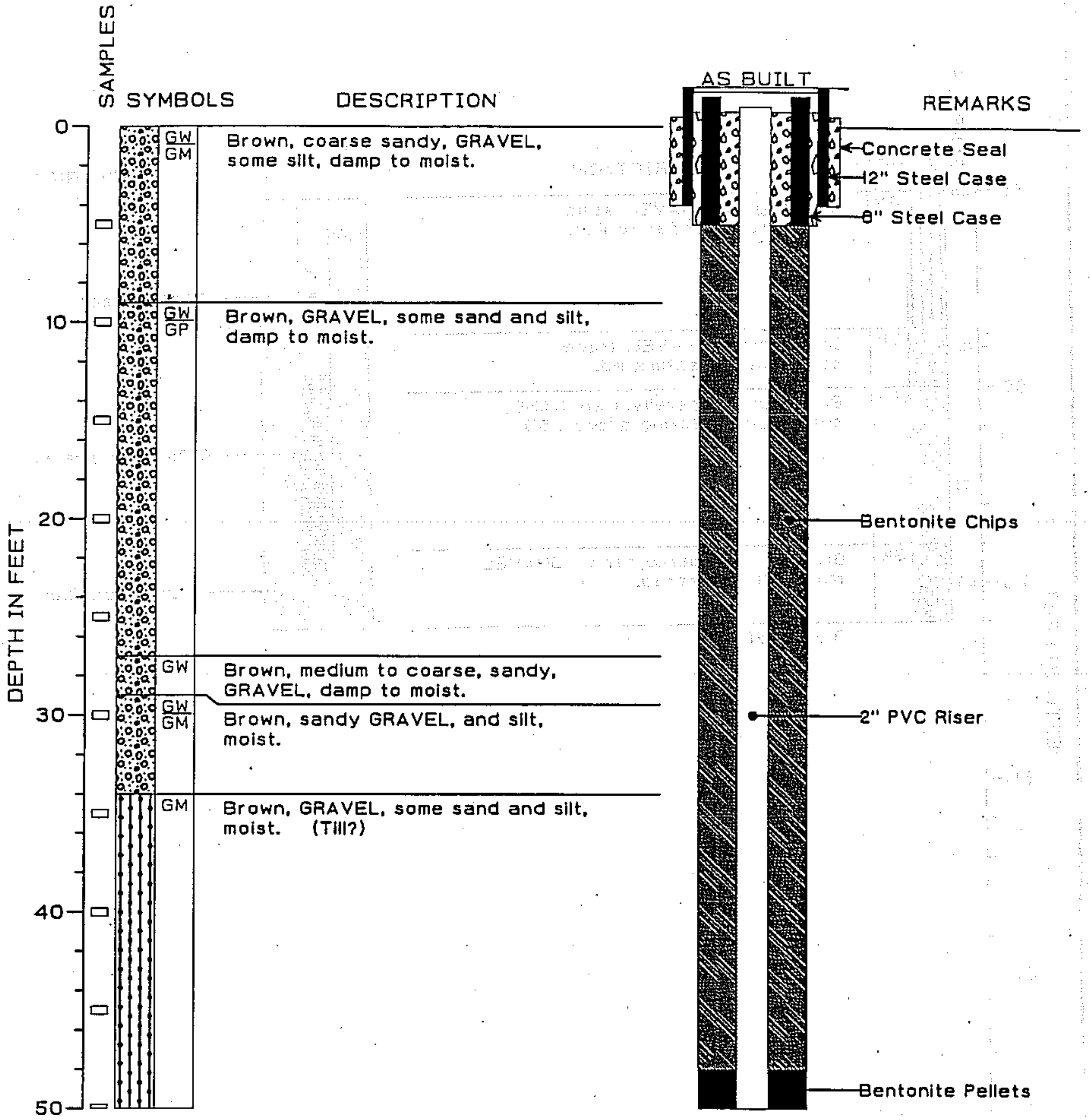
P.O. BOX 598, LYNNWOOD, WASHINGTON 98046, (206)774-0106

DRILLING COMPANY: Layne Environmental Services
DRILLING METHOD: Dual Wall Reverse Circulation
SAMPLING METHOD: Grab sample from cyclone.

WELL LOG

LOGGED BY: Dan Howard

TOTAL DEPTH: 72 FEET
DATE STARTED: 3-23-91
DATE FINISHED: 3-23-91



GW/GM Brown, coarse sandy, GRAVEL, some silt, damp to moist.

GW/GP Brown, GRAVEL, some sand and silt, damp to moist.

GW Brown, medium to coarse, sandy, GRAVEL, damp to moist.

GW/GM Brown, sandy GRAVEL, and silt, moist.

GM Brown, GRAVEL, some sand and silt, moist. (Till?)

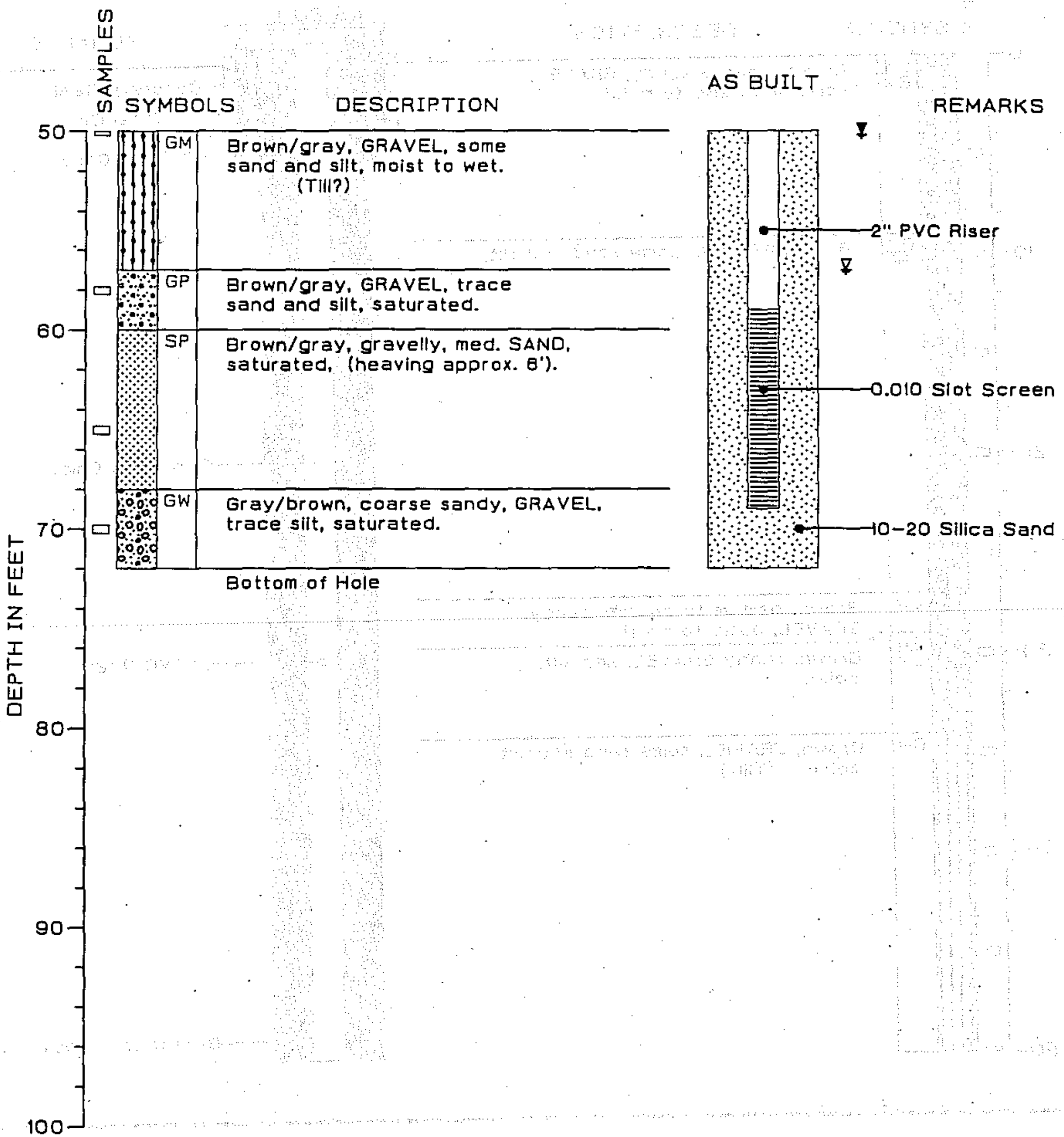
PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 788.53 ft.
MEASURING POINT EL.: 791.04 ft.

WELL MW-8

PROJECT NUMBER: 90131

PAGE: 1 OF 2

HONG WEST & ASSOCIATES
WELL LOG



GM Brown/gray, GRAVEL, some sand and silt, moist to wet. (Till?)

GP Brown/gray, GRAVEL, trace sand and silt, saturated.

SP Brown/gray, gravelly, med. SAND, saturated, (heaving approx. 8').

GW Gray/brown, coarse sandy, GRAVEL, trace silt, saturated.

Bottom of Hole

PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 788.53 ft.
MEASURING POINT EL.: 791.04 ft.

WELL MW-8

PROJECT NUMBER: 90131

PAGE: 2 OF 2

HONG WEST & ASSOCIATES

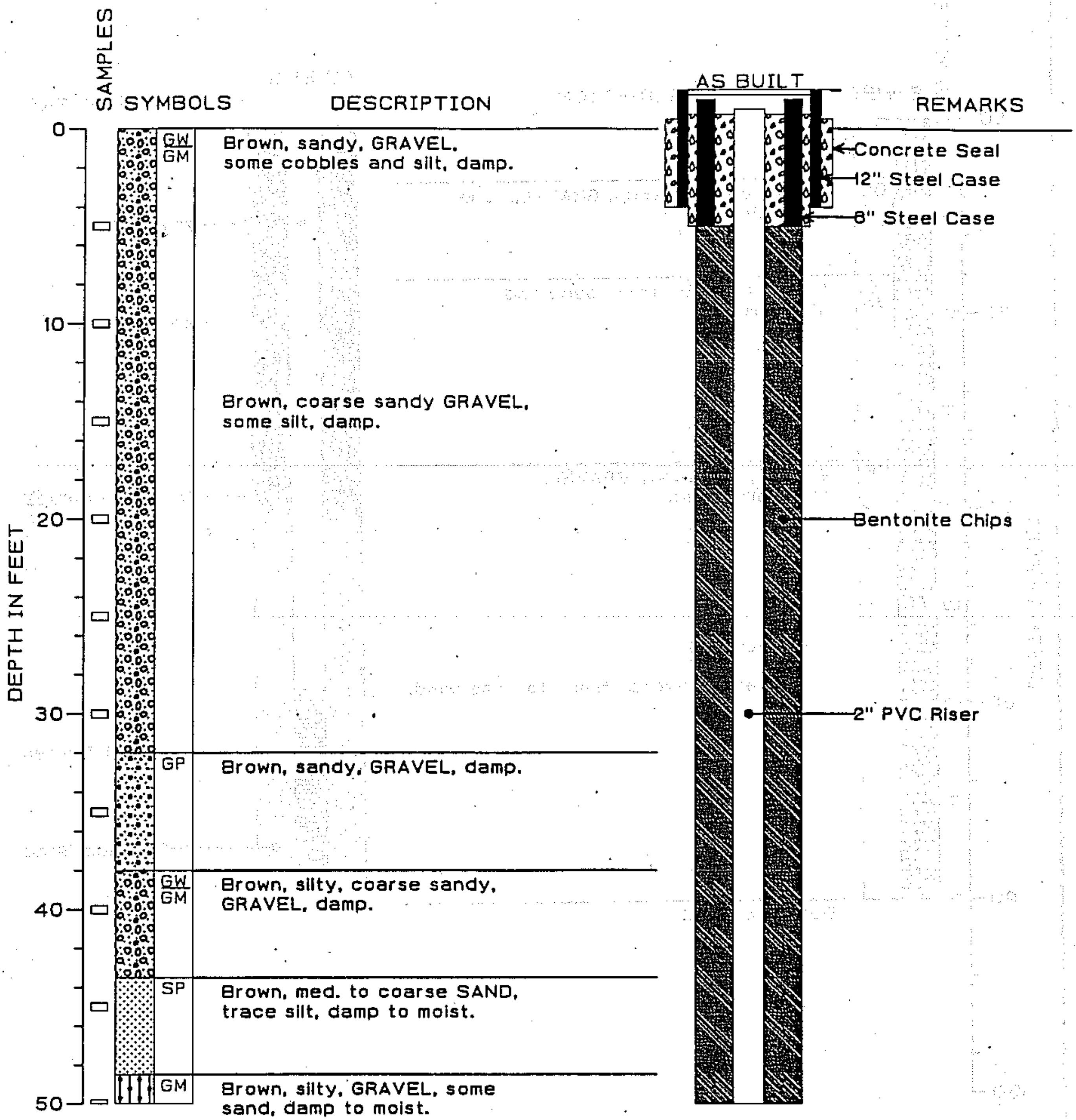
P.O. BOX 598, LYNNWOOD, WASHINGTON 98046, (206)774-0106

DRILLING COMPANY: Layne Environmental Services
DRILLING METHOD: Dual Wall Reverse Circulation
SAMPLING METHOD: Grab sample from cyclone.

WELL LOG

LOGGED BY: Dan Howard

TOTAL DEPTH: 90 FEET
DATE STARTED: 3-24-91
DATE FINISHED: 3-24-91



Brown, sandy, GRAVEL, some cobbles and silt, damp.

Brown, coarse sandy GRAVEL, some silt, damp.

Brown, sandy, GRAVEL, damp.

Brown, silty, coarse sandy, GRAVEL, damp.

Brown, med. to coarse SAND, trace silt, damp to moist.

Brown, silty, GRAVEL, some sand, damp to moist.

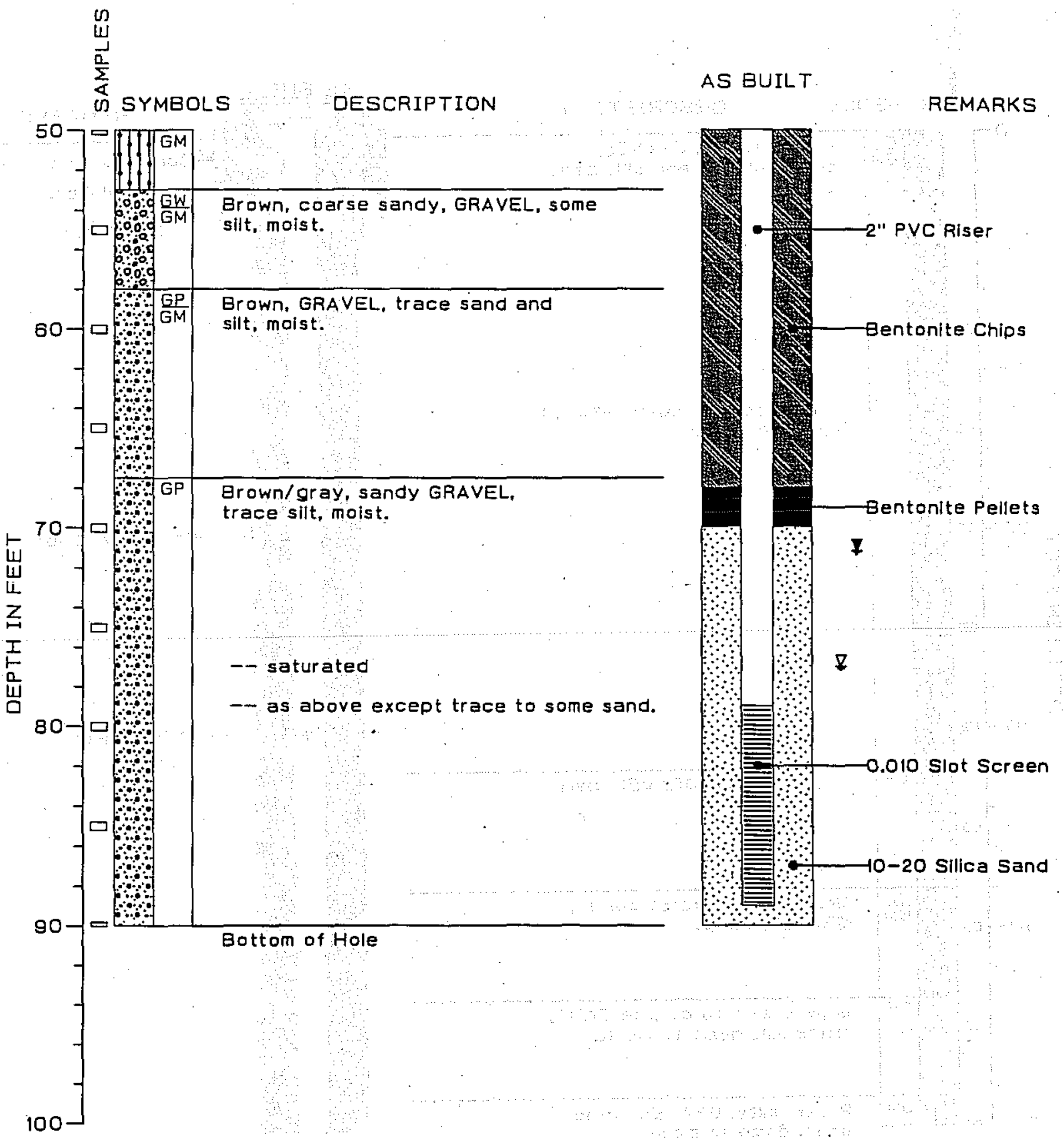
PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 741.80 ft.
MEASURING POINT EL.: 744.54 ft.

WELL MW-9

PROJECT NUMBER: 90131

PAGE: 1 OF 2

HONG WEST & ASSOCIATES
WELL LOG



Brown, coarse sandy, GRAVEL, some silt, moist.

Brown, GRAVEL, trace sand and silt, moist.

Brown/gray, sandy GRAVEL, trace silt, moist.

-- saturated

-- as above except trace to some sand.

Bottom of Hole

PROJECT: Silvigrow
LOCATION: Cumberland, WA
SURFACE ELEVATION: 741.80 ft.
MEASURING POINT EL.: 744.54 ft.

