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Evaluation of Perched Zone Interception and Possible Impacts to Wetland Hydrology Borrow Area 3 Sea-Tac Third Runway

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Prepared for
Port of Seattle

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EVALUATION OF PERCHED ZONE INTERCEPTION AND POSSIBLE IMPACTS TO WETLAND HYDROLOGY BORROW AREA 3 SEA-TAC THIRD RUNWAY

INTRODUCTION

Construction of the proposed Third Runway at Sea-Tac International Airport for the Port of Seattle requires the placement of a substantial embankment composed of fill materials (a mixture of gravel, sand, silt, and clay). The Port plans to obtain some fill materials from borrow areas located just to the south of the Airport (see Figure 1).

Excavation of fill materials from Borrow Area 3 will intercept part of the natural groundwater flow occurring in a shallow perched zone. Currently, part of the groundwater flow from this perched water-bearing zone supplies water to wetlands located in Area 3.

A recent report by Pacific Groundwater Group (PGG, 2000), commissioned by the Washington State Department of Ecology (Ecology), suggests that changes to perched groundwater levels supporting the wetlands "would likely have substantial impacts to wetland water flows, and possibly biota." This report explains why there will be no overall adverse impact on the hydrology of the wetlands.

SUMMARY

Drilling investigations in Borrow Areas 3 and 4 revealed the existence of a zone of shallow perched groundwater beneath Borrow Area 4, which extends into the northern half of Borrow Area 3 (Hart Crowser, 1999). The apparent direction of groundwater flow in the perched zone is from northwest to southeast. In conjunction with the Wetland Impacts Assessment of the Third Runway project (Parametrix, 1999b), the hydrologic role of this perched zone was identified as a source of continuous water supply to Wetland 29.

The concerns raised by Pacific Groundwater Group in their Hydrology Studies Report (PGG, 2000) appear to be based on early data and analyses performed when complete excavation of Borrow Area 3 was anticipated. The Port modified plans for the excavation of Borrow Area 3 to preserve all wetlands mapped by Parametrix (1999a) in the area. This revised mine plan was available to PGG, but was not reflected in some of the early analyses they also reviewed.

Data on water levels in the perched zone have been collected each month from eight surveyed monitoring well locations, for more than a year (see Tables 1 and 2). Groundwater elevation contour maps have been drawn based on these data, to determine groundwater flow directions. Based on discussion with Ecology on July 25, 2000, Hart Crowser developed a computer model of the perched zone to allow the effects of borrow area excavation to be better defined.

Mining of Borrow Area 3 north of the wetlands will result in the development of a seepage face where the perched zone is intersected in the western slope of the excavation (see Figure 6). Seepage modeling suggests that the top of the perched zone may be drawn down by as much as 6 feet at the seepage face. For comparison, annual seasonal fluctuation of the perched zone surface is on the order of about 2 to 3 feet (see Tables 1 and 2). Groundwater modeling indicates that drawdown at the seepage face may divert some groundwater flow away from the wetlands and into the new excavation. The maximum reduction in wetlands flow is calculated to be at most 20 percent, unless mitigation is provided.

The proposed mining plan for Borrow Area 3 included very simple mitigation to maintain the existing level of flow from the perched zone into the wetlands, by gravity drainage. The Port plans include a system to collect seepage from the perched zone north of the wetlands, and channel it southward to the wetlands in a swale following the perching layer. Groundwater modeling shows that seepage into and through the swale will provide recharge to the wetlands that is substantially greater (about six times as much) than the maximum loss of flow to the wetlands without mitigation. A portion of this seepage flow will be directed to the wetlands to mitigate any observed impacts, and thus permanently maintain the hydrology of the Borrow Area 3 wetlands after mining.

There will be no net adverse effects on the wetlands as a result of excavations in Borrow Area 3.

PURPOSE

The purpose of this report is to :

- Review the data available on the perched zone, including the water level monitoring data record, which now extends over a period in excess of 12 months;

- Present our understanding of the current groundwater conditions for the perched zone and the wetlands it supports;

- Evaluate the magnitude of potential impacts to the wetlands in the form of groundwater flow diversion into the proposed borrow excavation; and

- Provide additional technical evidence to support a plan for wetland flow mitigation, based on the collection and usage of groundwater seepage into the proposed borrow area excavation.

The groundwater flow model results (developed with Visual ModFlow™) presented in this report support Hart Crowser's previous assessment that was independently developed as a flow net analysis.

This report demonstrates that without mitigation there is likely to be a small impact to the flow of perched groundwater into the wetland (up to a 20 percent reduction in flowrate). The report also demonstrates that additional groundwater flows discharging from the perched zone which are separate from the existing flow to the wetland will be available for collection and diversion by swale into the wetlands. The net result of this mitigation is to avoid any adverse impacts to the hydrologic support system that maintains the wetlands in Borrow Area 3.

HYDROGEOLOGY OF PERCHED ZONE

Ground conditions in the borrow areas have been investigated by Hart Crowser and others, as detailed in Hart Crowser (1999).

The perched zone in Borrow Areas 3 and 4 was first identified in exploratory drilling conducted by Hart Crowser in 1998 and confirmed by review of drilling previously done by others (AGI, 1995). In recognition of the perched layer and the possible impacts of borrow excavation, Hart Crowser drilled four additional borings along the western side of Borrow Area 3 in 1999, expressly to examine and characterize groundwater conditions in the perched zone. Borings were completed as monitoring wells in the perched zone, and water levels have been measured every month since completion. Logs of borings in Borrow Areas 3 and 4 are presented in Hart Crowser (1999).

What is the Perching Layer?

The perching layer consists of a layer of till-like gravelly, sandy silt. It appears to have been formed as the result of a localized glacial advance during an overall period of recession, when a thin layer of till was mantled over the ground surface existing at that time. Borings encountered a water-bearing zone above this till-like unit where it was present in parts of Borrow Areas 3 and 4. Elevation contours for the top of the perching layer are shown on Figure 2.

The perching layer is not present in the central-southern part of Borrow Area 3, where the existing ground level is below the projected elevation of the perching layer. It has likely been removed by erosion/excavation in this area. To the south, the perching layer appears to thin out, and was not present in boring A3-B13-99. The perching layer is present in boring A3-B8-98, but moisture observations during drilling suggest the perched zone is dry at this location.