WELL MW-9

PROJECT NUMBER: 90131

PAGE: 2 OF 2

EXHIBIT B

GEOTECHNICAL LABORATORY ANALYSIS

AND

PERMEABILITY CALCULATIONS

HONG WEST & ASSOCIATES
GRAIN SIZE DISTRIBUTION

Project: Silvigrow

King County, Washington

Project Number: 90131

Date Tested: 4-16-91

Remarks: Brown, well graded GRAVEL with sand (GW)

Test Hole Number: MW-1

Sample Number:

Depth: 135 feet

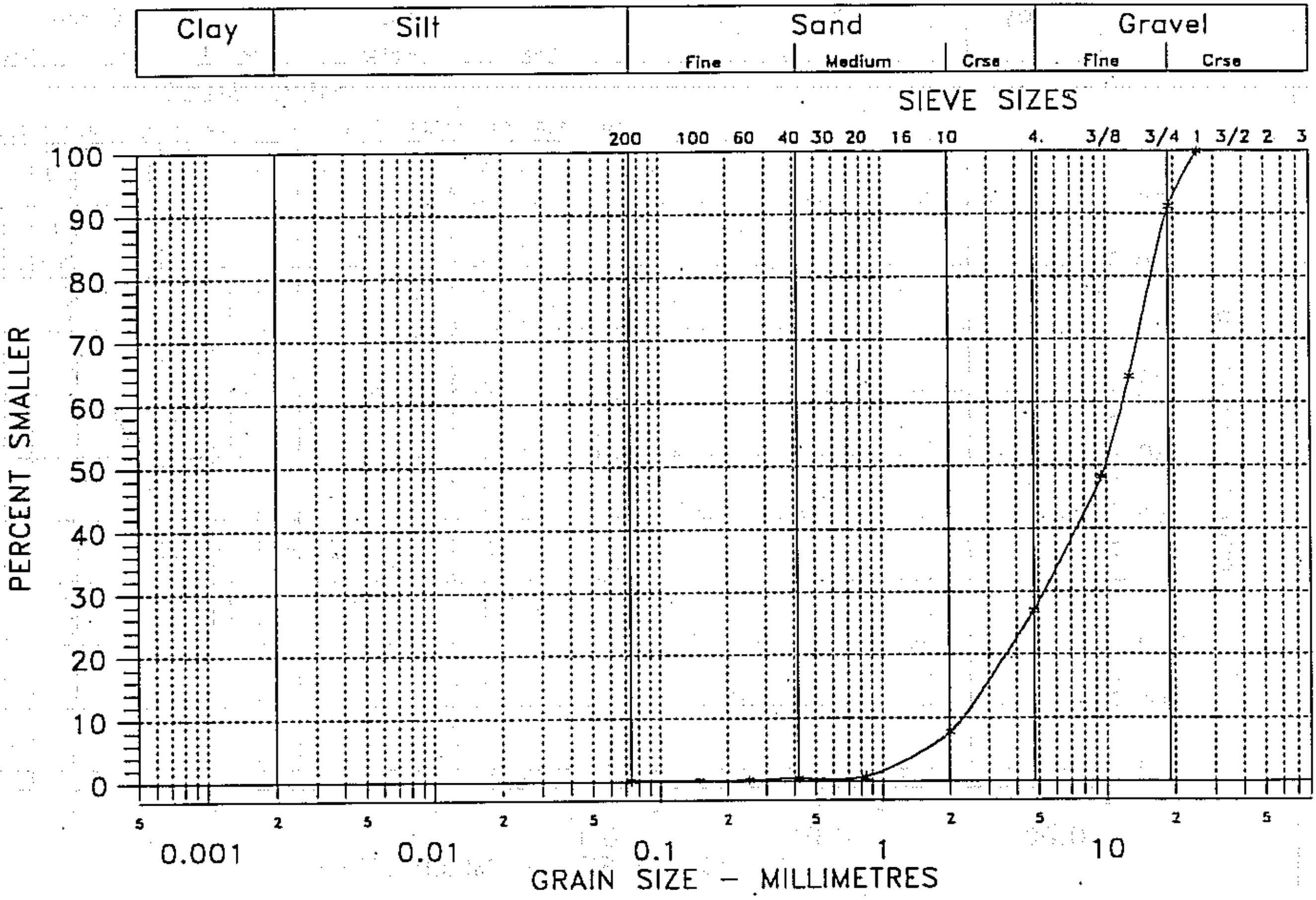
Sample Description:

Gravel: 73.1

Sand: 26.7

Silt: 0.2

Clay:



Reviewed By:

HONG WEST & ASSOCIATES
GRAIN SIZE DISTRIBUTION

Project: Silvigrow

King County, Washington

Project Number: 90131

Date Tested: 4-16-91

Remarks: Grayish brown, silty GRAVEL with sand(GM)

Test Hole Number: MW-2

Sample Number: Composite

Depth: 50+55 feet

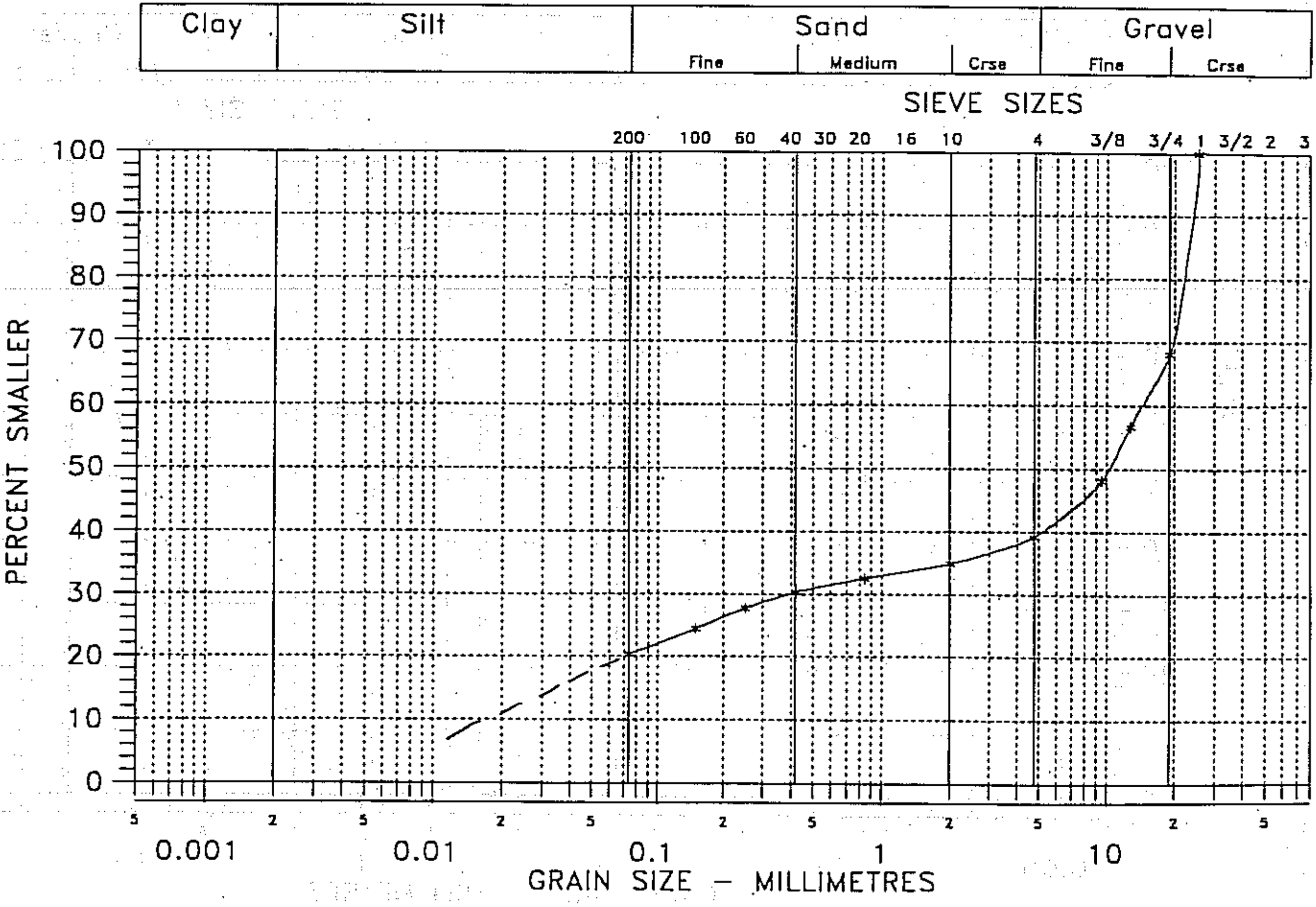
Sample Description:

Gravel: 60.8

Sand: 18.9

Silt: 20.3

Clay:

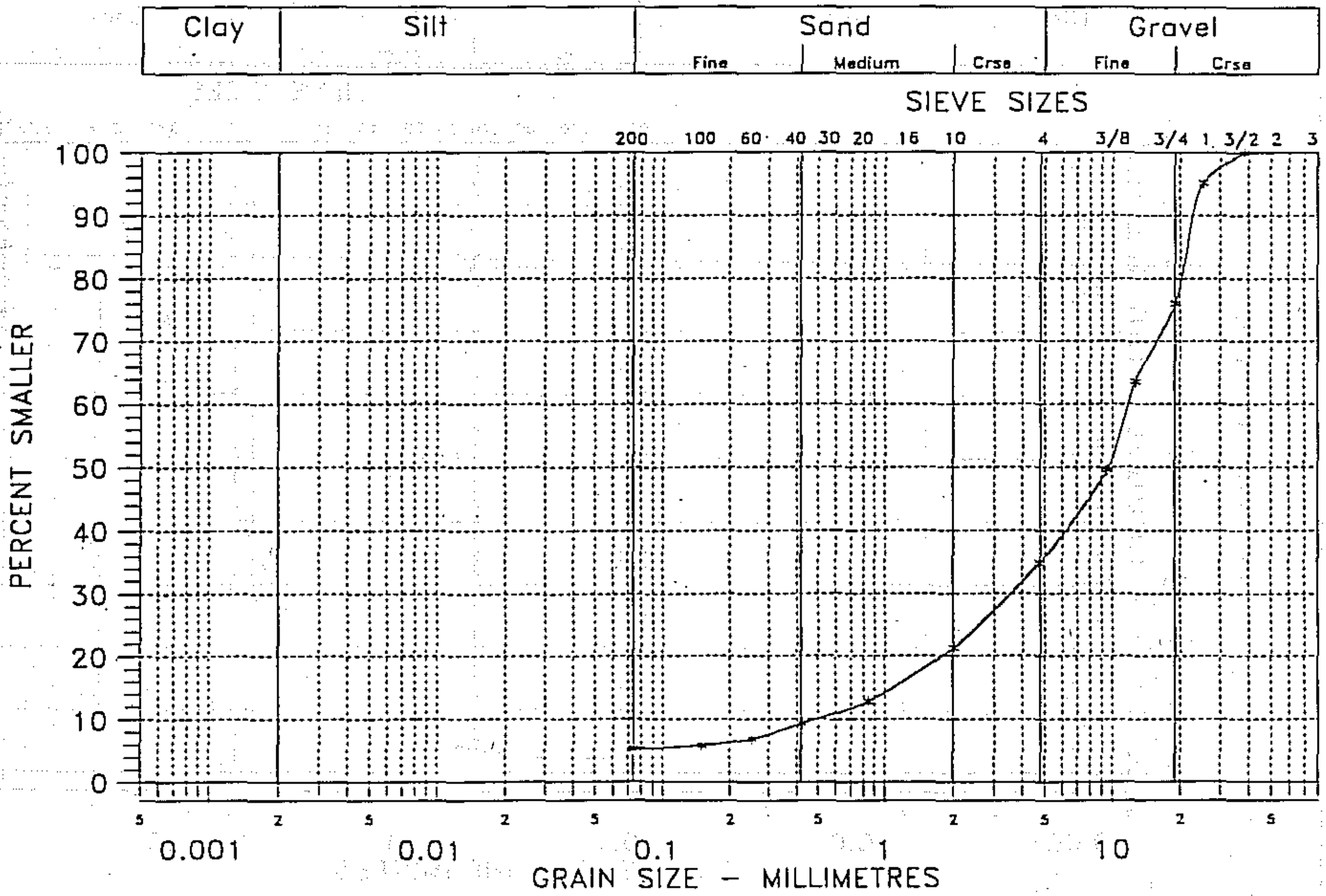


Reviewed By:

HONG WEST & ASSOCIATES
GRAIN SIZE DISTRIBUTION

Project: Silvigrow
King County, Washington
Project Number: 90131
Date Tested: 4-16-91
Remarks: Gray-brown, well graded GRAVEL with sand; some silt (GW-GM)

Test Hole Number: MW-3
Sample Number:
Depth: 38-39 feet
Sample Description:
Gravel: 65.2
Sand: 29.5
Silt: 5.3
Clay:



Reviewed By:

HONG WEST & ASSOCIATES
GRAIN SIZE DISTRIBUTION

Project: Silvigrow

King County, Washington

Project Number: 90131

Date Tested: 4-16-91

Remarks: Brown, well graded GRAVEL with sand; trace silt. (GW)

Test Hole Number: MW-4

Sample Number:

Depth: 90 feet

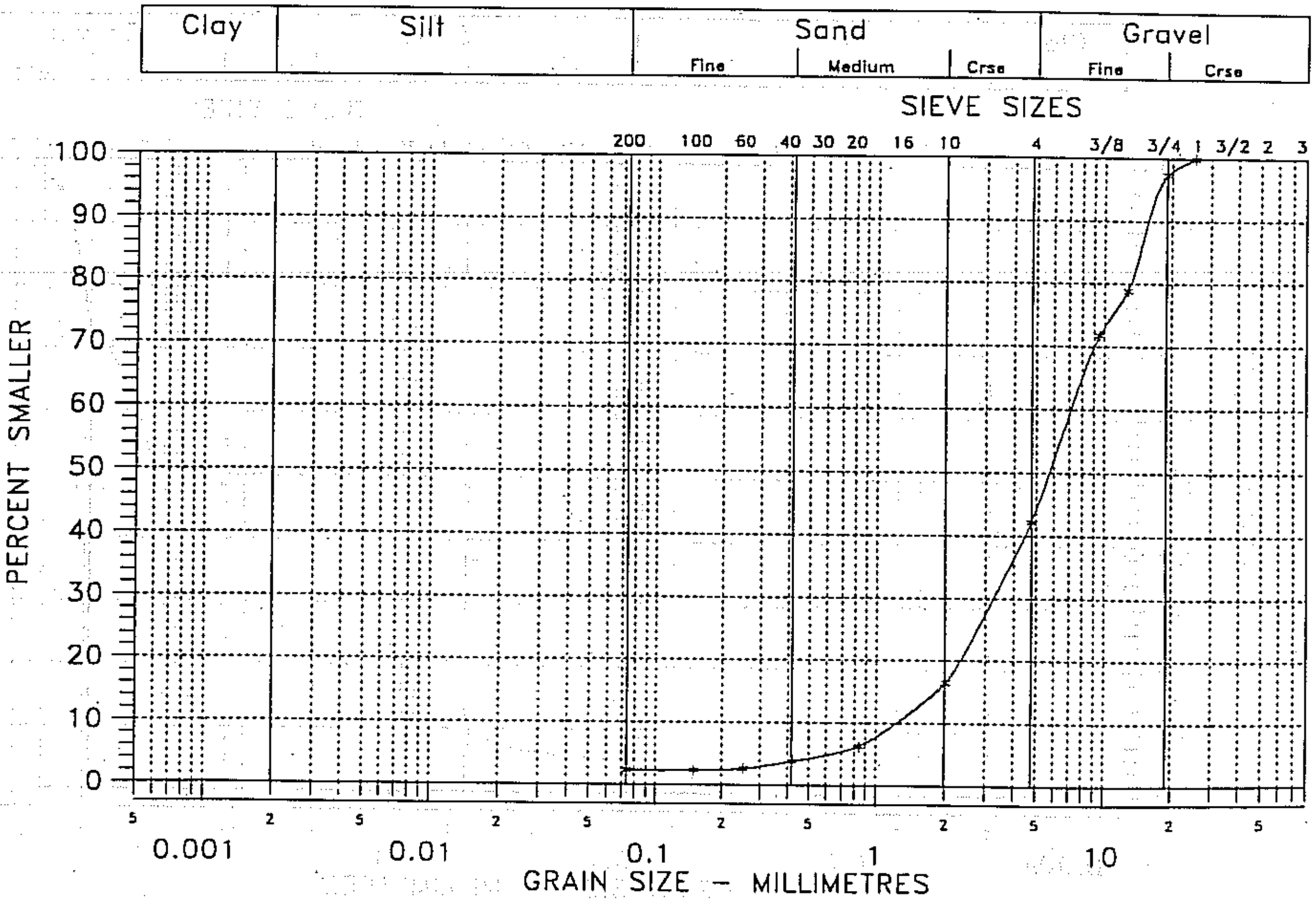
Sample Description:

Gravel: 57.8

Sand: 39.9

Silt: 2.3

Clay:

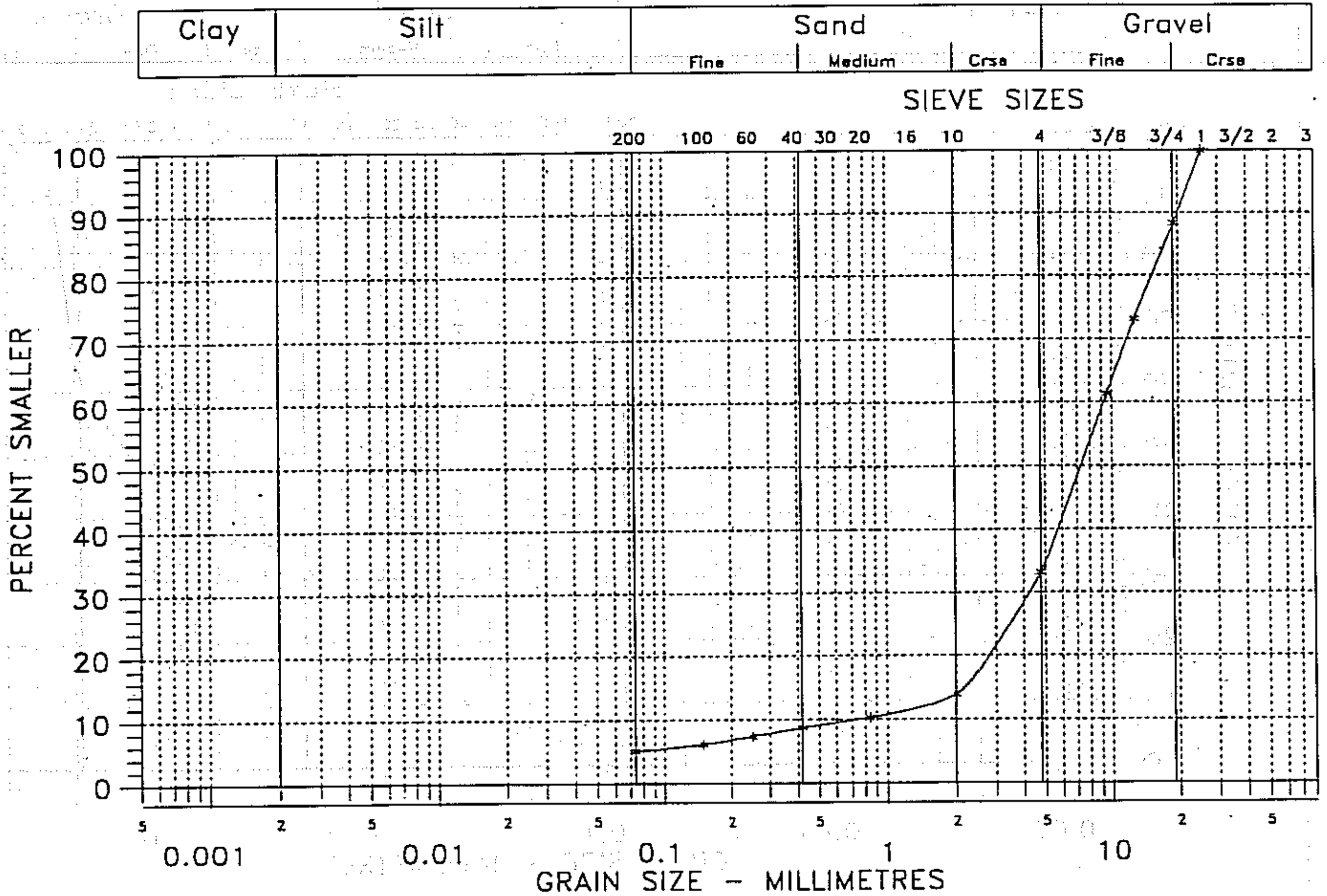


Reviewed By:

HONG WEST & ASSOCIATES
GRAIN SIZE DISTRIBUTION

Project: Silvigrow
King County, Washington
Project Number: 90131
Date Tested: 4-16-91
Remarks: Brown, well graded GRAVEL with sand; some silt. (GW-GM)

Test Hole Number: MW-6
Sample Number:
Depth: 20 feet
Sample Description:
Gravel: 66.9
Sand: 27.9
Silt: 5.2
Clay:



Reviewed By:

HONG WEST & ASSOCIATES
GRAIN SIZE DISTRIBUTION

Project: Silvigrow

King County, Washington

Project Number: 90131

Date Tested: 4-16-91

Remarks: Brown, poorly graded GRAVEL with sand; trace silt (GP)

Test Hole Number: MW-6

Sample Number:

Depth: 55 feet

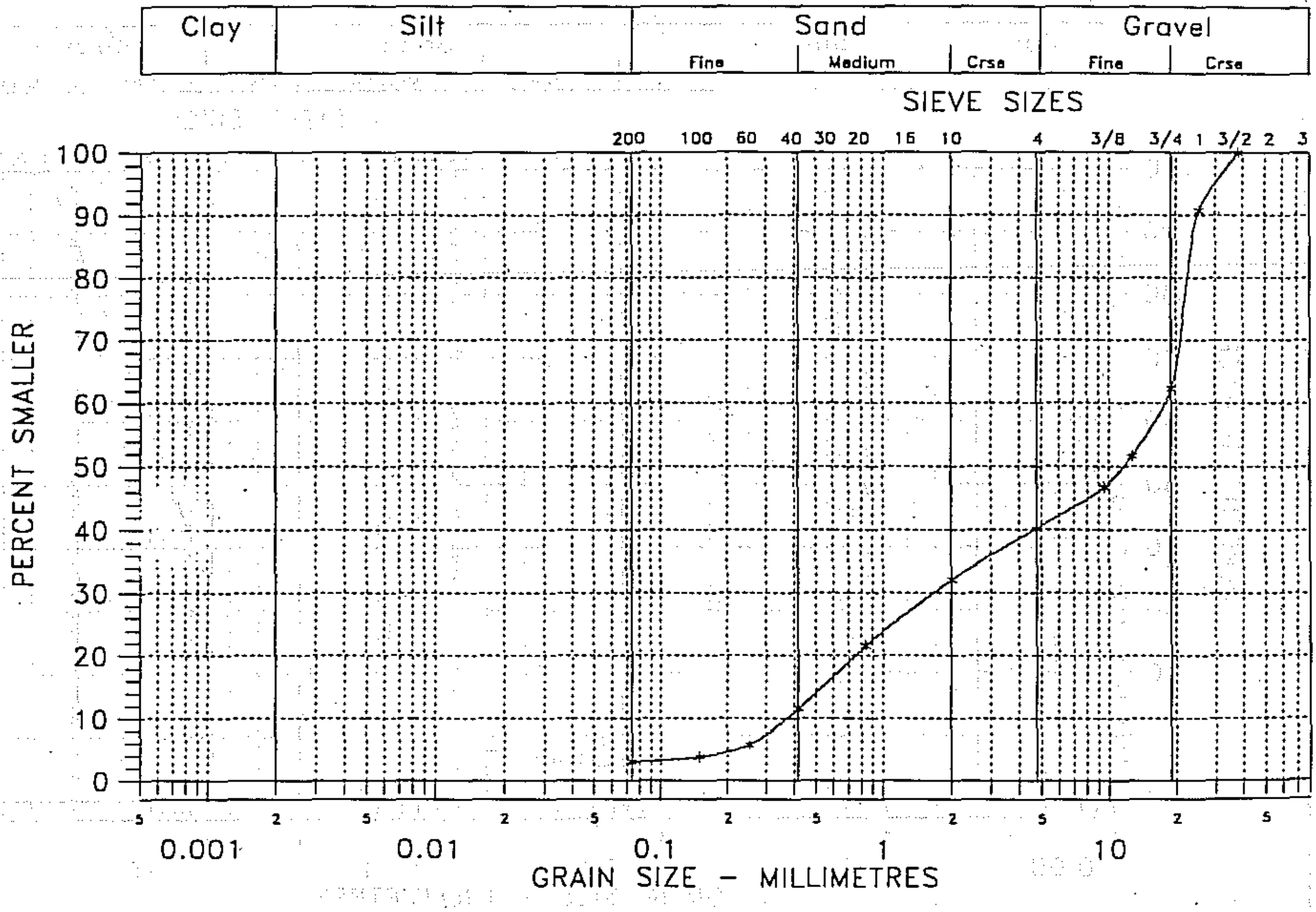
Sample Description:

Gravel: 59.9

Sand: 37.0

Silt: 3.1

Clay:



Reviewed By:

HONG WEST & ASSOCIATES
GRAIN SIZE DISTRIBUTION

Project: Silvigrow

King County, Washington

Project Number: 90131

Date Tested: 4-16-91

Remarks: Brown, poorly graded GRAVEL with sand; trace silt (GP)

Test Hole Number: MW-7

Sample Number:

Depth: 55 feet

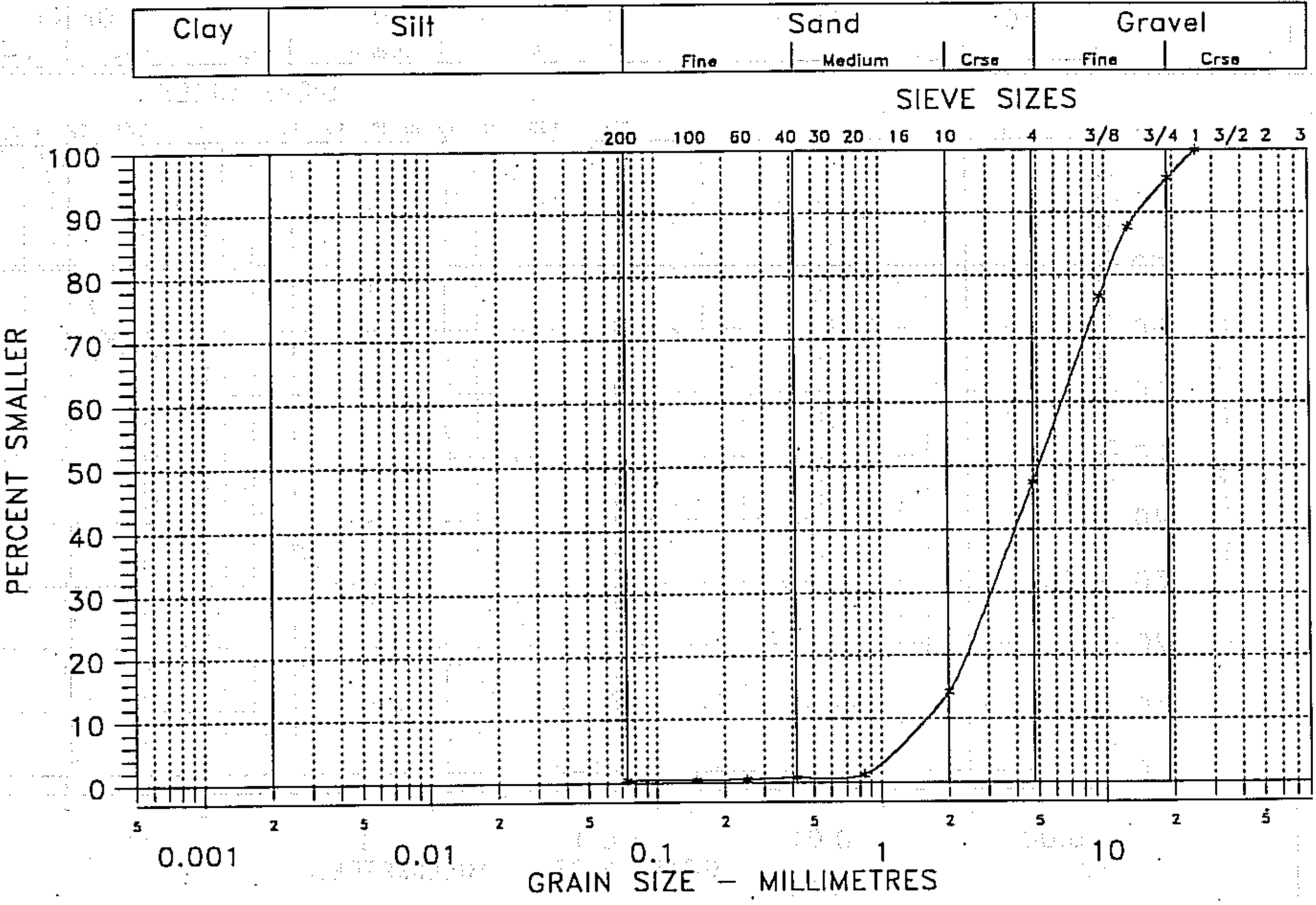
Sample Description:

Gravel: 52.6

Sand: 46.9

Silt: 0.5

Clay:

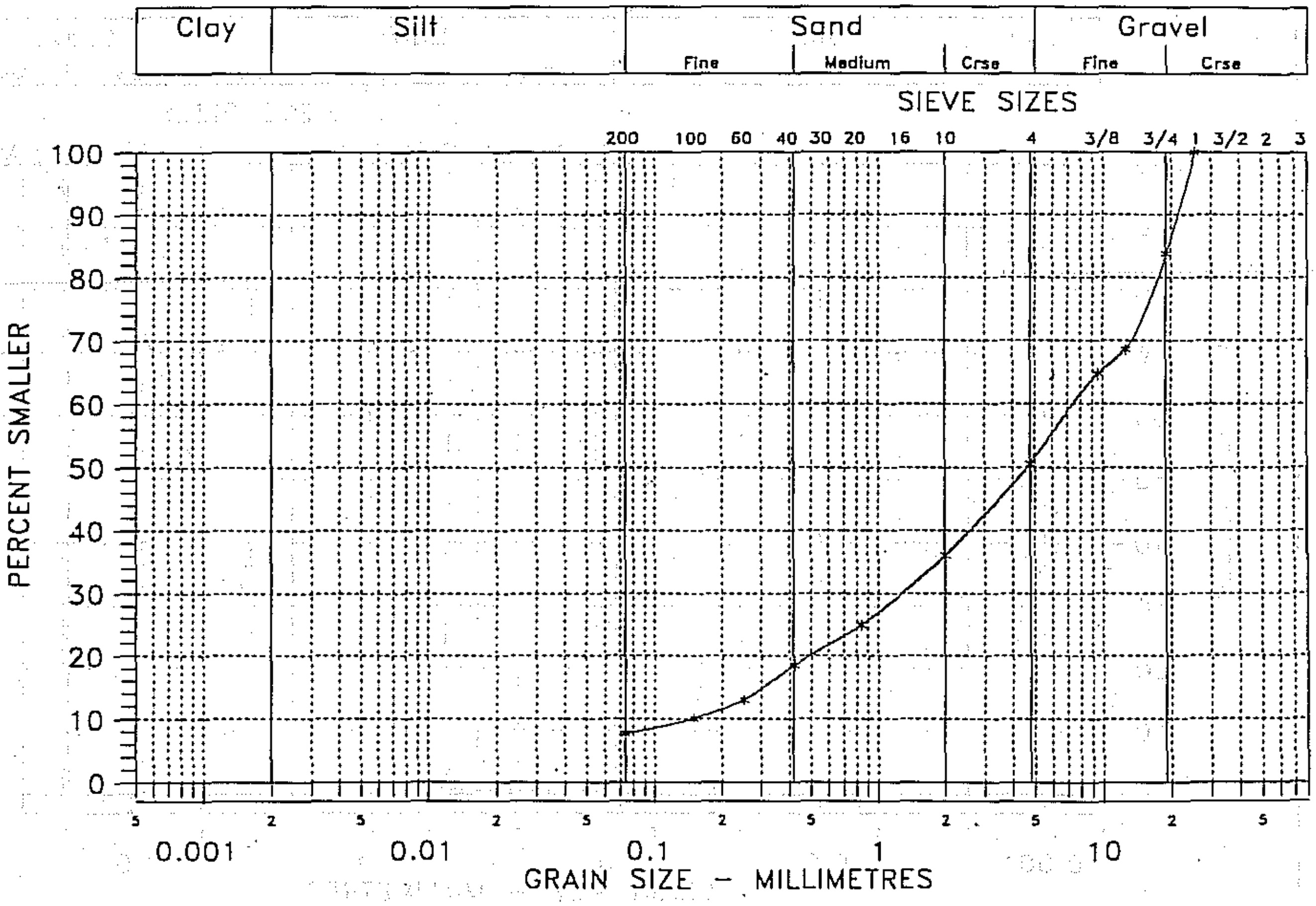


Reviewed By:

HONG WEST & ASSOCIATES
GRAIN SIZE DISTRIBUTION

Project: Silvigrow
King County, Washington
Project Number: 90131
Date Tested: 4-16-91
Remarks: Brown, well graded GRAVEL with sand; some silt (GW-GM)

Test Hole Number: MW-8
Sample Number:
Depth: 5 feet
Sample Description:
Gravel: 49.5
Sand: 42.8
Silt: 7.7
Clay:



Reviewed By:

HONG WEST & ASSOCIATES

Page 1 of

Job No. 90131

Project SILVIGROW

Date 5-13-91

Calculations for Permeability Estimate from Grain Size USING METHOD IN POWERS (1981)

Made by D. Geller

MW-1 135' sample K @ 135' (ADVANCE OUTWASH)

UNIFORMITY COEFFICIENT $C_U = \frac{D_{60}}{D_{10}} = \frac{10.5}{2.4} = 4.38$

ASSUME DENSE, FROM POWERS (1981) $K > .3$ cm/sec

($D_{50} = 10$) $> .6$ FT/MIN

MW-2 COMPOSITE SAMPLE FROM 50' and 55' (GLACIAL TILL)

$C_U = \frac{D_{60}}{D_{10}} = \frac{11.1}{.016} = 693.8$ - CANNOT ESTIMATE

$K > 1$ FT/MIN

($D_{50} = 10$)

MW-4 90' SAMPLE (ADVANCE OUTWASH)

$C_U = \frac{D_{60}}{D_{10}} = \frac{7.2}{1.3} = 5.54$ $K = .18$ cm/sec

$= .36$ FT/MIN

$D_{50} = 5.8$

MW-6 20' : SAMPLE (RECESSIONAL OUTWASH)

$C_U = \frac{D_{60}}{D_{10}} = \frac{9.3}{.85} = 10.9$ $K = > 1$ FT/MIN

$D_{50} = 7$

MW-6 55' SAMPLE (ADVANCE OUTWASH)

$C_U = \frac{D_{60}}{D_{10}} = \frac{19}{.37} = 51.35$ $K = > 1$ FT/MIN

$D_{50} = 12$

MW-7 55' SAMPLE (ADVANCE OUTWASH)

$C_U = \frac{D_{60}}{D_{10}} = \frac{5.5}{1.7} = 3.24$ $K = .3$ cm/sec

$.6$ FT/MIN

$D_{50} = 5$

MW-8 5' SAMPLE (RECESSIONAL/MORAINE)

$C_U = \frac{D_{60}}{D_{10}} = \frac{7.5}{.16} = 46.88$ K = CANNOT ESTIMATE

$D_{50} = 4.6$

Page 2 of

Job No. 96131

Date

Made by

Project

Calculations for

MW-3 38-39' DAMES & MOORE SAMPLE

$C_U = \frac{D_{60}}{D_{10}} = \frac{12}{4.6} = 2.61$ $K = > 1$ FT/MIN

$D_{50} = 9.5$

HONG CONSULTING ENGINEERS, INC.