Groundwater Flow Characteristics of the Perched Zone

The perched zone appears to be sustained by area-wide recharge occurring as deep percolation of precipitation that infiltrates through the ground surface in the borrow areas and adjacent suburban areas to the west. The downward percolation of this water is impeded by the presence of the perching layer, which acts hydrologically as an aquitard, with a lower permeability than the overlying recessional sands and gravels by virtue of its silt/clay content and degree of compaction. A portion of this water continues to percolate downward through the aquitard, to recharge the underlying shallow regional aquifer; the remainder ponds on top of the aquitard, to form a saturated zone that sustains lateral groundwater flow over the surface formed by the perching layer.

The perched zone extends across Borrow Area 4 and down into Borrow Area 3. Lateral flow in the perched zone is controlled in part by the topographic shape and elevation of the perching layer. Its surface dips gently to the east, and more steeply to the south, with the result that groundwater flow moves in these directions (see Figure 3).

No surface expression of groundwater discharge from the perched zone has been mapped in the eastern part of Borrow Area 3. The perching layer appears to become thinner in this direction, and it is inferred that most of the perched groundwater flow moving eastward percolates downward to the underlying shallow aquifer in this area. Percolation may occur through the thinner perching layer, or through "windows" that may have been eroded into the eastern edge of the perching layer.

Water levels have been monitored in eight wells completed in the perched layer, with readings taken on a monthly basis for the past fourteen months. The monitoring data are listed in Tables 1 and 2.

Seasonal water level changes observed to date range between 2 and 3 feet overall. Table 3 shows minimum, average, and maximum water levels observed over the last 12 months.

Groundwater flow directions are based on contouring of these average water table elevations, as shown on Figure 3. Groundwater flow directions are indicated by flow lines drawn perpendicular to these contours.

PGG's report commented on Hart Crowser's use of soil moisture observations as part of the basis for determining groundwater flow direction.

Such observations were used in the initial stages of our investigation (in 1998) to confirm and extrapolate the presence and lateral extent of the (previously unidentified) perched zone. This initial interpretation was validated by confirmatory wells drilled in 1999 and subsequent monitoring of the surveyed wells. The soil moisture data corroborate the later water level data obtained from surveyed monitoring wells, which are the primary indicators for determining groundwater flow directions.

How the Perched Zone Sustains Area 3 Wetlands

To the south, the lowest elevations of the perching layer occur in the area behind Wetland 29. It appears from the borehole logs that the surface of the perching layer may form a trough in this area. Groundwater flow from the perched zone is in part concentrated in this area as a result of topographic control, the point forming a "sink" of lower elevation than the rest of the perching layer.

Flow appears to daylight in this area and is attributed as a major factor sustaining the presence of a wetland on the existing slope in this area. The location of Wetland 29 and the low spot or trough in the perching layer is depicted on Figure 4, which is a cross section drawn through the borings along the western side of Borrow Area 3. The cross section is extended northward into Borrow Area 4 to demonstrate the lateral continuity with perched conditions encountered there.

Pacific Groundwater Group (2000) performed an independent interpretation of the data, indicating that water moves to the wetlands "from generally the northwest," and they go on to state that there is "considerable uncertainty about the precise direction." PGC provides no data or examples of this uncertainty, or any other information, which suggests that their analysis was based on review of the early, incomplete data set.

The surveyed water levels and other hydrogeologic evidence show that flow is from the northwest. (The level of uncertainty is consistent with any interpretation of flow direction that is based on water levels measured consistently and repeatedly over 12 months from a set of eight surveyed monitoring wells.)

Groundwater Modeling

To simulate the groundwater flow regime in the perched zone, a numerical groundwater flow model was assembled using Visual ModFlow™. The model was assembled to represent the existing flow system depicted by the perched zone groundwater contours shown on Figure 3, with base elevations defined by the top of the perching layer shown on Figure 2. The modeled area of interest extended westward to an assumed water divide at a distance of 1,000 feet west of Borrow Area 3.

Model Characteristics. The general characteristics of the ModFlow model are as follows:

- Type of Simulation: Steady state (average conditions);
- Grid spacing: 100 feet by 100 feet;
- Number of Rows: 24;
- Number of Columns: 22;
- Number of Layers: 3:
  - Upper Layer: Perched Zone (Aquifer);
  - Middle Layer: Perching Layer (Aquitard);
  - Lower Layer: Unsaturated zone below perching layer;
- Hydraulic Conductivities:
  - Perched Zone:
    - Horizontal, $K_{x,y}$ = 11.2 ft/d (4 x 10^{-3} cm/sec);
    - Vertical, K_z = 0.56 ft/d (2 x 10^{-4} cm/sec);
  - Perching Layer:
    - Horizontal, $K_{x,y}$ = 0.028 ft/d (1 x 10^{-5} cm/sec);
    - Vertical, K_z = 0.00134 ft/d (4.7 cm/sec);
- Applied Recharge: 0.00365 ft/d = 16 inches per year;

- Upgradient Boundary: Fixed head, 300 feet elevation on west side;

- Downgradient Boundary: Drain cells with drain elevations set at 1 foot above the top of the perching layer; drain conductance = 100 ft^2/d;

- Lower boundary: Constant head, 1 foot above base of aquitard (see below).

Notes. Flow in the model occurs from the upgradient fixed-head boundary in the west, to the series of drain cells in the east and south. Flow is controlled in part by the elevation of the drain cells which reflect the local elevation of the perching layer. Recharge applied over the full area of the model provides an additional driving force for the groundwater flow.

The elevation of the perching layer varies on a cell-by-cell basis across the model, following the interpolated elevation contours presented on Figure 2. The layer is assumed to be 10 feet thick, and is assigned a uniform conductance (= conductivity divided by thickness).

Explicit modeling of the perching layer within a three-layer model allows its hydraulic function as an aquitard to be more accurately represented. Downward leakage through the aquitard is encouraged by applying a constant-head boundary condition in Layer 3 at the base of the perching layer. The constant head is set for each cell as the elevation of the base of the overlying aquitard, plus 1 foot. In this way, the amount of downward leakage occurring in the model should vary in proportion to the saturated thickness in the overlying perched zone.

The hydraulic conductivity for the perched zone is based on the geometric mean of values measured in slug tests performed in wells completed in the perched zone (Hart Crowser, 1999).

Calibration. The ModFlow model for existing conditions was calibrated against the average water levels observed in the monitoring wells (Table 3). Simulated water levels are generally within 1 to 2 feet of the measured average levels, which is reasonable for a model of this type. The results of the calibration are listed in Table 4.

Results. The results of the groundwater modeling for existing conditions are shown on Figure 5. The groundwater flow contours closely follow those interpolated from the monitoring well data (Figure 3), with the calibrated heads being similar to the recorded average water levels.

Flow lines have been added to the water table elevation contours on Figure 5 to represent the perched groundwater flow occurring to Wetland 29. In this simulation, the flow to the wetland totals about 2,000 ft^3/d.

Sensitivity. The sensitivity of the model was checked during the model calibration process, and the model was found to be relatively sensitive to the main parameters, especially the hydraulic conductivity of the perched aquifer, and the amount of recharge. The recharge was varied between 8 and 24 inches per year, with the model recalibrated in each case. With corresponding adjustments made to the hydraulic conductivity of the aquifer and the perching layer, broadly similar water-table configurations were obtained. However, flows from the wetlands were affected by a factor of about 20 percent.

This sensitivity analysis shows that seasonal changes in recharge rate likely cause fluctuations in flow to the wetlands on the order of ± 20 percent, (the same magnitude as the result of mining, discussed below).

EFFECTS OF BORROW AREA DEVELOPMENT

Proposed Plan for Borrow Area Excavation

The Port's plan for excavation of the borrow areas, including preservation of wetlands in Borrow Area 3, are shown on Figure 6. The plan shows no excavation will occur within the 50-foot setbacks established to provide protective buffers for the wetlands. The bulk of the excavation will occur in the northern half of Borrow Area 3. As excavation proceeds, the perched zone will be exposed in the northern and western cut slopes created within the excavation. Final slopes are shown on Figure 6.

Note that excavation in Borrow Area 4 will occur entirely above the perched water table. Consequently, the development of Borrow Area 4 will not intercept groundwater flowing in the perched zone.

How the Excavation Will Affect Groundwater Flow

As the perched zone becomes exposed in the borrow area excavation, seepage will occur from the zone into the excavation. The net effect of the excavation will be to move the current discharge point for the aquifer back to the west. This will shorten flowpaths, and reduce the hydraulic resistance to flow within the aquifer as a whole. The manifested result will be a drop in water levels at the edge of the excavation as a seepage face is developed where the excavation slope intersects the perched zone. This drop in water level will result in localized drawdown of the water table behind the slope, and the possibility that some of the flow going to the wetlands may be diverted into the new excavation. The magnitude of such diversion was evaluated by the modeling described below.

Groundwater Modeling

Hart Crowser used two groundwater models to study what will happen to the groundwater regime as a result of the borrow area excavation. We used a finite-element seepage model, SEEP/W™ (Geo-Slope, 1999) to examine the formation and height of the seepage face likely to occur on the excavation slopes. We then used the ModFlow finite-difference groundwater flow model as described above, to see how the effect of this drawdown at the seepage face. These model results are consistent with each other, and with the previously developed flow-net analysis.

SEEP/W Model. The SEEP/W model is a simple slice model oriented perpendicular to the excavation slope, so that it represents a slice running back into the perched aquifer. The model represents steady flow in an inclined perched zone, with a variform saturated thickness of 10 feet. For this case, we ignored recharge from above, and leakage through the underlying aquitard since they were assumed to be similar for both the "before" and "after" mining conditions.

Modeling Assumptions. We assumed a constant-head upgradient boundary, set back from the excavation by approximately 1,000 feet. The lateral hydraulic conductivity of the perched aquifer is set to 3×10^{-3} cm/sec in the model based on slug tests in the completed monitoring wells. The vertical conductivity was reduced by a factor of 10 to account for anisotropy.

The downgradient boundary condition applied on the cut slope of the excavation is atmospheric pressure with the hydraulic head set to equal the elevation head using special nodes in SEEP/W called "review nodes," to represent the seepage face.

Results. Creation of a seepage face on the excavated slope of the borrow area is estimated to lower water levels, leaving approximately a 4-foot-high seepage face (see Figure 7). Drawdowns resulting from the development of the seepage face on the cut slope are progressively less with increasing distance from the slope and will vary depending on saturated thickness.

ModFlow Modeling. The calculated seepage face height from the slice model was used in modifying the previously cited ModFlow model to simulate excavated post-mining conditions in the perched zone flowing into Borrow Area 3. All model parameters and assumptions remained the same as described earlier, except that part of the eastern drain-cell boundary was moved westward to simulate groundwater discharge from the final cut slope of the excavated borrow area. Drain cell elevations were adjusted to reflect the elevation of the perching layer at the location of the final excavation slope.

Results. The overall direction groundwater flow remains generally the same in the mined condition as it was prior to mining. A slight change in discharge location for part of the perched zone does have a small impact on the groundwater contours and flow lines for the perched aquifer, as shown on Figure 8 (compare with Figure 6).

As a result of the contour change, flow to the area of the wetland is slightly reduced in the post-mining condition, representing a potential impact to the wetland in the absence of mitigation. The modeling shows this decrease in average flow on the order of 20 percent (1,600 ft^3/d, down from 2,000 ft^3/d).

The model also provides the basis for calculating the discharge from the intercepted part of the perched zone which does not contribute to the existing flow to the wetlands. This totals about 2,400 ft^3/d from the northern and western faces of the main cut slope—approximately six times the estimated loss of the flow to the wetlands.

The mitigation plan for potential impacts to the wetlands is to take part of this seepage flow and direct it into the wetland(s) via gravity flow in a swale (see Figure 9). The modeling results demonstrate that substantially more groundwater flow can be collected as seepage than will be lost by diversion from the wetlands. The Port will be able to divert adequate seepage flow to the wetlands, to maintain existing pre-mining condition. About six times more flow is available than needed, which provides ample reserve capacity, if needed.

The groundwater modeling shows that drawdown impacts due to the development of a seepage face within the borrow area excavation will be limited to an area of 200 to 300 feet behind the excavation. Figure 10 shows a plot of water-table drawdowns in the perched zone (generated from the difference between contours on Figure 6 and Figure 8). Note that these drawdowns do not extend to the area of the wetlands. The modeling suggests that water levels in the area of the perched aquifer supplying water to the wetlands will not be substantially changed as a result of borrow area excavation.

USE OF THIS REPORT

This report has been prepared for the exclusive use of the Port of Seattle for specific application to the site and project discussed herein. We completed this work in accordance with conventionally accepted hydrogeologic and geotechnical engineering practices for the nature and conditions of work completed in the same or similar localities at the time the work was accomplished. We make no other warranties, express or implied.