FALLING HEAD PERMEABILITY TEST REPORT

Project: METRO SILVIGROW

Address: Section 16/20

Project Number: 90131

Date Tested: 4-91 By: SEG

Test Apparatus:

Machine Number:

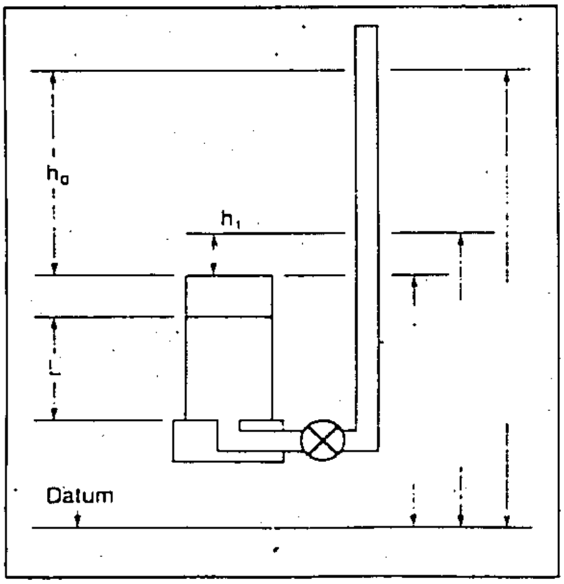
Test Hole Number: MW - 3

Depth: 38-39'

Test Number:

Sample Description: Brown Sandy gravel with some silt

Load Increment						
Trial Number	1	2	3	1	2	3
Area of Burette cm² (a)	29.49	→				
Sample Height cm (L)	10.16	→				
Sample Diameter cm (D)	6.13	→				
Sample Area cm² (A)	29.49	→				
Initial Head cm (ho)	15.24	15.24	15.24			
Final Head cm (h')	10.24	10.24	10.24			
Initial Time sec. (to)	0	0	0			
Final Time sec. (t')	11	12	13			
	.0062	.0057	.0052	cm/sec		



$$k = 2.3 \frac{aL}{A(t_1 - t_0)} \log_{10} \frac{h_0}{h_1}$$

Remarks:

$K = 5.6 \times 10^{-3}$ cm/sec

EXHIBIT C

HYDRAULIC CONDUCTIVITY TESTING

DATA AND CALCULATIONS

MW-1 FALLING HEAD TEST DATA

```
      SE1000B
 Environmental Logger
    05/01  10:08

 Unit# 00997  Test# 0

INPUT 1:  Level (F)

Reference        10.69
Scale factor     10.11
Offset            0.00

Step# 0   05/01  09:25

Elapsed Time    Value
------------  ---------
   0.0000        10.69
   0.0033        10.79
   0.0066        11.33
   0.0099        12.13
   0.0133        11.77
   0.0166        11.06
   0.0200        10.84
   0.0233        10.79
   0.0266        10.76
   0.0300        10.75
   0.0333        10.74
   0.0500        10.77
   0.0666        10.76
   0.0833        10.76
   0.1000        10.76
   0.1166        10.76
   0.1333        10.74
   0.1500        10.74
   0.1666        10.74
   0.1833        10.74
   0.2000        10.73
   0.2166        10.74
   0.2333        10.73
   0.2500        10.73
   0.2666        10.73
   0.2833        10.73
   0.3000        10.73
   0.3166        10.73
   0.3333        10.72
   0.4167        10.72
   0.5000        10.72
   0.5833        10.71
   0.6667        10.71
   0.7500        10.71
   0.8333        10.71
   0.9167        10.70
   1.0000        10.70
   1.0833        10.70
   1.1667        10.70
   1.2500        10.70
   1.3333        10.70
   1.4166        10.70
   1.5000        10.70
```

```
   1.5833        10.69
   1.6667        10.70
   1.7500        10.69
   1.8333        10.70
   1.9167        10.70
   2.0000        10.69
   2.5000        10.69
   3.0000        10.69
   3.5000        10.69
   4.0000        10.68
   4.5000        10.68
   5.0000        10.68
   5.5000        10.69
   6.0000        10.69
   6.5000        10.69
   7.0000        10.68
   7.5000        10.68
   8.0000        10.69
   8.5000        10.69
   9.0000        10.68
   9.5000        10.68
  10.0000        10.68
  12.0000        10.68
```

MW-1 RISING HEAD TEST DATA

```
        SE1000B
  Environmental Logger
      05/01   10:10

  Unit# 00997   Test# 1

INPUT 1:  Level (F)

Reference          10.69
Scale factor       10.11
Offset              0.00

Step# 0   05/01   09:40
```

Elapsed Time	Value
0.0000	10.67
0.0033	10.46
0.0066	10.21
0.0099	10.14
0.0133	10.17
0.0166	10.27
0.0200	10.35
0.0233	10.39
0.0266	10.45
0.0300	10.50
0.0333	10.52
0.0500	10.61
0.0666	10.64
0.0833	10.65
0.1000	10.67
0.1166	10.67
0.1333	10.67
0.1500	10.67
0.1666	10.67
0.1833	10.68
0.2000	10.68
0.2166	10.68
0.2333	10.68
0.2500	10.69
0.2666	10.68
0.2833	10.68
0.3000	10.68
0.3166	10.69
0.3333	10.68
0.4167	10.68
0.5000	10.69
0.5833	10.69
0.6667	10.69
0.7500	10.69
0.8333	10.69
0.9167	10.69
1.0000	10.69
1.0833	10.69
1.1667	10.69
1.2500	10.69
1.3333	10.69
1.4166	10.69
1.5000	10.69
1.5833	10.69
1.6667	10.69
1.7500	10.69
1.8333	10.69
1.9167	10.69
2.0000	10.69
2.5000	10.69
3.0000	10.68
3.5000	10.69
4.0000	10.69
4.5000	10.68
5.0000	10.69
5.5000	10.68
6.0000	10.69
6.5000	10.69
7.0000	10.69
7.5000	10.69
8.0000	10.68
8.5000	10.68
9.0000	10.69
9.5000	10.68
10.0000	10.68
12.0000	10.68
14.0000	10.67

MW-2 FALLING HEAD TEST DATA

```
          SE1000B
  Environmental Logger
     05/01  11:55

  Unit# 00997  Test# 2

INPUT 1:  Level (F)

Reference          12.90
Scale factor       10.11
Offset              0.00

Step# 0   05/01   10:50

Elapsed Time     Value
------------   ---------
    0.0000         15.88
    0.0033         15.49
    0.0066         15.51
    0.0099         14.94
    0.0133         13.38
    0.0166         13.86
    0.0200         14.01
    0.0233         14.04
    0.0266         14.06
    0.0300         13.77
    0.0333         13.55
    0.0500         13.54
    0.0666         13.54
    0.0833         13.54
    0.1000         13.48
    0.1166         13.46
    0.1333         13.42
    0.1500         13.40
    0.1666         13.36
    0.1833         13.36
    0.2000         13.34
    0.2166         13.31
    0.2333         13.30
    0.2500         13.29
    0.2666         13.28
    0.2833         13.27
    0.3000         13.26
    0.3166         13.24
    0.3333         13.23
    0.4167         13.20
    0.5000         13.18
    0.5833         13.16
    0.6667         13.13
    0.7500         13.13
    0.8333         13.11
    0.9167         13.09
    1.0000         13.09
    1.0833         13.08
    1.1667         13.07
    1.2500         13.07
    1.3333         13.05
    1.4166         13.05
    1.5000         13.05
```

```
    1.5833         13.05
    1.6667         13.04
    1.7500         13.04
    1.8333         13.03
    1.9167         13.02
    2.0000         13.02
    2.5000         13.02
    3.0000         13.00
    3.5000         13.00
    4.0000         12.99
    4.5000         12.98
    5.0000         12.97
    5.5000         12.97
    6.0000         12.97
    6.5000         12.96
    7.0000         12.96
    7.5000         12.95
    8.0000         12.96
    8.5000         12.96
    9.0000         12.95
    9.5000         12.95
   10.0000         12.95
   12.0000         12.93
   14.0000         12.93
   16.0000         12.92
   18.0000         12.93
   20.0000         12.92
   22.0000         12.92
   24.0000         12.91
   26.0000         12.91
   28.0000         12.92
   30.0000         12.91
   32.0000         12.92
```

```
       SE1000B
 Environmental Logger
     05/01  11:57

 Unit# 00997  Test# 3      MW-2 RISING HEAD TEST DATA

INPUT 1:  Level (F)

Reference        12.90
Scale factor     10.11
Offset            0.00

Step# 0   05/01  11:23

Elapsed Time    Value
------------  ---------
    0.0000       12.40
    0.0033       11.59
    0.0066       11.67
    0.0099       11.81
    0.0133       11.28
    0.0166       11.24
    0.0200       11.26
    0.0233       11.34
    0.0266       11.46
    0.0300       11.60
    0.0333       11.73
    0.0500       12.10
    0.0666       12.17          1.5833       12.74
    0.0833       12.23          1.6667       12.74
    0.1000       12.29          1.7500       12.74
    0.1166       12.33          1.8333       12.76
    0.1333       12.36          1.9167       12.75
    0.1500       12.39          2.0000       12.76
    0.1666       12.41          2.5000       12.78
    0.1833       12.43          3.0000       12.79
    0.2000       12.46          3.5000       12.80
    0.2166       12.47          4.0000       12.80
    0.2333       12.48          4.5000       12.81
    0.2500       12.50          5.0000       12.81
    0.2666       12.51          5.5000       12.82
    0.2833       12.52          6.0000       12.82
    0.3000       12.53          6.5000       12.82
    0.3166       12.53          7.0000       12.83
    0.3333       12.55          7.5000       12.83
    0.4167       12.58          8.0000       12.83
    0.5000       12.61          8.5000       12.83
    0.5833       12.63          9.0000       12.83
    0.6667       12.65          9.5000       12.83
    0.7500       12.66         10.0000       12.84
    0.8333       12.68         12.0000       12.84
    0.9167       12.69         14.0000       12.85
    1.0000       12.70         16.0000       12.85
    1.0833       12.71         18.0000       12.86
    1.1667       12.71         20.0000       12.85
    1.2500       12.72         22.0000       12.85
    1.3333       12.73         24.0000       12.86
    1.4166       12.73         26.0000       12.87
    1.5000       12.74         28.0000       12.86
```

MW-4 FALLING HEAD TEST DATA

```
       SE1000B
  Environmental Logger
      05/01  12:58

  Unit# 00997  Test# 4

INPUT 1:  Level (F)

Reference         12.73
Scale factor      10.11
Offset             0.00

Step# 0   05/01  12:28

Elapsed Time    Value
------------  ---------
   0.0000        12.65
   0.0033        12.66
   0.0066        13.33
   0.0099        15.51
   0.0133        15.71
   0.0166        14.15
   0.0200        13.03
   0.0233        13.21
   0.0266        13.46
   0.0300        13.31
   0.0333        13.03
   0.0500        13.09
   0.0666        12.88
   0.0833        12.84
   0.1000        12.81
   0.1166        12.80
   0.1333        12.78
   0.1500        12.77
   0.1666        12.76
   0.1833        12.76
   0.2000        12.75          1.5833         12.73
   0.2166        12.74          1.6667         12.73
   0.2333        12.74          1.7500         12.73
   0.2500        12.74          1.8333         12.73
   0.2666        12.74          1.9167         12.73
   0.2833        12.74          2.0000         12.73
   0.3000        12.74          2.5000         12.73
   0.3166        12.73          3.0000         12.73
   0.3333        12.73          3.5000         12.73
   0.4167        12.73          4.0000         12.73
   0.5000        12.73          4.5000         12.73
   0.5833        12.74          5.0000         12.73
   0.6667        12.73          5.5000         12.73
   0.7500        12.73          6.0000         12.73
   0.8333        12.73          6.5000         12.73
   0.9167        12.73          7.0000         12.74
   1.0000        12.73          7.5000         12.73
   1.0833        12.73          8.0000         12.73
   1.1667        12.74          8.5000         12.73
   1.2500        12.74          9.0000         12.73
   1.3333        12.73          9.5000         12.74
   1.4166        12.73         10.0000         12.73
   1.5000        12.73         12.0000         12.73
```

MW-4 RISING HEAD TEST DATA

```
       SE1000B
 Environmental Logger
     05/01  13:00

 Unit# 00997  Test# 5

INPUT 1:  Level (F)

Reference        12.73
Scale factor     10.11
Offset            0.00

Step# 0   05/01  12:44

Elapsed Time     Value
------------   ---------
   0.0000        12.67
   0.0033        11.96
   0.0066        11.56
   0.0099        11.98
   0.0133        11.62
   0.0166        11.55
   0.0200        11.60
   0.0233        11.71
   0.0266        11.82
   0.0300        11.95
   0.0333        12.07
   0.0500        12.42
   0.0666        12.57
   0.0833        12.63
   0.1000        12.66
   0.1166        1[illegible]
   0.1333        12.[illegible]
   0.1500        12.66
   0.1666        12.69
   0.1833        12.69
   0.2000        12.69
   0.2166        12.69        1.5833        12.71
   0.2333        12.70        1.6667        12.71
   0.2500        12.70        1.7500        12.71
   0.2666        12.69        1.8333        12.71
   0.2833        12.70        1.9167        12.71
   0.3000        12.69        2.0000        12.72
   0.3166        12.70        2.5000        12.71
   0.3333        12.70        3.0000        12.72
   0.4167        12.70        3.5000        12.72
   0.5000        12.71        4.0000        12.71
   0.5833        12.70        4.5000        12.71
   0.6667        12.70        5.0000        12.71
   0.7500        12.71        5.5000        12.71
   0.8333        12.70        6.0000        12.72
   0.9167        12.71        6.5000        12.72
   1.0000        12.71        7.0000        12.72
   1.0833        12.71        7.5000        12.72
   1.1667        12.71        8.0000        12.71
   1.2500        12.71        8.5000        12.71
   1.3333        12.71        9.0000        12.70
   1.4166        12.71        9.5000        12.71
   1.5000        12.71       10.0000        12.72
```

MW-5 FALLING HEAD TEST DATA

```
      SE1000B
 Environmental Logger
     04/15 . 17:36

 Unit# 00997  Test# 0

INPUT 1:  Level (F)

Reference          13.70
Scale factor       10.11
Offset              0.00

Step# 0   04/15   10:51

Elapsed Time     Value
------------   ---------
   0.0000          13.72
   0.0033          13.74
   0.0066          13.88
   0.0099          14.24
   0.0133          14.54
   0.0166          14.76
   0.0200          14.64
   0.0233          14.38
   0.0266          14.01
   0.0300          13.75
   0.0333          13.69
   0.0500          13.67
   0.0666          13.72
   0.0833          13.76
   0.1000          13.75
   0.1166          13.74
   0.1333          13.73
   0.1500          13.72
   0.1666          13.73
   0.1833          13.73
   0.2000          13.72
   0.2166          13.72         1.5833        13.72
   0.2333          13.73         1.6667        13.72
   0.2500          13.72         1.7500        13.71
   0.2666          13.72         1.8333        13.72
   0.2833          13.72         1.9167        13.72
   0.3000          13.72         2.0000        13.72
   0.3166          13.72         2.5000        13.72
   0.3333          13.72         3.0000        13.73
   0.4167          13.72         3.5000        13.72
   0.5000          13.71         4.0000        13.73
   0.5833          13.72         4.5000        13.72
   0.6667          13.72         5.0000        13.72
   0.7500          13.72         5.5000        13.72
   0.8333          13.71         6.0000        13.73
   0.9167          13.72         6.5000        13.72
   1.0000          13.73         7.0000        13.72
   1.0833          13.72         7.5000        13.72
   1.1667          13.72         8.0000        13.72
   1.2500          13.71         8.5000        13.72
   1.3333          13.71         9.0000        13.73
   1.4166          13.71         9.5000        13.72
   1.5000          13.73        10.0000        13.71
```

MW-5 RISING HEAD TEST DATA

```
       SE1000B
  Environmental Logger
     04/15   17:37

  Unit# 00997   Test# 1

INPUT 1:   Level  (F)

Reference          13.70
Scale factor       10.11
Offset              0.00

Step# 0    04/15   11:05

Elapsed Time     Value
------------   ---------
   0.0000         13.54
   0.0033         13.43
   0.0066         13.43
   0.0099         13.41
   0.0133         13.40
   0.0166         13.39
   0.0200         13.41
   0.0233         13.39
   0.0266         13.41
   0.0300         13.41
   0.0333         13.45
   0.0500         13.74
   0.0666         13.82
   0.0833         13.65
   0.1000         13.68
   0.1166         13.75
   0.1333         13.72
   0.1500         13.70
   0.1666         13.72
   0.1833         13.73
   0.2000         13.71
   0.2166         13.72
   0.2333         13.72
   0.2500         13.72
   0.2666         13.72
   0.2833         13.72          1.5833         13.72
   0.3000         13.72          1.6667         13.72
   0.3166         13.72          1.7500         13.72
   0.3333         13.72          1.8333         13.72
   0.4167         13.71          1.9167         13.72
   0.5000         13.72          2.0000         13.73
   0.5833         13.73          2.5000         13.73
   0.6667         13.72          3.0000         13.73
   0.7500         13.71          3.5000         13.73
   0.8333         13.72          4.0000         13.72
   0.9167         13.72          4.5000         13.73
   1.0000         13.72          5.0000         13.73
   1.0833         13.72          5.5000         13.73
   1.1667         13.73          6.0000         13.73
   1.2500         13.72          6.5000         13.72
   1.3333         13.72          7.0000         13.72
   1.4166         13.72          7.5000         13.72
   1.5000         13.73          8.0000         13.72
```

MW-7 FALLING HEAD TEST DATA

```
      SE1000B
 Environmental Logger
    04/15  17:41

 Unit# 00997  Test# 4

INPUT 1:  Level (F)

Reference          13.28
Scale factor       10.11
Offset              0.00

Step# 0   04/15  13:30
```

Elapsed Time	Value
0.0000	13.27
0.0033	13.33
0.0066	13.49
0.0099	13.58
0.0133	13.74
0.0166	13.92
0.0200	13.87
0.0233	13.70
0.0266	13.49
0.0300	13.26
0.0333	13.24
0.0500	13.14
0.0666	13.20
0.0833	13.29
0.1000	13.31
0.1166	13.27
0.1333	13.24
0.1500	13.26
0.1666	13.28
0.1833	13.28
0.2000	13.27
0.2166	13.27
0.2333	13.27
0.2500	13.26
0.2666	13.27
0.2833	13.27
0.3000	13.27
0.3166	13.27
0.3333	13.27
0.4167	13.27
0.5000	13.27
0.5833	13.27
0.6667	13.26
0.7500	13.27
0.8333	13.27
0.9167	13.27
1.0000	13.27
1.0833	13.27
1.1667	13.27
1.2500	13.27
1.3333	13.28
1.4166	13.26
1.5000	13.27
1.5833	13.26
1.6667	13.27
1.7500	13.27
1.8333	13.27
1.9167	13.27
2.0000	13.27
2.5000	13.28
3.0000	13.27
3.5000	13.27
4.0000	13.27
4.5000	13.27
5.0000	13.26
5.5000	13.27
6.0000	13.27
6.5000	13.27
7.0000	13.27
7.5000	13.26
8.0000	13.26
8.5000	13.27
9.0000	13.27
9.5000	13.26
10.0000	13.26

MW-7 RISING HEAD TEST DATA

```
     SE1000B
 Environmental Logger
   04/15  17:42

 Unit# 00997  Test# 5

INPUT 1:  Level (F)

Reference          13.28
Scale factor       10.11
Offset              0.00

Step# 0   04/15   13:44

Elapsed Time     Value
------------   ---------
    0.0000        12.51
    0.0033        12.82
    0.0066        12.89
    0.0099        12.94
    0.0133        12.91
    0.0166        12.96
    0.0200        13.01
    0.0233        13.11
    0.0266        13.17
    0.0300        13.25
    0.0333        13.31
    0.0500        13.41
    0.0666        13.26
    0.0833        13.19
    0.1000        13.23
    0.1166        13.29
    0.1333        13.28
    0.1500        13.25
    0.1666        13.26
    0.1833        13.28
    0.2000        13.26
    0.2166        13.26          1.5833        13.27
    0.2333        13.26          1.6667        13.28
    0.2500        13.26          1.7500        13.28
    0.2666        13.27          1.8333        13.28
    0.2833        13.26          1.9167        13.28
    0.3000        13.26          2.0000        13.28
    0.3166        13.26          2.5000        13.28
    0.3333        13.26          3.0000        13.27
    0.4167        13.26          3.5000        13.27
    0.5000        13.27          4.0000        13.28
    0.5833        13.26          4.5000        13.28
    0.6667        13.27          5.0000        13.27
    0.7500        13.27          5.5000        13.27
    0.8333        13.27          6.0000        13.27
    0.9167        13.27          6.5000        13.27
    1.0000        13.27          7.0000        13.28
    1.0833        13.27          7.5000        13.28
    1.1667        13.27          8.0000        13.27
    1.2500        13.27          8.5000        13.28
    1.3333        13.27          9.0000        13.28
    1.4166        13.27          9.5000        13.28
    1.5000        13.27         10.0000        13.28
```

MW-9 FALLING HEAD TEST DATA

```
       SE1000B
  Environmental Logger
     04/15  17:38

 Unit# 00997  Test# 2

INPUT 1:  Level (F)

Reference         12.72
Scale factor      10.11
Offset             0.00

Step# 0   04/15  12:23

Elapsed Time    Value
------------  ---------
    0.0000      12.73
    0.0033      12.90
    0.0066      13.03
    0.0099      13.05
    0.0133      12.87
    0.0166      12.67
    0.0200      12.60
    0.0233      12.64
    0.0266      12.67
    0.0300      12.68
    0.0333      12.67
    0.0500      12.64
    0.0666      12.71
    0.0833      12.74
    0.1000      12.73
    0.1166      12.71
    0.1333      12.69
    0.1500      12.72
    0.1666      12.73
    0.1833      12.72
    0.2000      12.70
    0.2166      12.71       1.5833      12.72
    0.2333      12.72       1.6667      12.72
    0.2500      12.72       1.7500      12.72
    0.2666      12.72       1.8333      12.72
    0.2833      12.72       1.9167      12.72
    0.3000      12.71       2.0000      12.72
    0.3166      12.72       2.5000      12.73
    0.3333      12.72       3.0000      12.72
    0.4167      12.72       3.5000      12.71
    0.5000      12.72       4.0000      12.72
    0.5833      12.72       4.5000      12.72
    0.6667      12.72       5.0000      12.72
    0.7500      12.72       5.5000      12.72
    0.8333      12.72       6.0000      12.71
    0.9167      12.72       6.5000      12.72
    1.0000      12.72       7.0000      12.72
    1.0833      12.72       7.5000      12.72
    1.1667      12.72       8.0000      12.72
    1.2500      12.72       8.5000      12.72
    1.3333      12.71       9.0000      12.72
    1.4166      12.72       9.5000      12.72
    1.5000      12.72      10.0000      12.72
```

MW-9 RISING HEAD TEST DATA

```
        SE1000B
  Environmental Logger
     04/15   17:40

 Unit# 00997   Test# 3

INPUT 1:  Level (F)

Reference          12.72
Scale factor       10.11
Offset              0.00

Step# 0    04/15   12:36

Elapsed Time     Value
------------   ---------
    0.0000         26.81
    0.0033         26.67
    0.0066         26.71
    0.0099         26.71
    0.0133         26.73
    0.0166         26.70
    0.0200         26.68
    0.0233         26.70
    0.0266         26.72
    0.0300         26.76
    0.0333         26.81
    0.0500         26.98
    0.0666         26.88
    0.0833         26.77
    0.1000         26.81
    0.1166         26.90
    0.1333         26.89
    0.1500         26.83
    0.1666         26.82
    0.1833         26.87
    0.2000         26.84
    0.2166         26.84          1.5833          26.88
    0.2333         26.84          1.6667          26.88
    0.2500         26.85          1.7500          26.87
    0.2666         26.86          1.8333          26.88
    0.2833         26.85          1.9167          26.89
    0.3000         26.84          2.0000          26.88
    0.3166         26.85          2.5000          26.88
    0.3333         26.84          3.0000          26.88
    0.4167         26.82          3.5000          26.87
    0.5000         26.87          4.0000          26.87
    0.5833         26.88          4.5000          26.88
    0.6667         26.87          5.0000          26.88
    0.7500         26.87          5.5000          26.88
    0.8333         26.87          6.0000          26.88
    0.9167         26.87          6.5000          26.88
    1.0000         26.87          7.0000          26.88
    1.0833         26.87          7.5000          26.88
    1.1667         26.88          8.0000          26.87
    1.2500         26.88          8.5000          26.88
    1.3333         26.87          9.0000          26.88
    1.4166         26.88          9.5000          26.88
    1.5000         26.87         10.0000          26.87
```

HONG WEST & ASSOCIATES

Page 1 of 3
Job No. 90131
Project SILVIGROW
Date 5-2-91
Calculations for K FROM SLUG TESTS (HVORSLEV METHOD)
Made by DJH
Chkd by PFD

MW-1

FALLING HEAD

r = .167 FEET
R = .75 FEET
L = 10 FEET
t_0 = .015 MINUTES

$$K = \frac{r^2 \ln(L/R)}{2Lt_0}$$

$$= \frac{.167^2 \ln(10/.75)}{2(10)(.015)}$$

$$= .24 \text{ ft/min}$$

$$\boxed{= .12 \text{ cm/SEC}}$$

FROM SLUGTST

k = .077 ft/min
= .039 cm/SEC
to
k = .19 ft/min
.096 cm/SEC

RISING HEAD

t_0 = .029 MINUTES

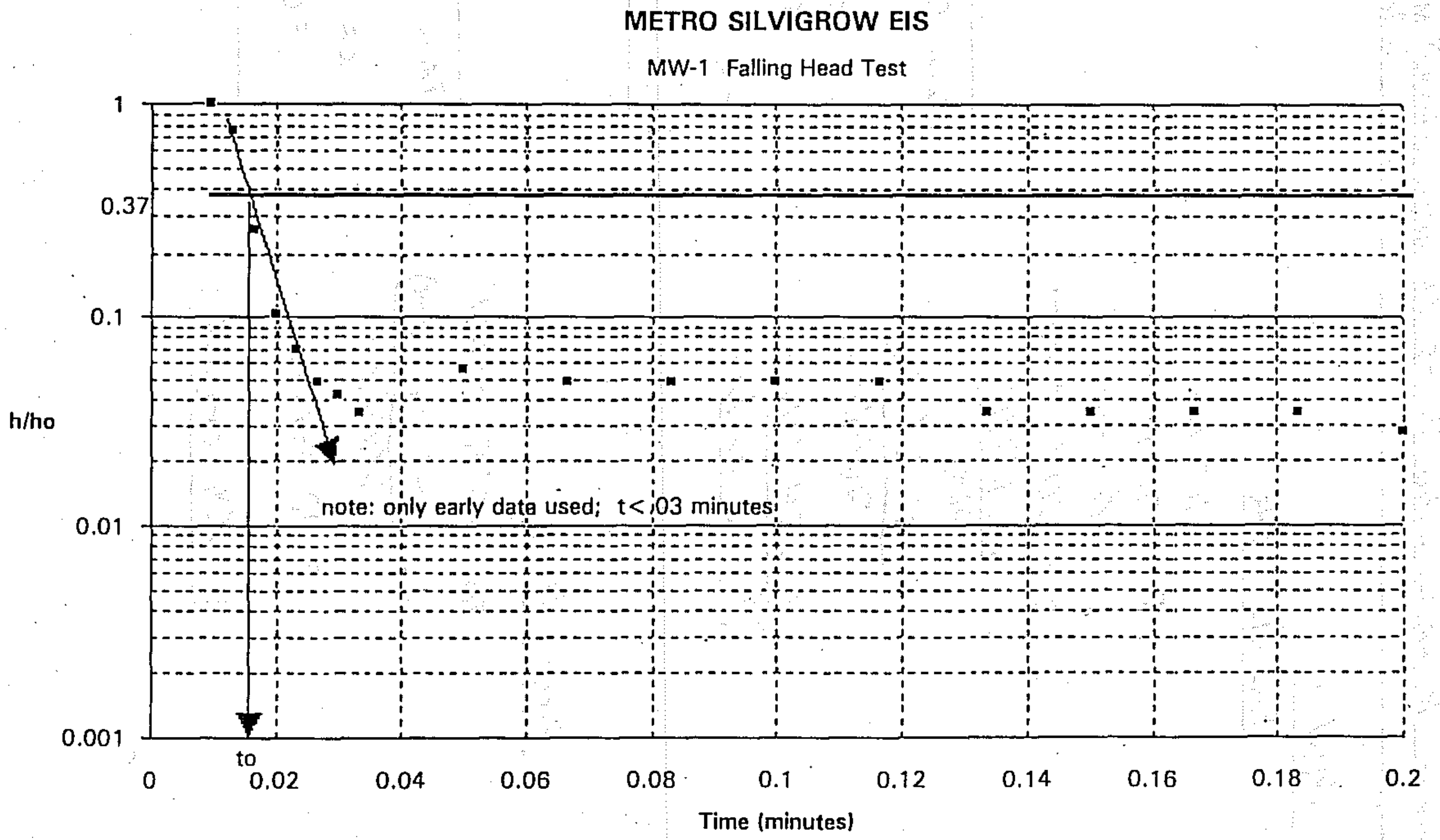
$$K = \frac{.167^2 \ln(10/.75)}{2(10)(.029)}$$

$$= .12 \text{ ft/min}$$

$$\boxed{= .06 \text{ cm/SEC}}$$

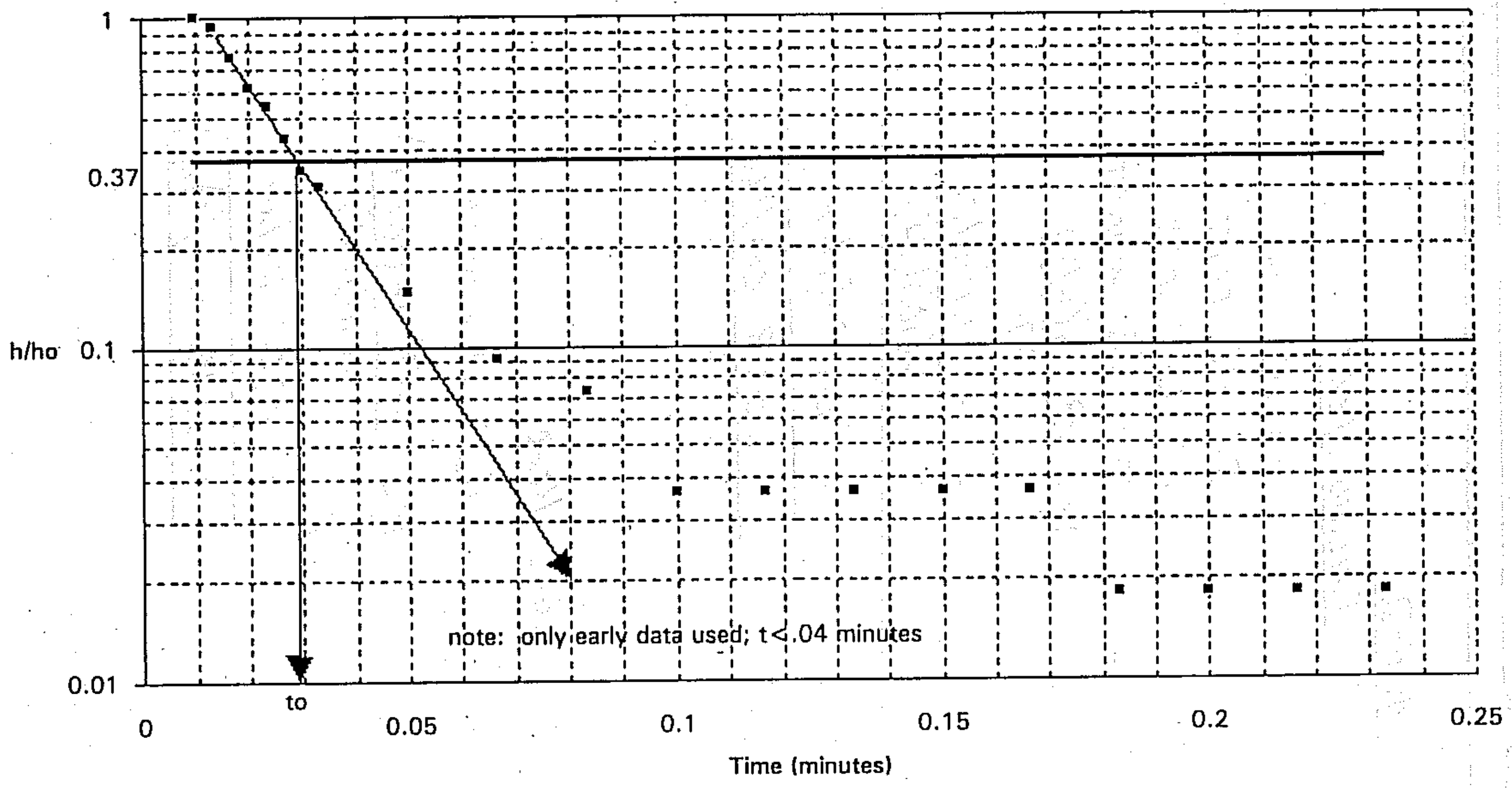
FROM SLUGTST

k = 0.18 ft/min
= 0.09 cm/sec


METRO SILVIGROW EIS
MW-1 Falling Head Test
h/ho
1
0.37
0.1
0.01
0.001
to
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
Time (minutes)
note: only early data used; t< .03 minutes