We appreciate the opportunity to assist you on this project. Please call if you have any questions.

Sincerely,

HART CROWSER, INC.

DRAFT

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Senior Associate Hydrogeologist

MICHAEL J. BAILEY
Project Manager

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Table 1 - Water Level Data for Borrow Area 3

	A3-B14-99		A3-B15-99		A3-B16-99		A3-B17-99	
	Depth* in Feet	Elevation in Feet	Depth* in Feet	Elevation in Feet	Depth* in Feet	Elevation in Feet	Depth* in Feet	Elevation in Feet
Top of Monument	-0.28	293.28	-0.26	303.28	-0.61	346.63	-0.48	304.86
Measuring Point	0.00	293.00	0.00	303.02	0.00	346.02	0.00	304.38
Ground Level*	2.5	290.5	3.3	299.7	2.0	344.0	1.8	302.6
Top of Screen*	37.5	255.5	22.3	280.7	55.0	291.0	18.3	286.1
Bottom of Well*	42.5	250.5	27.3	275.7	60.0	286.0	23.3	281.1
Date: 12/28/94	87.3	#REF!	-	-	-	-	-	-
1/26/1995	86.6	#REF!	-	-	-	-	-	-
(ATD)	38.0	255.00	21.5	281.52	51.0	295.02	18.0	286.38
5/15/1998								
5/22/1998								
6/2/1998								
4/23/1999	37.75	255.25	21.81	281.21	50.6	295.42	18.25	286.13
4/27/1999	37.73	255.27	21.44	281.58	50.65	295.37	18.37	286.01
5/5/1999	37.87	255.13	21.66	281.36	50.76	295.26	18.59	285.79
6/14/1999	38.60	254.40	22.28	280.74	51.23	294.79	19.37	285.01
7/13/1999	39.01	253.99	22.85	280.17	51.82	294.20	19.88	284.50
8/13/1999	39.23	253.77	23.41	279.61	52.54	293.48	20.43	283.95
9/14/1999	38.08	254.92	23.88	279.14	53.16	292.86	20.97	283.41
10/13/1999	40.41	252.59	24.37	278.65	53.79	292.23	21.59	282.79
11/11/1999	41.05	251.95	24.62	278.40	54.23	291.79	22.02	282.36
12/10/1999	39.96	253.04	23.72	279.30	54.76	291.26	22.15	282.23
1/12/2000	39.39	253.61	23.40	279.62	54.78	291.24	21.61	282.77
2/15/2000	38.59	254.41	22.88	280.14	54.65	291.37	20.76	283.62
3/13/2000	39.35	253.65	22.38	280.64	54.20	291.82	19.90	284.48
4/12/2000	39.60	253.40	22.99	280.03	53.97	292.05	20.19	284.19
5/10/2000	40.11	252.89	23.43	279.59	53.92	292.10	20.62	283.76
6/21/2000	40.61	252.39	23.90	279.12	54.33	291.69	21.34	283.04
7/11/2000	40.92	252.08	24.21	278.81	54.51	291.51	21.71	282.67

Italics = Estimated
Depth* All depths are below measuring point (NOT below the ground surface)
- Indicates data not available.

Table 2 - Water Level Data for Perched Zone in Borrow Area 4

	A4-B1		A4-B4		A4-B5		A4-B6	
	Depth* in Feet	Elevation in Feet	Depth* in Feet	Elevation in Feet	Depth* in Feet	Elevation in Feet	Depth* in Feet	Elevation in Feet
Top of Monument	-0.50	392.84	-0.35	385.71	-0.30	371.26	-0.26	401.48
Measuring Point	0.00	392.34	0.00	385.36	0.00	370.96	0.00	401.22
Ground Level*	1.94	390.4	2.36	383.0	2.66	368.3	2.72	398.5
Top of Screen*	109.44	282.90	97.86	287.50	72.86	298.10	118.52	282.70
Bottom of Well*	119.44	272.90	108.06	277.30	83.11	287.85	128.72	272.50
Date: 12/28/94	100.2	290.2	-	-	-	-	-	-
1/26/1995	102.3	288.1	-	-	-	-	-	-
5/15/1998	-	-	-	-	-	-	-	-
5/22/1998	100.98	291.36	93.29	292.07	80.67	290.29	107.37	293.85
6/2/1998	100.70	291.64	92.98	292.38	80.43	290.53	106.92	294.30
6/15/1999	-	-	90.71	294.65	78.65	292.31	104.97	296.25
7/13/1999	-	-	91.09	294.27	78.80	292.16	105.23	295.99
8/13/1999	-	-	91.42	293.94	79.08	291.88	105.47	295.75
9/14/1999	-	-	91.82	293.54	79.28	291.68	105.80	295.42
10/13/1999	-	-	92.27	293.09	79.42	291.54	106.17	295.05
11/11/1999	100.20	292.14	92.60	292.76	79.75	291.21	106.61	294.61
12/10/1999	-	-	93.13	292.23	Dry	Dry	106.87	294.35
1/12/2000	-	-	93.48	291.88	80.56	290.40	107.15	294.07
2/15/2000	101.10	291.24	93.71	291.65	Dry	Dry	107.35	293.87
3/13/2000	101.03	291.31	93.58	291.78	80.72	290.24	107.23	293.99
4/12/2000	101.07	291.27	93.55	291.81	80.70	290.26	107.22	294.00
5/10/2000	101.01	291.33	93.46	291.90	80.69	290.27	107.21	294.01
6/21/2000	100.96	291.38	93.34	292.02	80.60	290.36	107.19	294.03
7/11/2000	100.95	291.39	93.34	292.02	80.62	290.34	107.17	294.05

Italics = Estimated
Depth* All depths are below measuring point (NOT below the ground surface)
- Indicates data not available.

Table 3 - Summary of Surveyed Water Levels

	Water Level Elevation in Feet		
Monitoring Well	**Minimum**	**Average**	**Maximum**
A3-B14-99	252.0	253.4	254.9
A3-B15-99	278.4	279.5	280.6
A3-B16-99	291.2	292.2	294.2
A3-B17-99	282.2	283.4	284.5
A4-B1-93	291.2	291.4	291.6
A4-B4-98	291.7	292.6	294.3
A4-B5-98	290.2	291.0	292.2
A4-B6-98	293.9	294.6	296.0

Table 4 - Results of ModFlow Calibration

	Water Level Elevation in Feet	
Monitoring Well	**Average**	**Modeled**
A3-B9-98	~265	266.57
A3-B15-99	279.5	280.68
A3-B17-99	283.4	285.95
A3-B16-99	292.2	290.95
A4-B6-98	294.6	295.20

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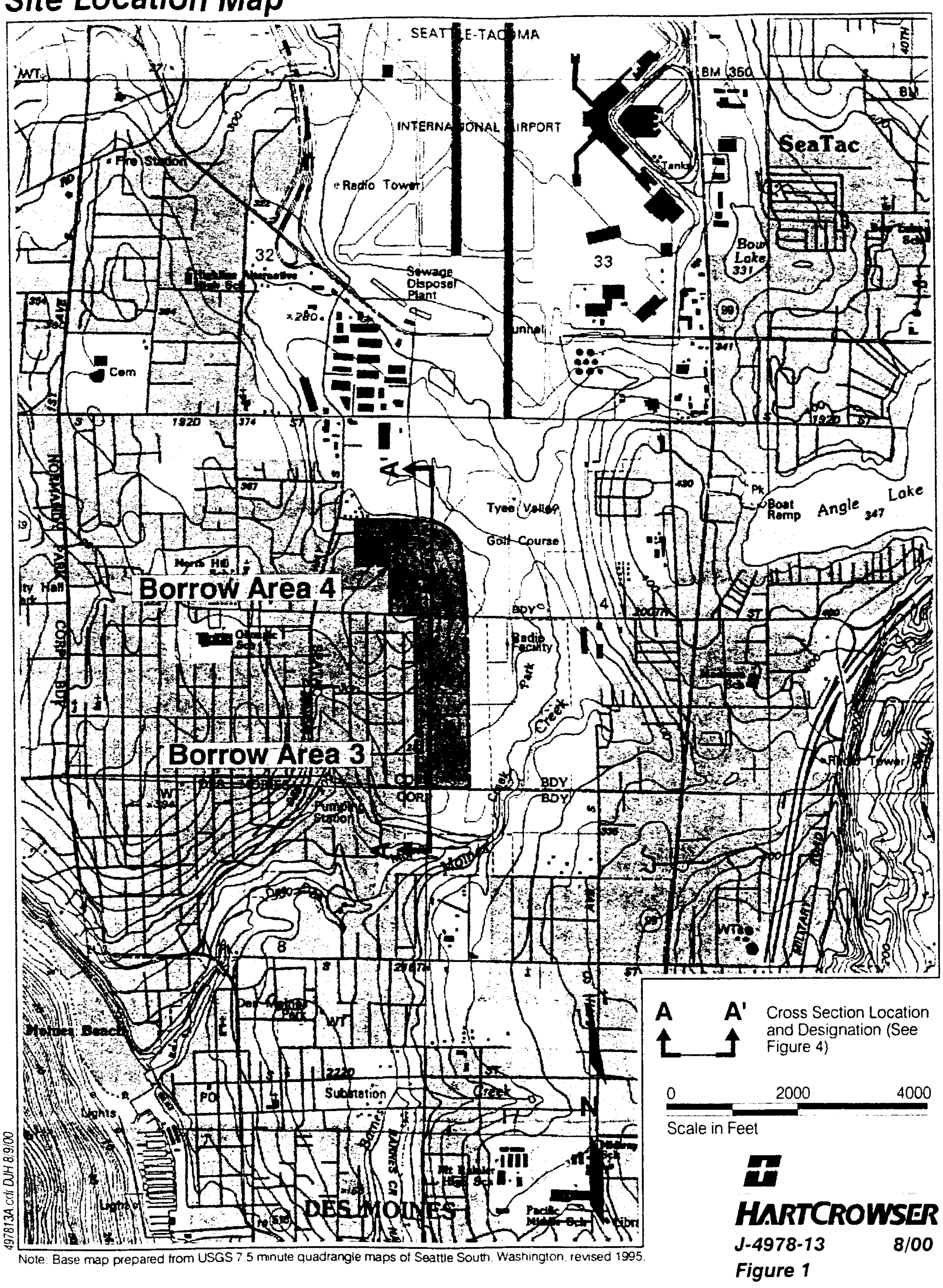
Site Location Map



Note: Base map prepared from USGS 7.5 minute quadrangle maps of Seattle South, Washington, revised 1995.

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Figure 1

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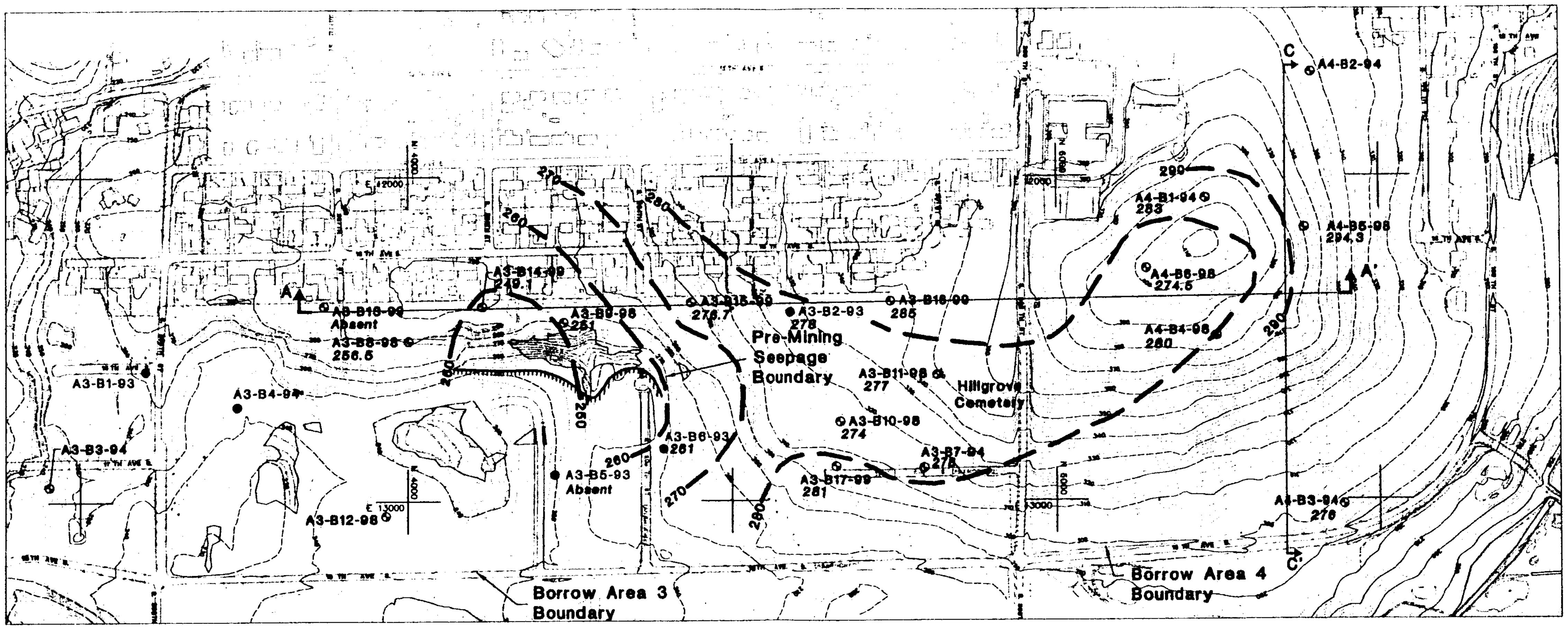
Elevation Contour Map of Top of Perching Horizon