METRO SILVIGROW EIS

MW-1 Rising Head Test



note: only early data used; t < .04 minutes

Job No. 90171
Date 5-2-91
Made by DJH
Chkd by JEC

Project SILUIGROW
Calculations for

MW-2

FALLING HEAD

$r = .167$ FEET
$R = .75$ FEET
$L = 10$ FEET
$t_0 = .2$ MINUTES

$$K = \frac{r^2 \ln(L/R)}{2L t_0}$$

$$= \frac{.167^2 \ln(10/.75)}{2(10)(.2)}$$

$$= .017 \text{ ft/MIN}$$

$$\boxed{= .009 \text{ cm/SEC}}$$

FROM SLUGTST
$k = .0047$ ft/MIN
$= .0024$ cm/SEC

RISING HEAD

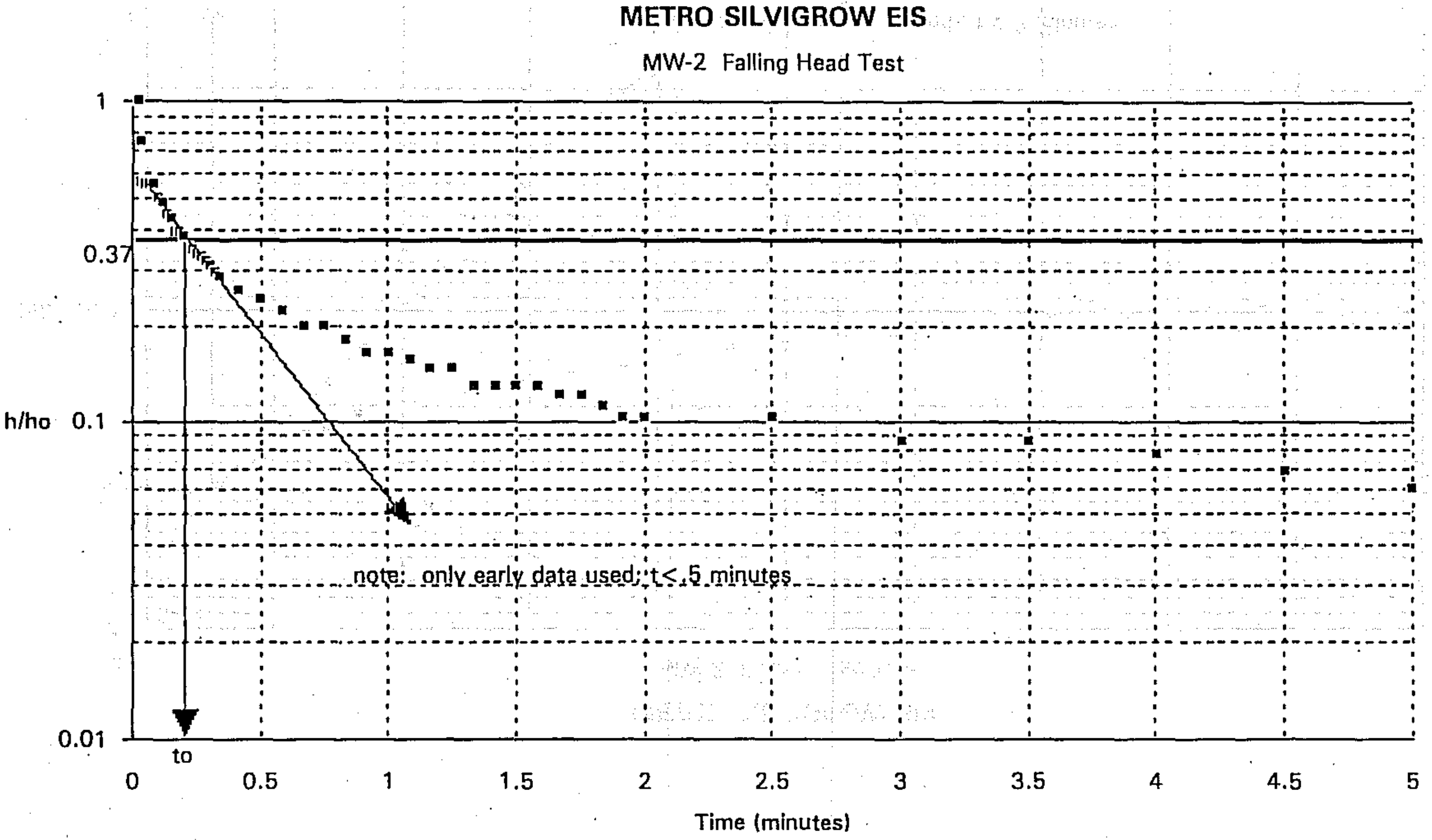
$t_0 = .1$ MINUTES

$$K = \frac{.167^2 \ln(10/.75)}{2(10)(.1)}$$

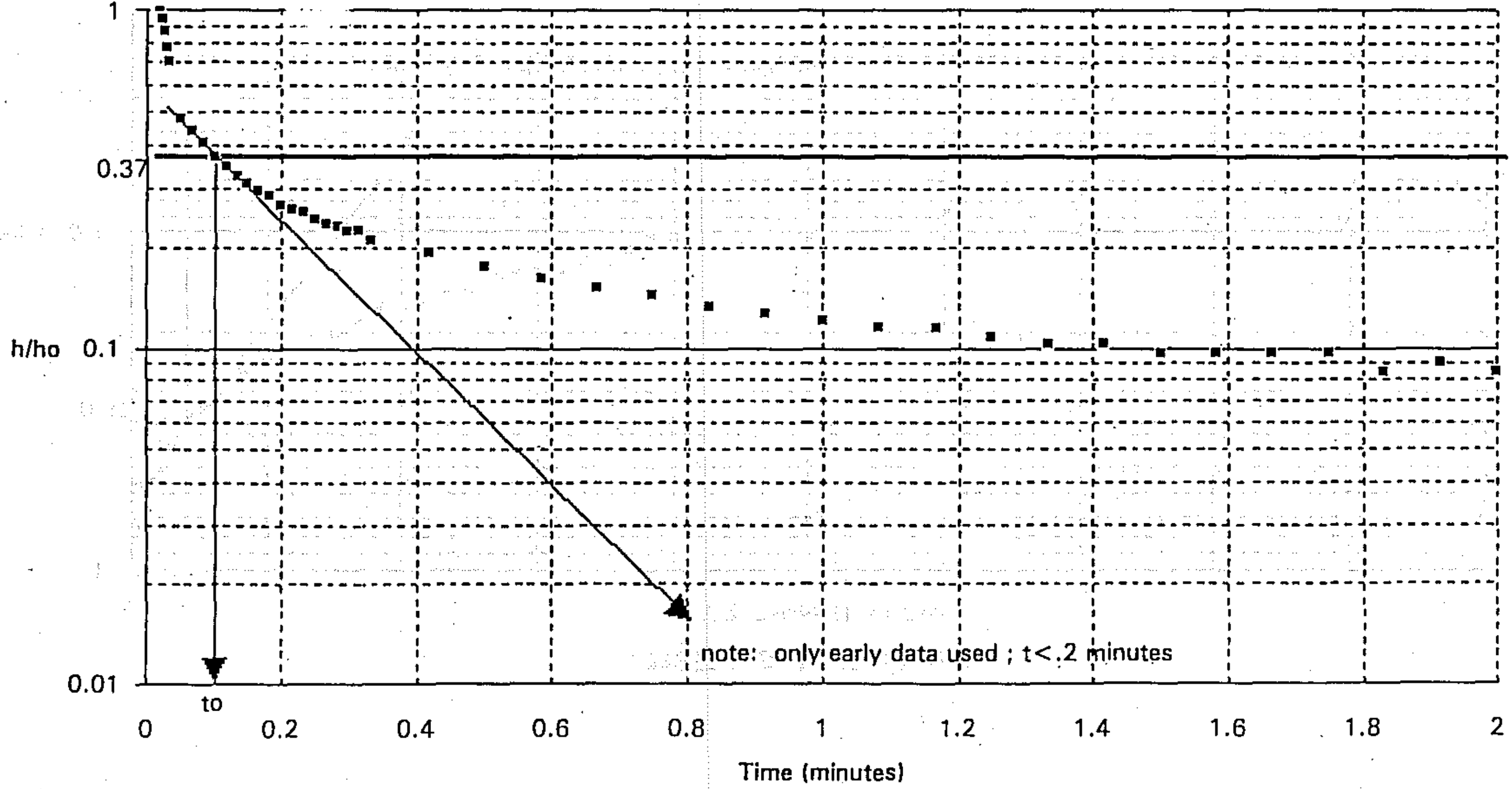
$$= .036 \text{ ft/MIN}$$

$$\boxed{= .018 \text{ cm/SEC}}$$

FROM SLUGTST
$k = .0036$ ft/MIN
$= .0018$ cm/SEC


METRO SILVIGROW EIS
MW-2 Falling Head Test
h/ho
1
0.37
0.1
0.01
to
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (minutes)
note: only early data used; t<.5 minutes

MW-2R. Chart 1



METRO SILVIGROW EIS

MW-2 Rising Head Test

note: only early data used ; t<.2 minutes

Page 3 of 3
Job No. 9061
Date 5-2-91
Made by EJH
Chkd by PFL

Project SILVIGROW
Calculations for

MW-4

FALLING HEAD

$r = .167$ FEET
$R = .75$ FEET
$L = 10$ FEET
$t_0 = .035$ MINUTES

$$K = \frac{r^2 \ln(L/R)}{2Lt_0}$$

$$= \frac{.167^2 \ln(10/.75)}{2(10)(.035)}$$

$$= .10 \text{ ft/min}$$

$$\boxed{= .05 \text{ cm/SEC}}$$

FROM SLUGTST
$K = .068$ ft/min
$= .035$ cm/SEC

RISING HEAD

$t_0 = .05$ MINUTES

$$K = \frac{.167^2 \ln(10/.75)}{2(10)(.05)}$$

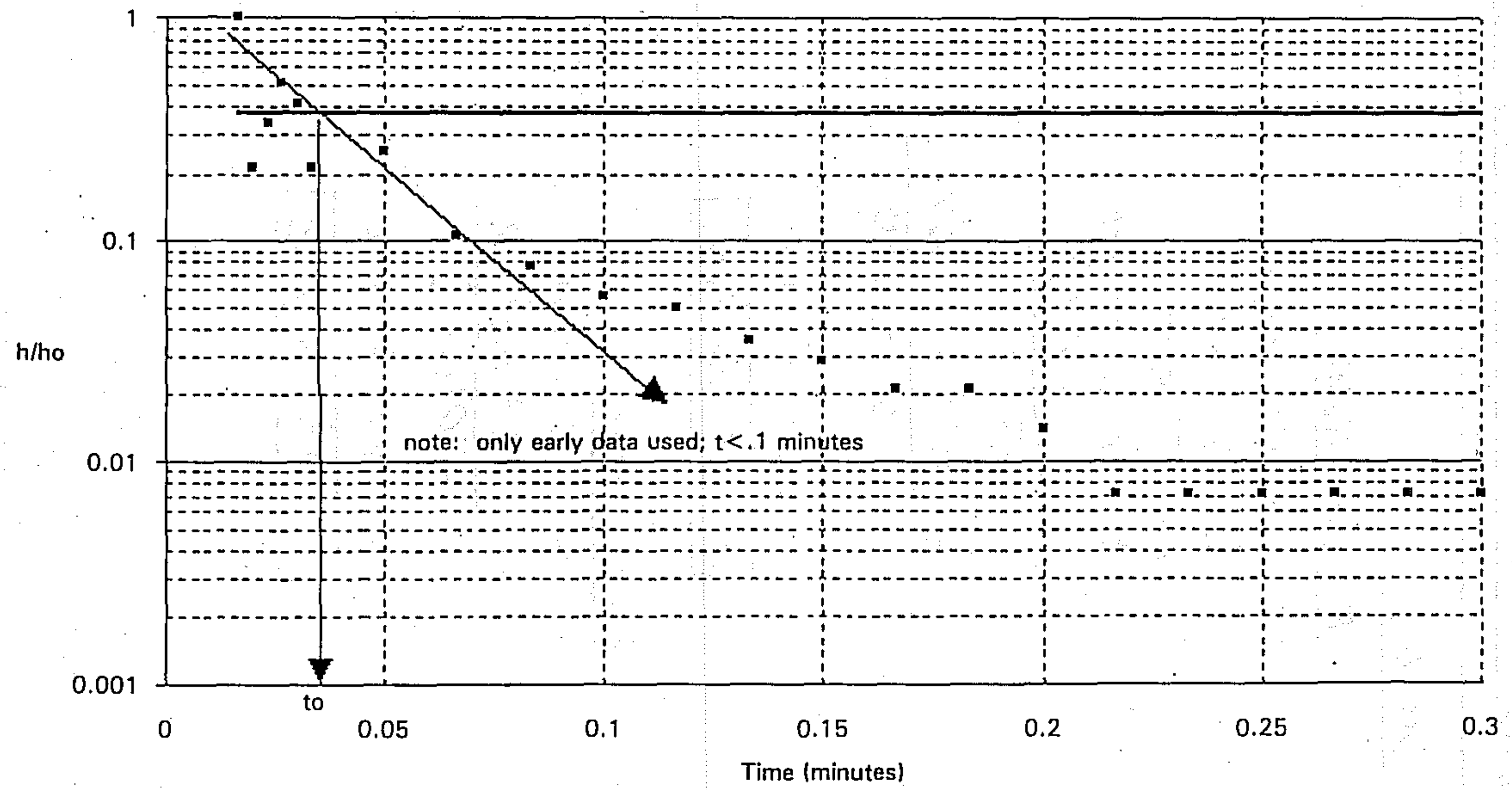
$$= .07 \text{ ft/min}$$

$$\boxed{= .04 \text{ cm/SEC}}$$

FROM SLUGTST
$K = .099$ ft/MIN
$= .05$ cm/SEC

METRO SILVIGROW EIS

MW-4 Falling Head Test

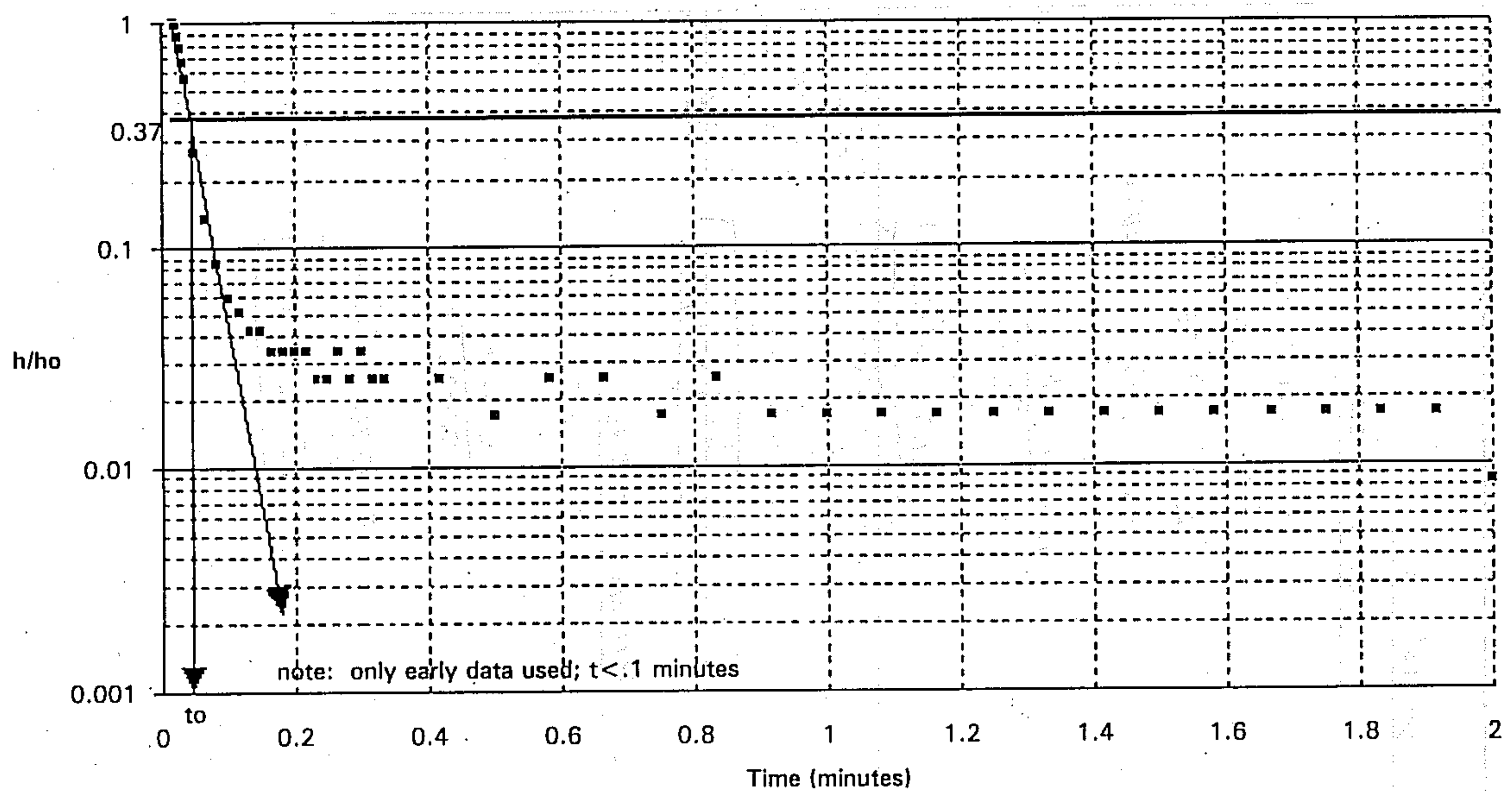


note: only early data used; t<.1 minutes

MW-4R. Chart 1

METRO SILVIGROW EIS

MW-4 Rising Head Test



Page 1 of 3
Job No. 90135
Project Silvergreen
Date 4-17-91
Calculations for K from Slug Tests (Hvorslev Method)
Made by DJH
Checked by PF

MW-5

FALLING HEAD

$r = .167$ FEET
$R = .5$ FEET
$L = 10$ FEET
$t_0 = .025$ MINUTES

$$K = \frac{r^2 \ln(L/R)}{2L t_0}$$

$$= \frac{.167^2 \ln(10/.5)}{2(10)(.025)}$$

$$= .167 \text{ ft/min}$$

$$\boxed{= .085 \text{ cm/sec}}$$

FROM SLUG TST
= .08 ft/min
= .04 cm/sec

RISING HEAD

$t_0 = .055$

$$K = \frac{.167^2 \ln(10/.5)}{2(10)(.055)}$$

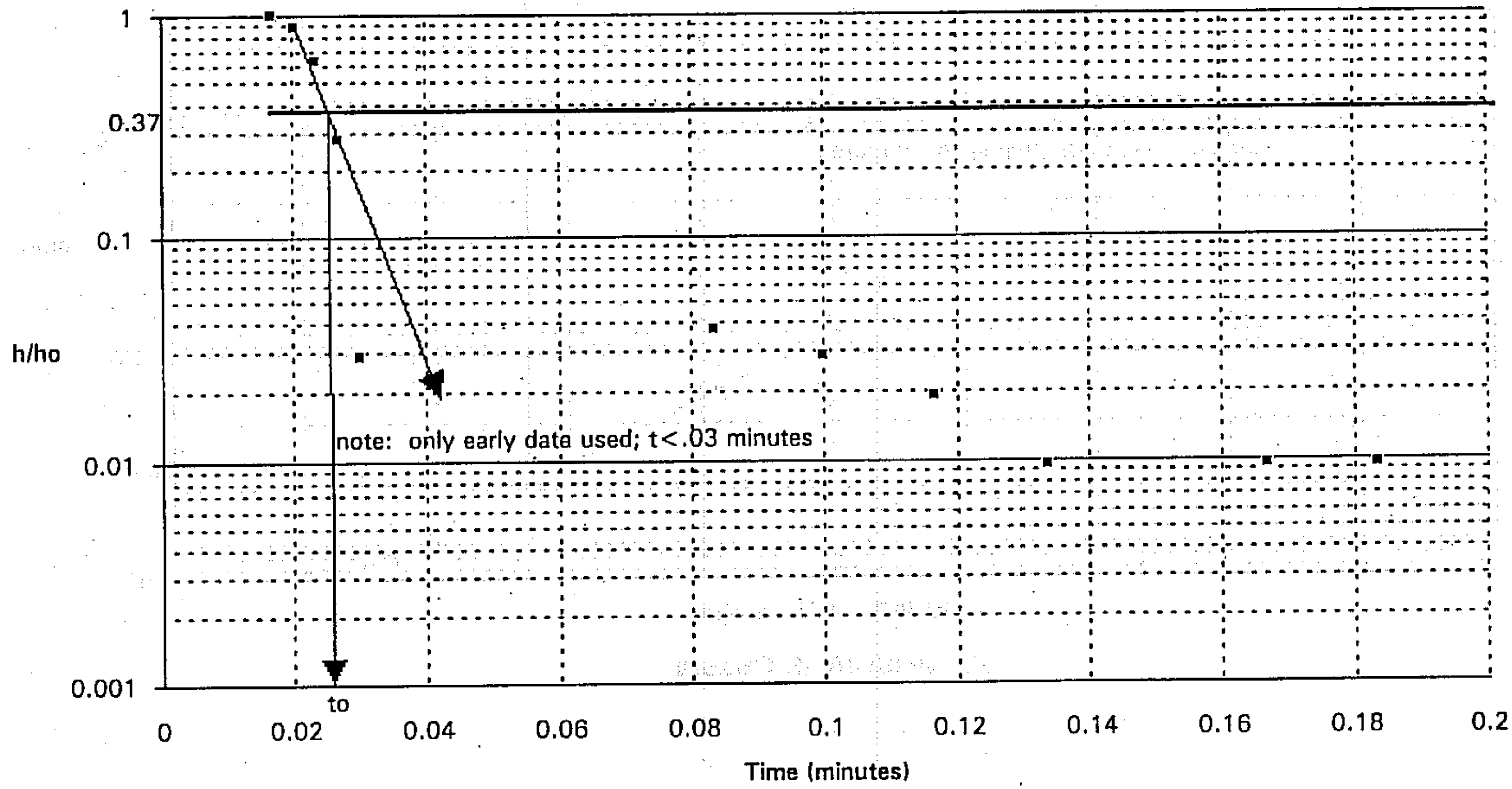
$$= .076 \text{ ft/min}$$

$$\boxed{= .039 \text{ cm/sec}}$$

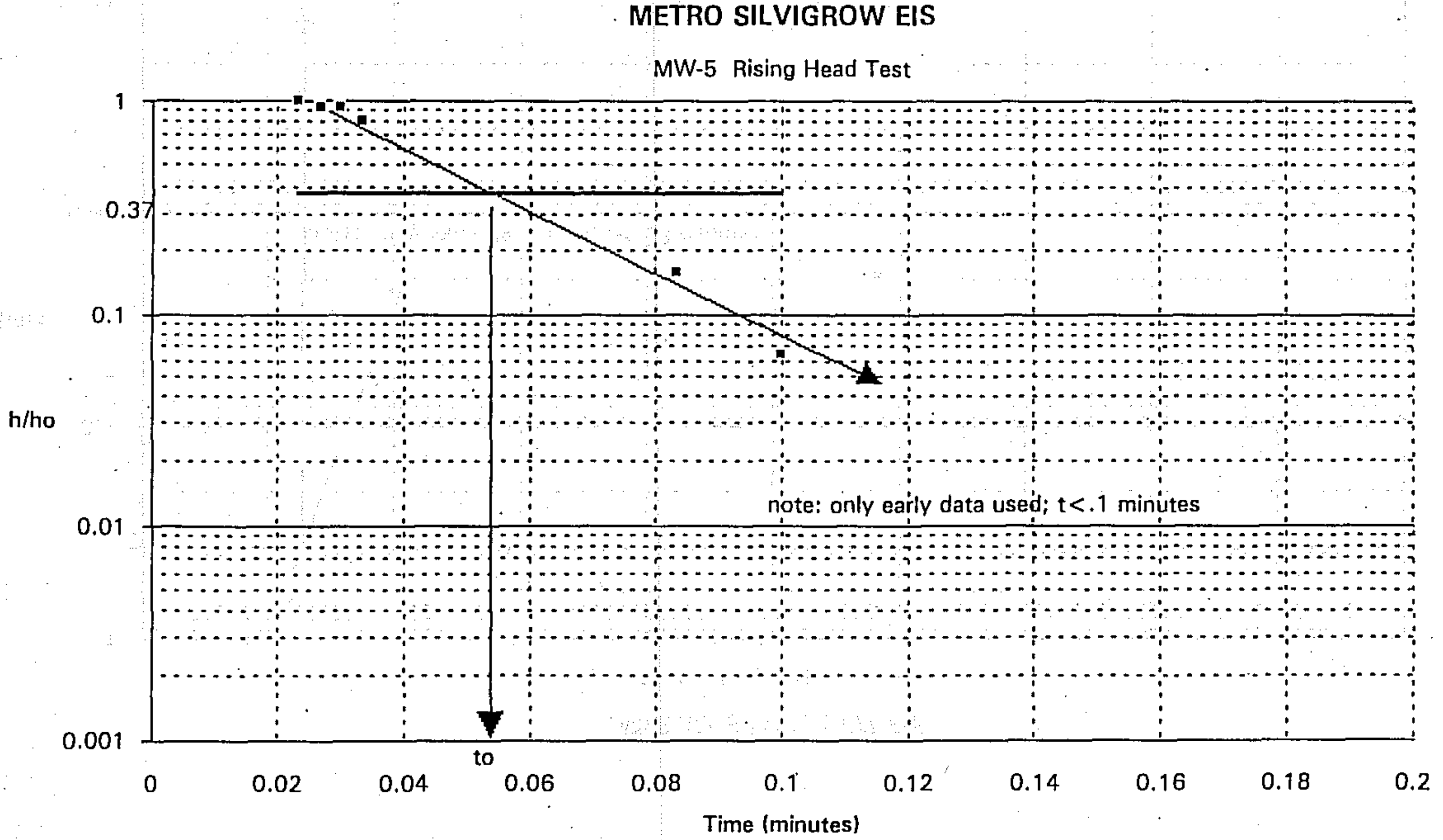
ASSUMPTIONS:
1) UNCONFINED
2) HOMOGENEOUS, ISOTROPIC, INFINITE MEDIUM

METRO SILVIGROW EIS

MW-5 Failing Head Test



note: only early data used; t < .03 minutes


METRO SILVIGROW EIS
MW-5 Rising Head Test
1
0.37
0.1
0.01
0.001
h/ho
to
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
Time (minutes)
note: only early data used; t<.1 minutes

Page 2 of 3
Job No. 90131
Date 4-17-91
Made by DJH
Ck'd by PFD

Project Silvergrav
Calculations for

MW-7

FALLING HEAD

$r = .167$ FEET
$R = .75$ FEET
$L = 10$ FEET
$t_0 = .025$ MINUTES

$$K = \frac{r^2 \ln(L/R)}{2Lt_0}$$

$$= \frac{.167^2 \ln(10/.75)}{2(10)(.025)}$$

$$= .144 \text{ ft/MIN}$$

$$\boxed{= .073 \text{ cm/SEC}}$$

FROM SLUGTST
= .075 ft/MIN
= .038 cm/SEC

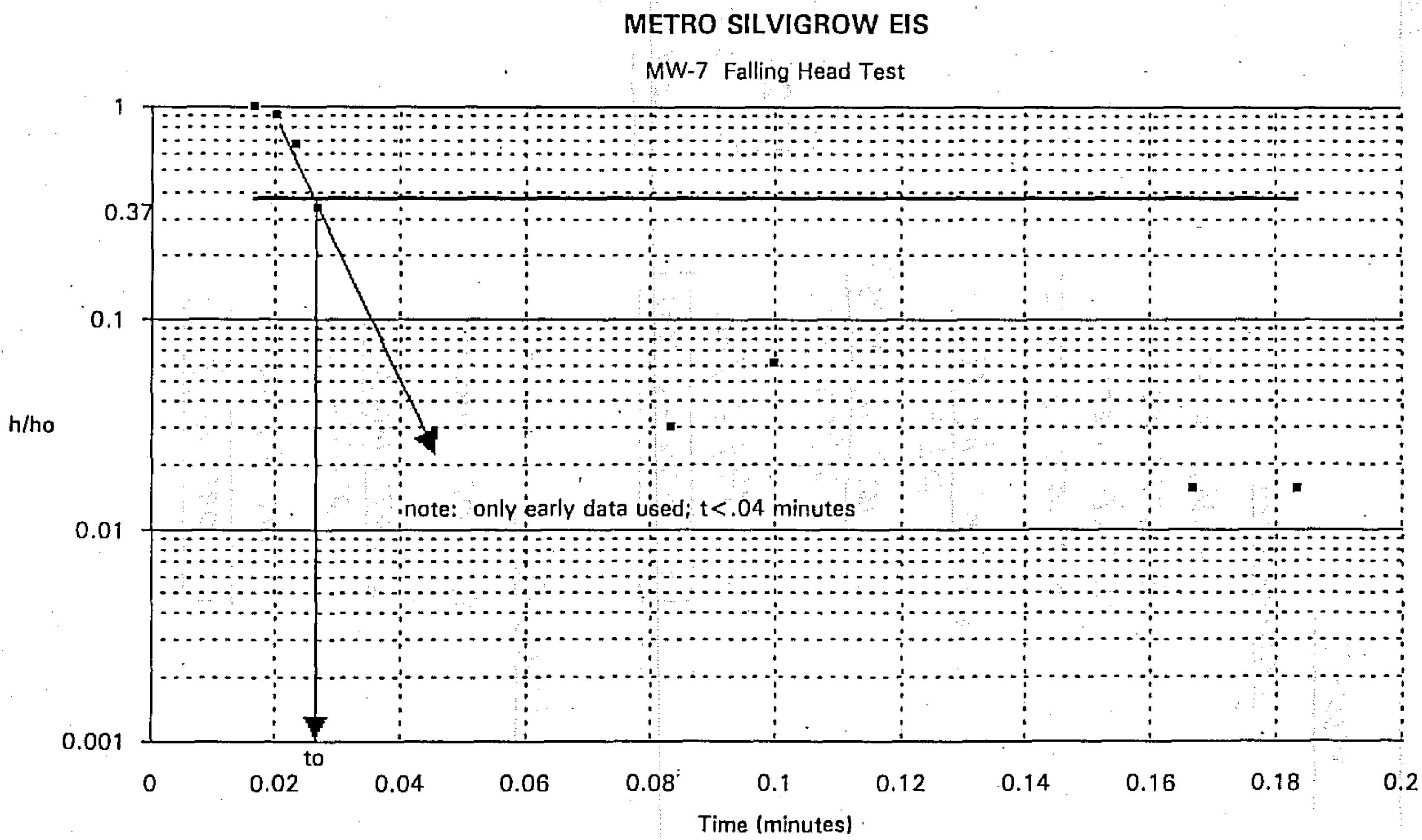
RISING HEAD

$t_0 = .02$ MINUTES

$$K = \frac{.167^2 \ln(10/.75)}{2(10)(.02)}$$

$$= .18 \text{ ft/MIN}$$

$$\boxed{= .092 \text{ cm/SEC}}$$



METRO SILVIGROW EIS

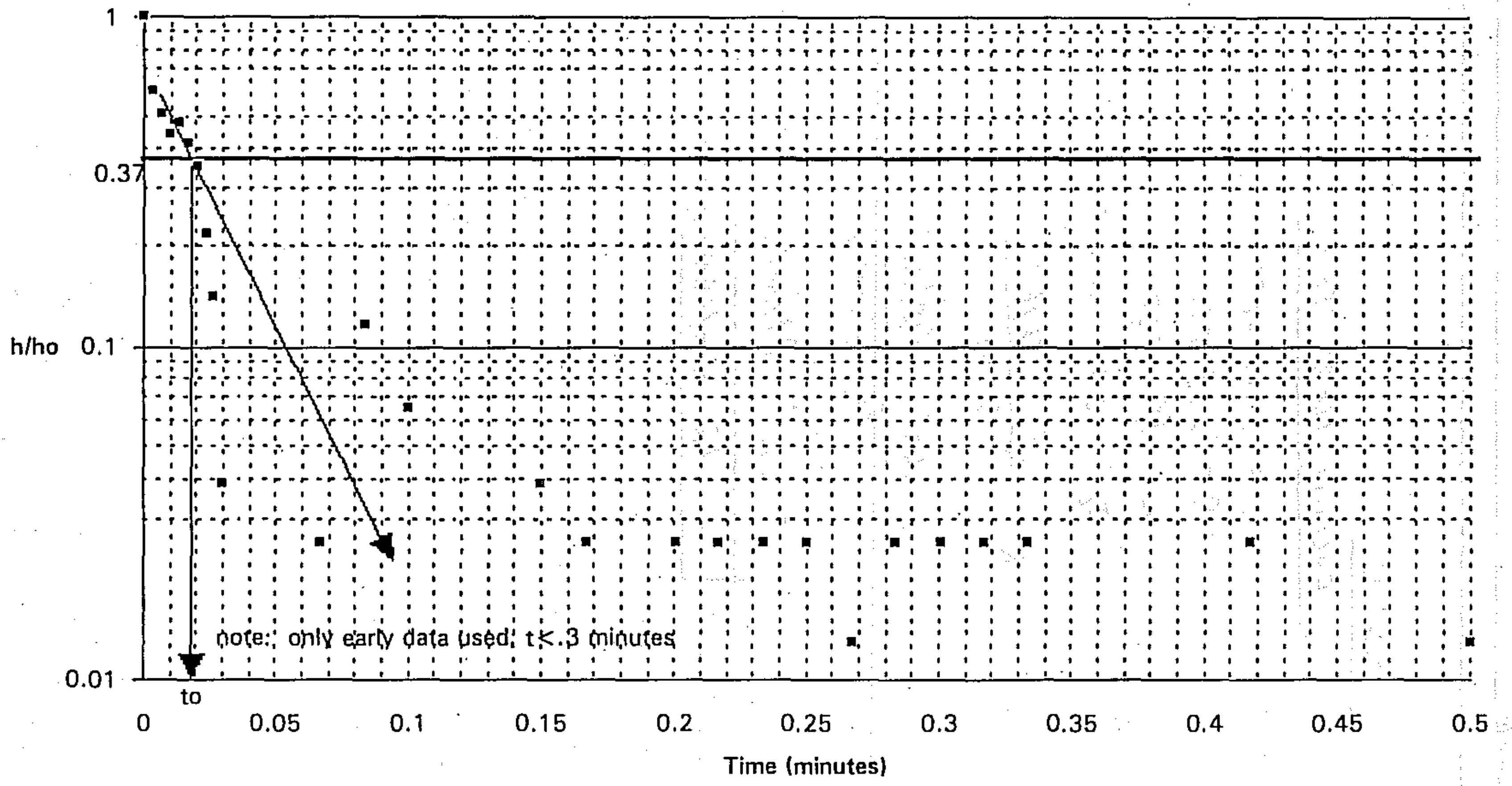
MW-7 Falling Head Test

note: only early data used; t<.04 minutes

MW7RH.XLC

METRO SILVIGROW EIS

MW-7 Rising Head Test



Page 3 of 3
Job No. 90131
Date 4-17-91
Made by DJH
Chkd by: DED

Project
Calculations for

MW-9

FALLING HEAD TEST

$r = .167$ FEET
$R = .75$ FEET
$L = 10$ FEET
$t_0 = .015$ MINUTES

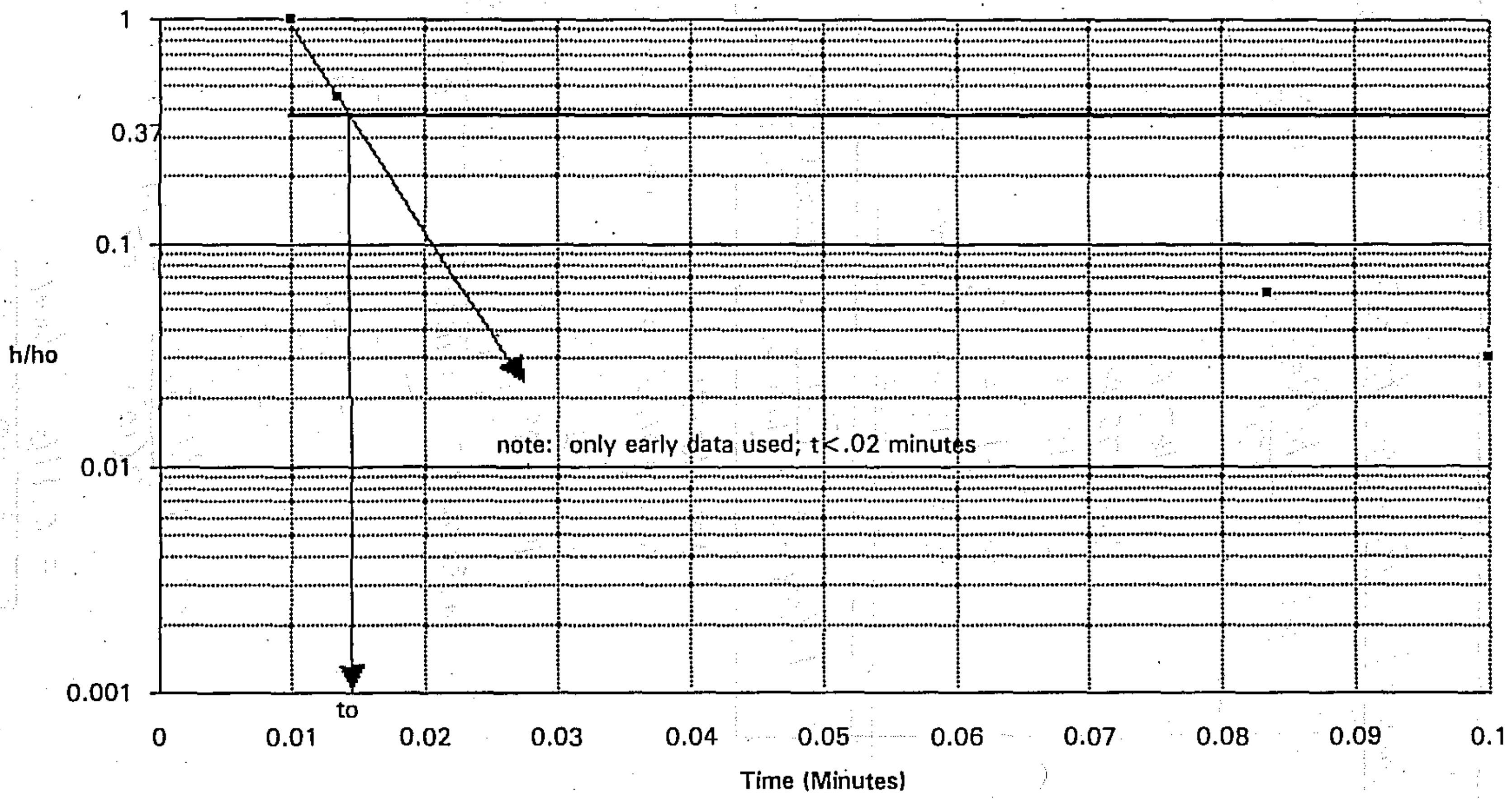
✯ ONLY CONTAINED 2 GOOD DATA POINTS

$$K = \frac{r^2 \ln(L/R)}{2 L t_0}$$

$$= \frac{.167^2 \ln(10/.75)}{2(10)(.015)}$$

$= .24$ ft/MIN

$\boxed{= .12 \text{ cm/SEC}}$



METRO SILVIGROW EIS

MW-9 Falling Head Test

Page 1 of 4
Job No. 9[illegible]1
Date 5/14/91
Made by DJH
chkd by PFD

Project Sturgeon
Calculations for K from Slug Tests (Bouwer & Rice)