Borrow Area 3 Perched Zone



Notes:
1) Base map from drawing provided by HNTB entitled "Borrow Areas 3 & 4 Grading Plan", dated April 13, 1998.
2) Wetland delineation prepared from drawing provided by Parametrix entitled, "W_062700.dwg", dated June 27, 2000.

● A3-B4-94 Boring Location and Number

⊙ A3-B10-98 Boring Location with Monitoring Well and Number

274 Spot Elevation of Top of Perching Horizon in Feet

280 Elevation Contour in Feet for Top of Perching Horizon

Wetland Location

AA' Cross Section Location and Designation

Inferred Outcrop of Perching Horizon

N

0 400 800

Scale in Feet

AR 045619

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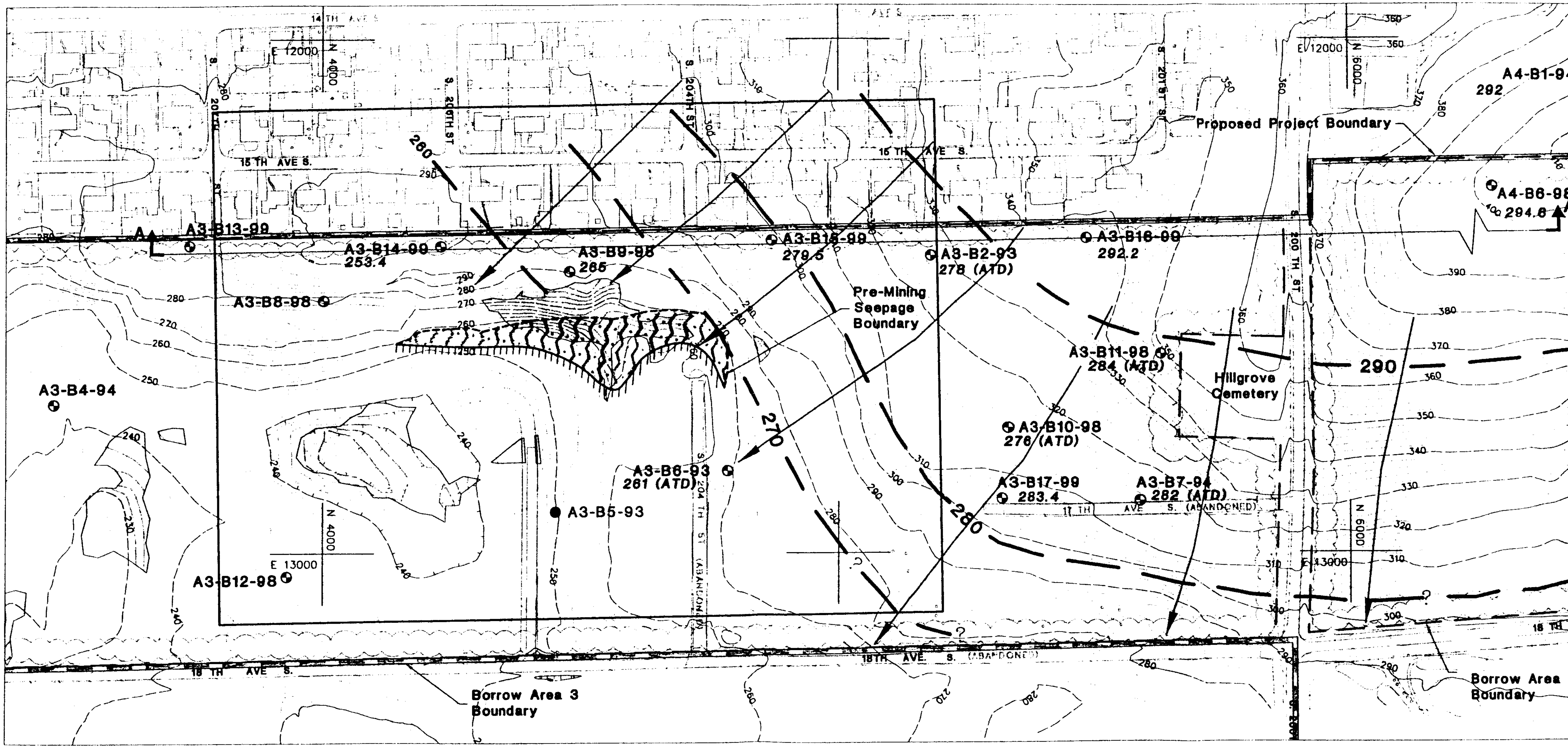
Figure 2

DJH 8/9/00 1"=400 (xref)see drawing file/charlie.pc2
49781301

Flow Net for Existing Conditions (Groundwater Elevation Contour Map)

Borrow Area 3 Perched Zone



Notes:
1) Base map from drawing provided by HNTB entitled "Borrow Areas 3 & 4 Grading Plan", dated April 13, 1998.
2) Wetland delineation prepared from drawing provided by Parametrix entitled, "W_062700.dwg", dated June 27, 2000.