MW-1 RISING HEAD

$$K = \frac{r_c^2 \ln(R_e/r_w)}{2L} \quad \frac{1}{t} \ln \frac{y_o}{y_t} \qquad \text{eq 1}$$

$r_c = .167$ ft
$r_w = .75$ ft
$L = 10$ ft

$y_o = 1$ ft
$t = .017$ min
$y_t = .4$ ft
} from graph

$$\ln(R_e/r_w) = \left[\frac{1.1}{\ln(H/r_w)} + \frac{A + B\ln[(D-H)/r_w]}{L/r_w}\right]^{-1} \qquad \text{eq 2}$$

$H = 10$ ft
$\ln[(D-H)/r_w] = 4$ (VALUE OF D UNKNOWN ASSUME ~50

$A = 2$
$B = .25$
} FROM TYPE CURVES

$$\ln(R_e/r_w) = \left[\frac{1.1}{\ln(10/.75)} + \frac{2 + .25(4)}{10/.75}\right]^{-1}$$

$$= \left[.42 + .225\right]^{-1}$$

$$= 1.55$$

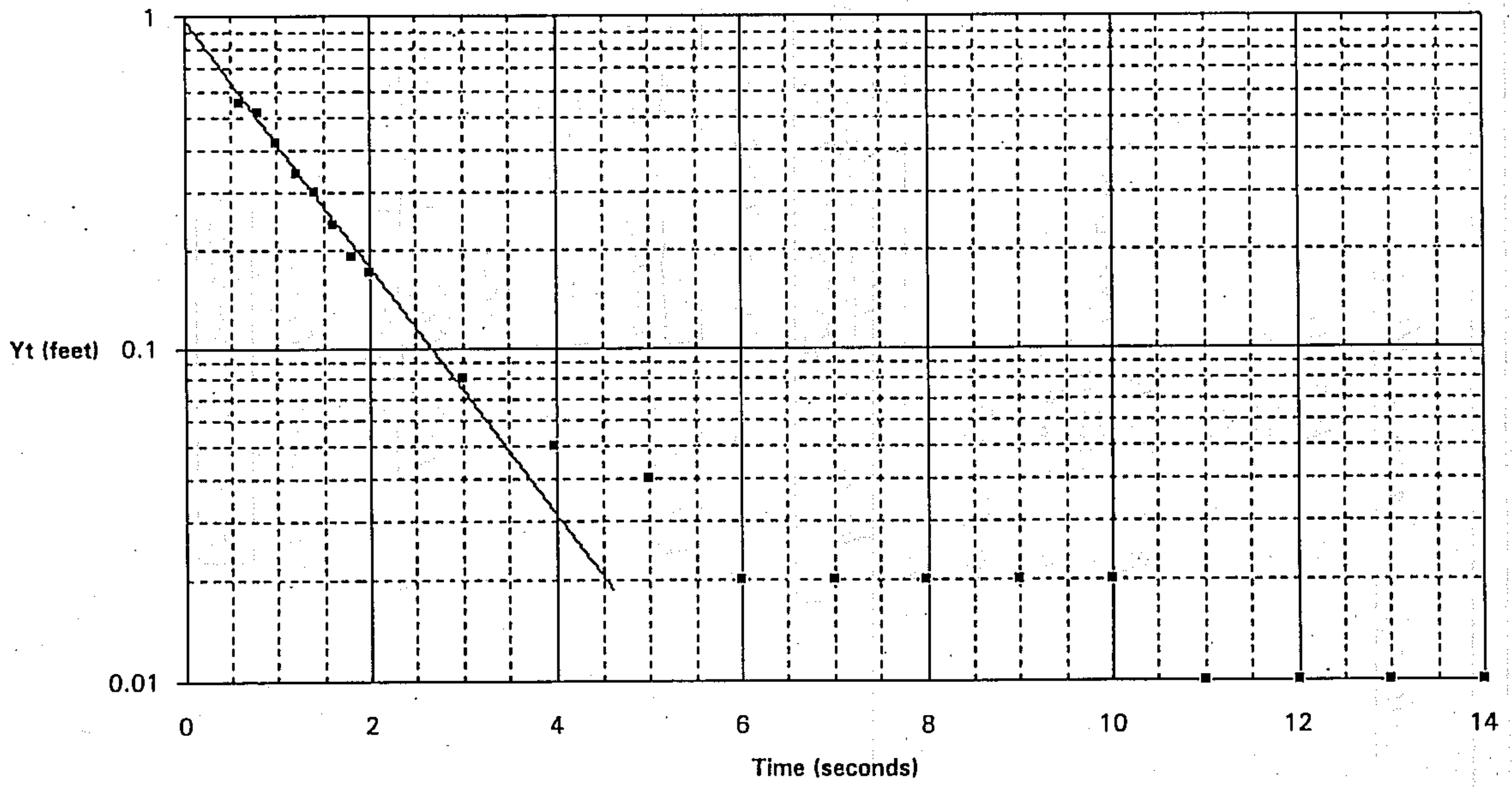
$$K = \frac{.167^2(1.55)}{2(10)} \quad \frac{1}{.017} \ln \frac{1}{.4}$$

$= 0.116$ ft/MIN

$\boxed{= 0.058 \text{ cm/SEC}}$

METRO SILVIGROW EIS

MW-1 Rising Head Test



Page 2 of 4
Job No. 90171
Project Sellingrow
Date 5/14/91
Calculations for K (Bouwer & Rice)
Made by DJH
Checked by PFD

MW-2 FALLING HEAD

$r_c = .167$ ft
$r_w = .75$ ft
$L = 10$ ft

$$\left.\begin{aligned} y_0 &= .77 \text{ ft} \\ t &= .33 \text{ min} \\ y_t &= .32 \text{ ft} \end{aligned}\right\} \text{FROM GRAPH}$$

$H = D = 10$ ft

$\therefore$ USE

$$\boxed{\ln(R_e/r_w) = \left[\frac{1.1}{\ln(H/r_w)} + \frac{C}{L/r_w}\right]^{-1} \quad \text{eq } 3}$$

$C = 1.5$ – FROM TYPE CURVE

$$\ln(R_e/r_w) = \left[\frac{1.1}{\ln(10/.75)} + \frac{1.5}{10/.75}\right]^{-1}$$

$$= [.425 + .1125]^{-1}$$

$$= 1.86$$

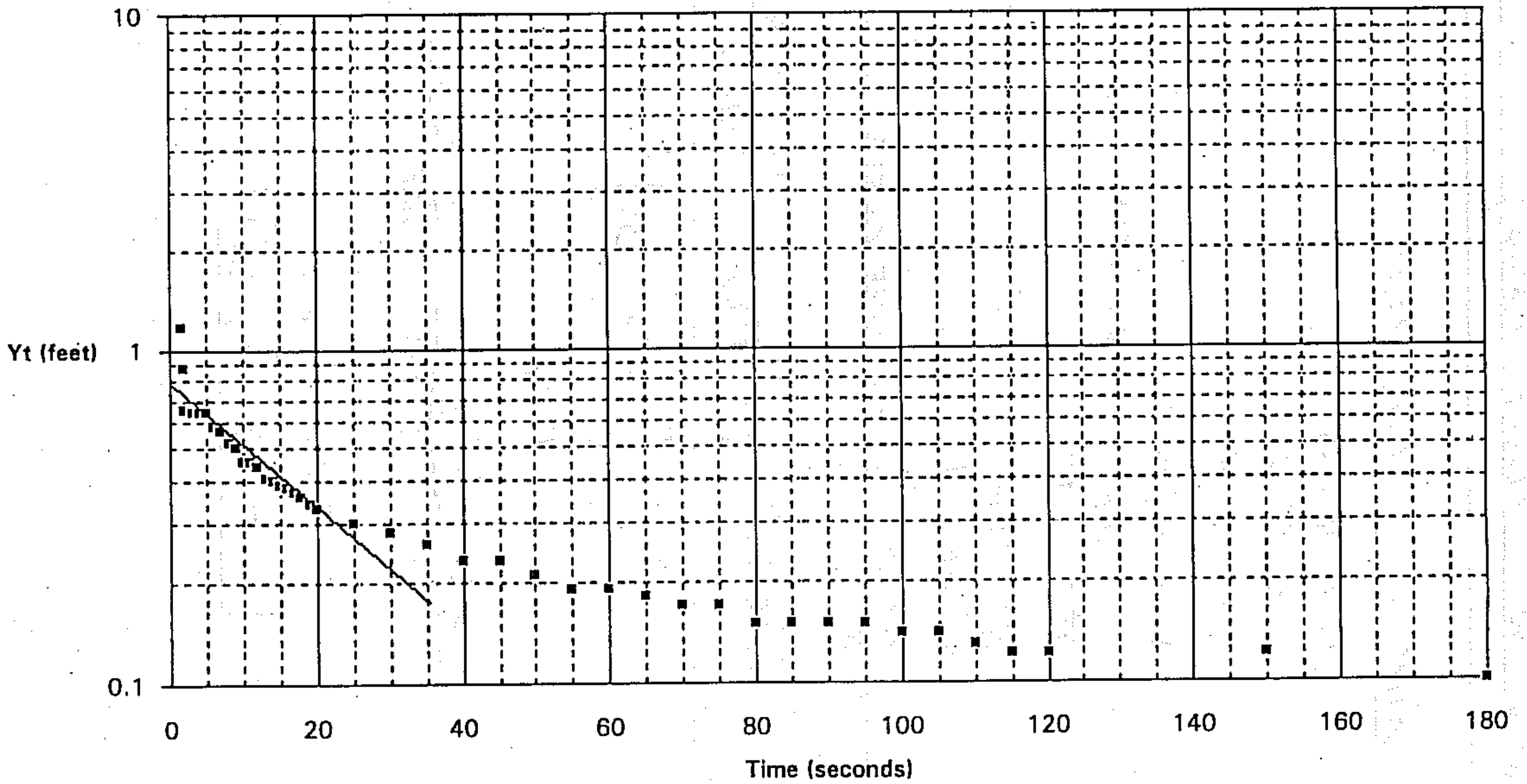
$$K = \frac{.167^2(1.86)}{2(10)} \frac{1}{.33} \ln \frac{.77}{.32}$$

$$= .007 \text{ ft/min}$$

$$\boxed{= .0035 \text{ cm/SEC}}$$

METRO SILVIGROW EIS

MW-2 Falling Head Test



HONG WEST & ASSOCIATES

Page 3 of 4
Job No. 9F131
Date 5/14/91
Made by DJH
Ck'd By: PFT

Project SILVIGROW
Calculations for K (Bouwer + RICE)

MW-4 RISING HEAD

$r_c = .167$ ft
$r_w = .75$ ft
$L = 10$ ft

$y_0 = 1.5$ ft
$t = .08$ min
$y_t = .1$ ft
} FROM GRAPH

$H = 19$ ft
$\ln[(D-H)/r_w] = 4$

$A = 2$
$B = .25$
} FROM TYPE CURVE

$$\ln(Re/rw) = \left[\frac{1.1}{\ln(19/.75)} + \frac{2 + .25(4)}{10/.75}\right]^{-1} \leftarrow eq\,2$$

$$= \left[.34 + .225\right]^{-1}$$

$$= 1.77$$

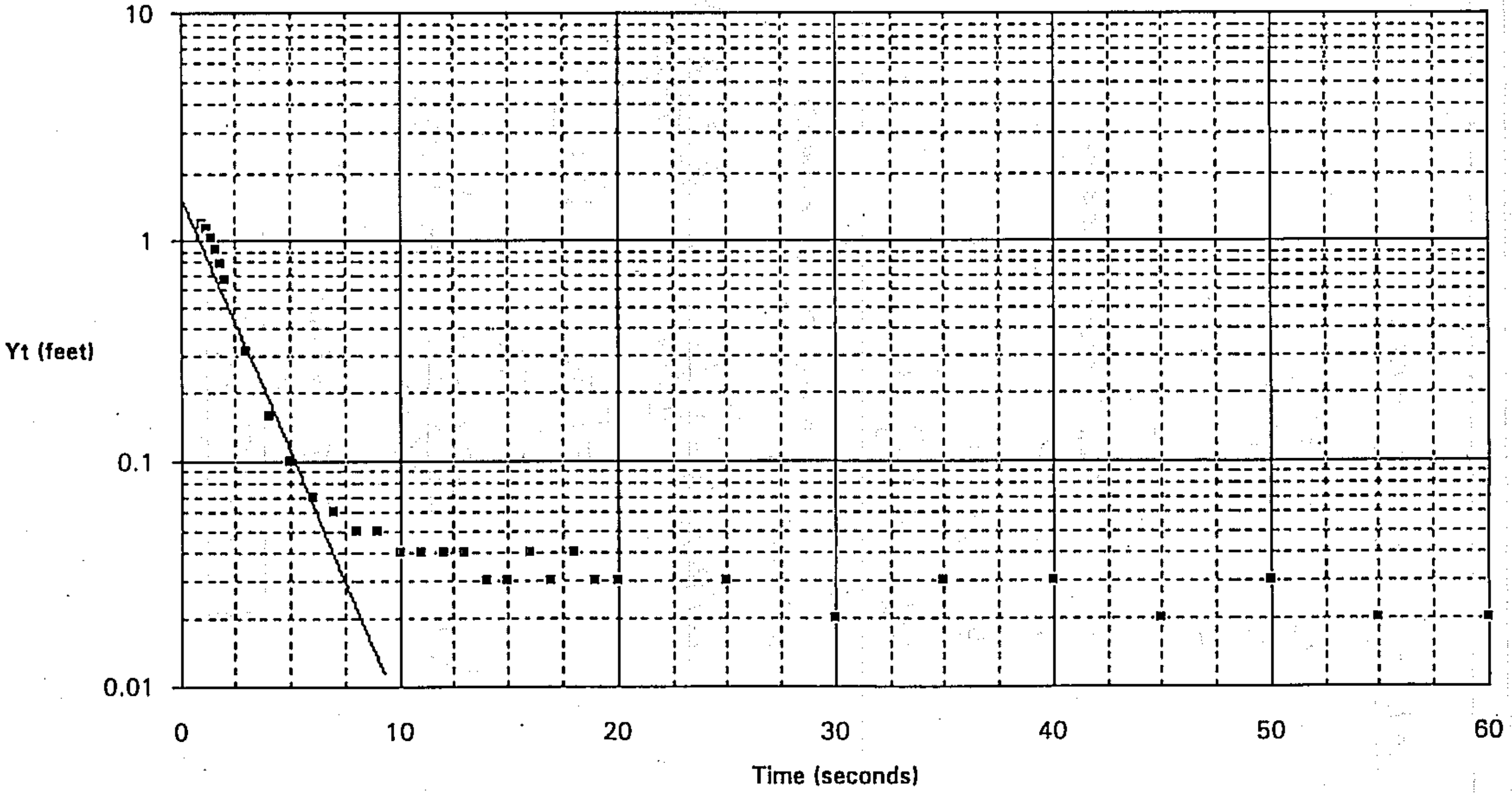
$$K = \frac{.167^2(1.77)}{2(10)} \quad \frac{1}{.08} \ln \frac{1.5}{.1}$$

$$= 0.08 \text{ ft/min}$$

$$\boxed{= 0.04 \text{ cm/SEC}}$$

METRO SILVIGROW EIS

MW-4 Rising Head Test



Page 4 of 4
Job No. 90131
Date 5/14/91
Made by DJH
chkd by PFD

Project [illegible]
Calculations for k (Bouwer & Rice)

MW-7 RISING HEAD

r_c = .167 ft
r_w = .75 ft
L = 10 ft

y_0 = .9 ft
t = .017 min } FROM GRAPH
y_t = .23 ft

H = 17 ft

$\ln[(D-H)/r_w] = 4$

A = 2 } FROM TYPE CURVES
B = .25

$$\ln(Re/rw) = \left[\frac{1.1}{\ln(17/.75)} + \frac{2. + .25(4)}{10/.75}\right]^{-1} \leftarrow eq\ 2$$

$$= [.35 + .225]^{-1}$$

$$= 1.74$$

$$K = \frac{.167^2(1.74)}{2(10)} \frac{1}{.017} \ln\frac{.9}{.23}$$

$$= 0.19 \text{ ft/MIN}$$

$$\boxed{= 0.099 \text{ cm/SEC}}$$

METRO SILVIGROW EIS

MW-7 Rising Head Test