● A3-B4-94	Boring Location and Number
⊗ A3-B10-98	Boring Location with Monitoring Well and Number
274	Surveyed Perched Zone Groundwater Elevation in Feet (Average over last 12 months or at time of drilling (ATD))
280	Perched Zone Groundwater Elevation Contour in Feet
←	Groundwater Flow Direction
	Wetland Location
AA'	Cross Section Location and Designation
	Inferred Seepage Face
	Inferred Outcrop of Perching Horizon

0 200 400
Scale in Feet

N

AR 045620

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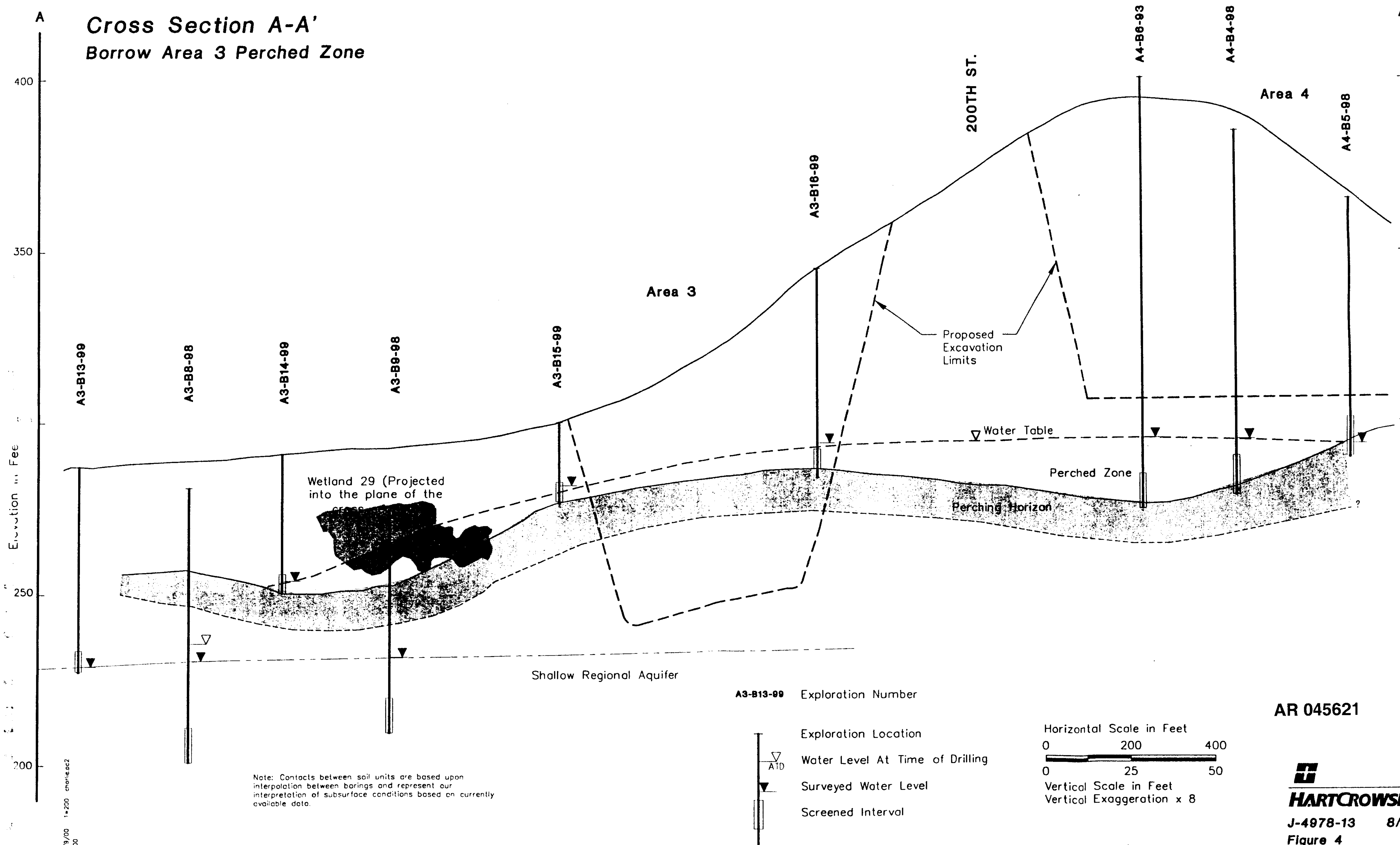
Figure 3

Dwn 8/9/00 1=200 (xref)see drawing file/charlie.pc2
49781302

Cross Section A-A'

Borrow Area 3 Perched Zone



Note: Contacts between soil units are based upon interpolation between borings and represent our interpretation of subsurface conditions based on currently available data.

AR 045621

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Figure 4

DJH 8/9/00 1=200 charlie.pc2
4978130O

DJH 8/9/00 1=1 chorhe.pc2 49781304

Modeled Existing Conditions

Borrow Area 3 Perched Zone

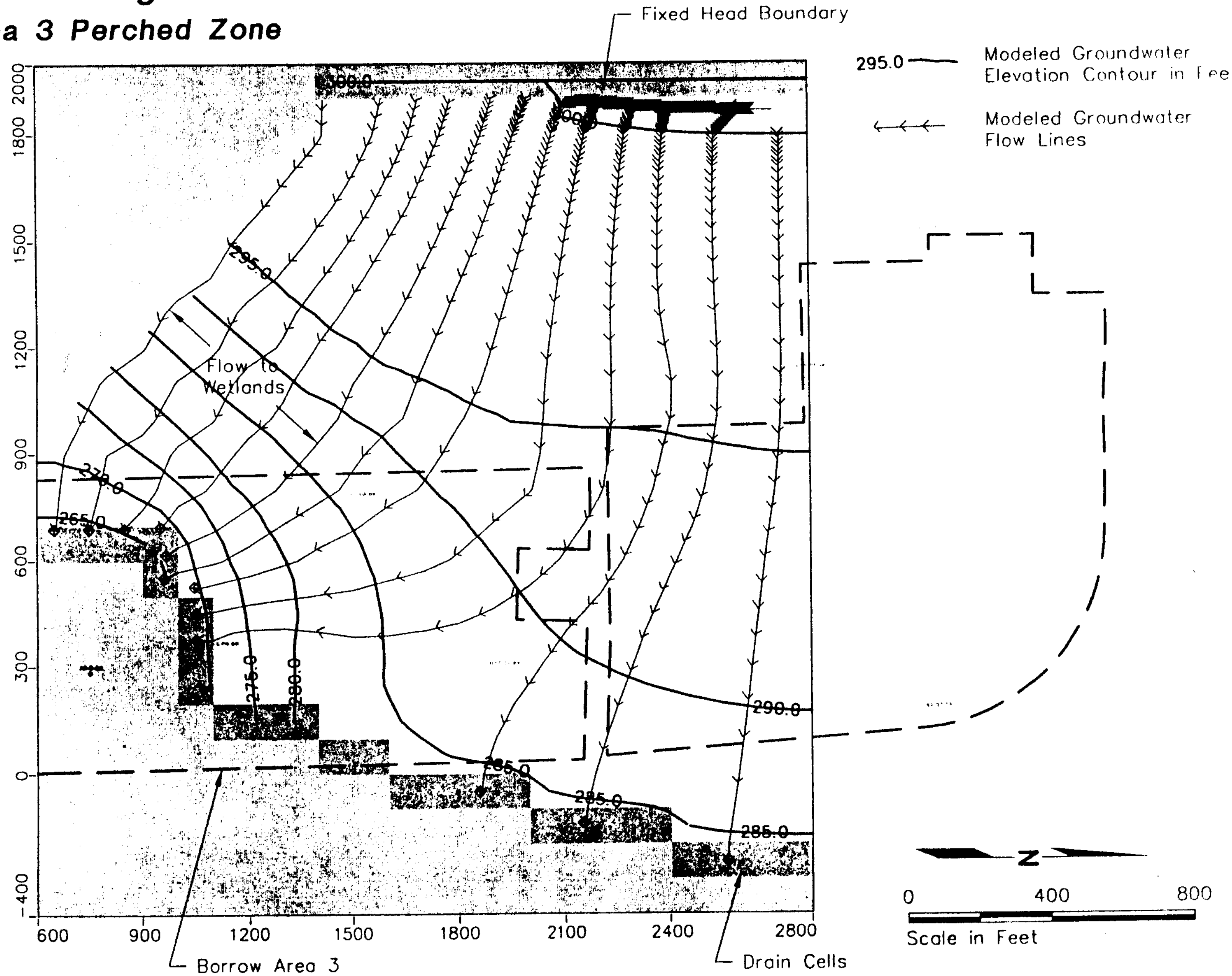

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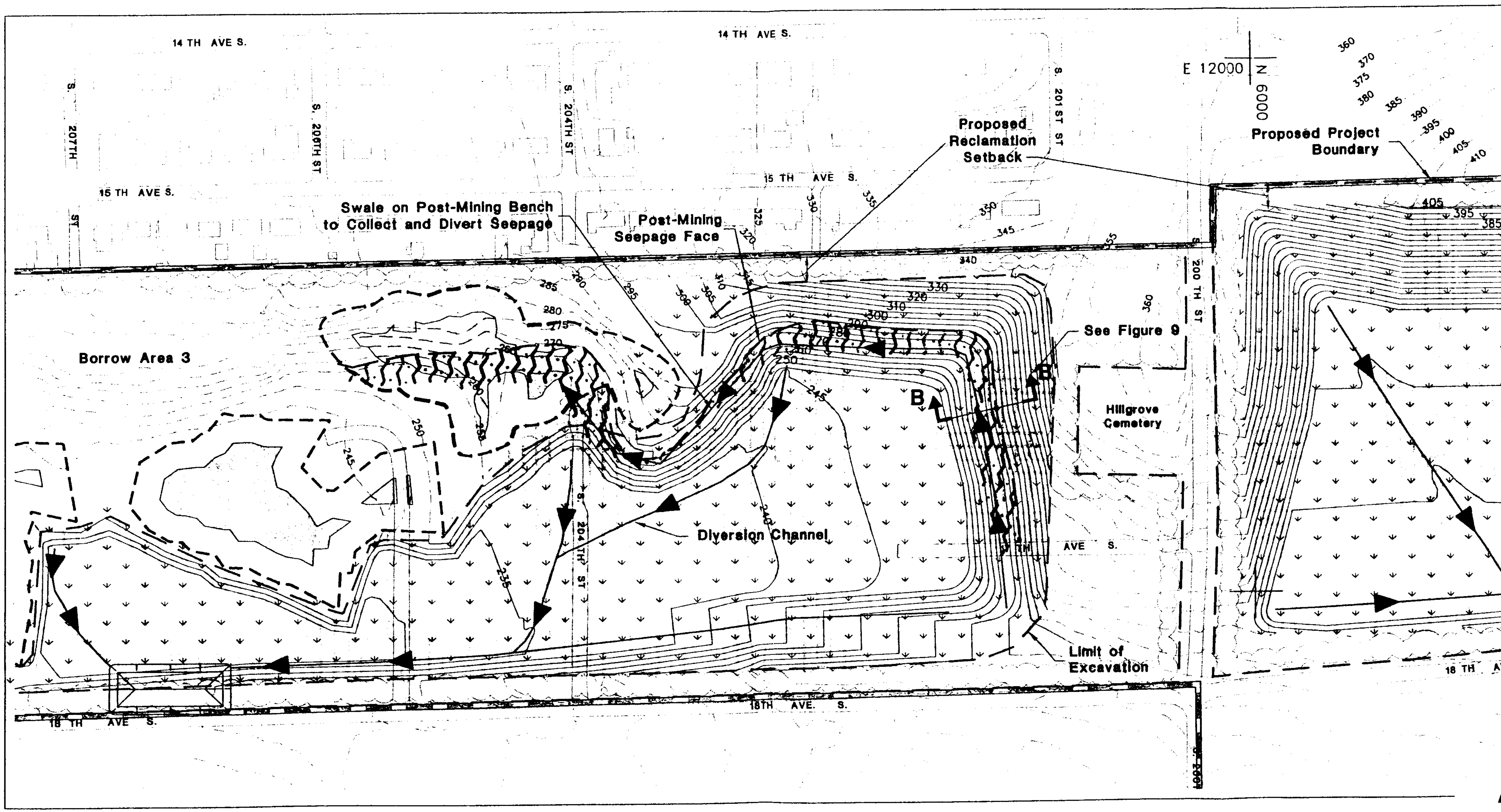
Figure 5

Exposure in Proposed Borrow Area Excavation

Borrow Area 3 Perched Zone



AR 045623

Notes:
1) Base map from drawing provided by HNTB entitled "Borrow Areas 3 & 4 Grading Plan", dated April 13, 1998.
2) Wetland delineation prepared from drawing provided by Parametrix entitled, "W_062700.dwg", dated June 27, 2000.

Wetland Location and 50-Foot Buffer

N

0 200 400

Scale in Feet

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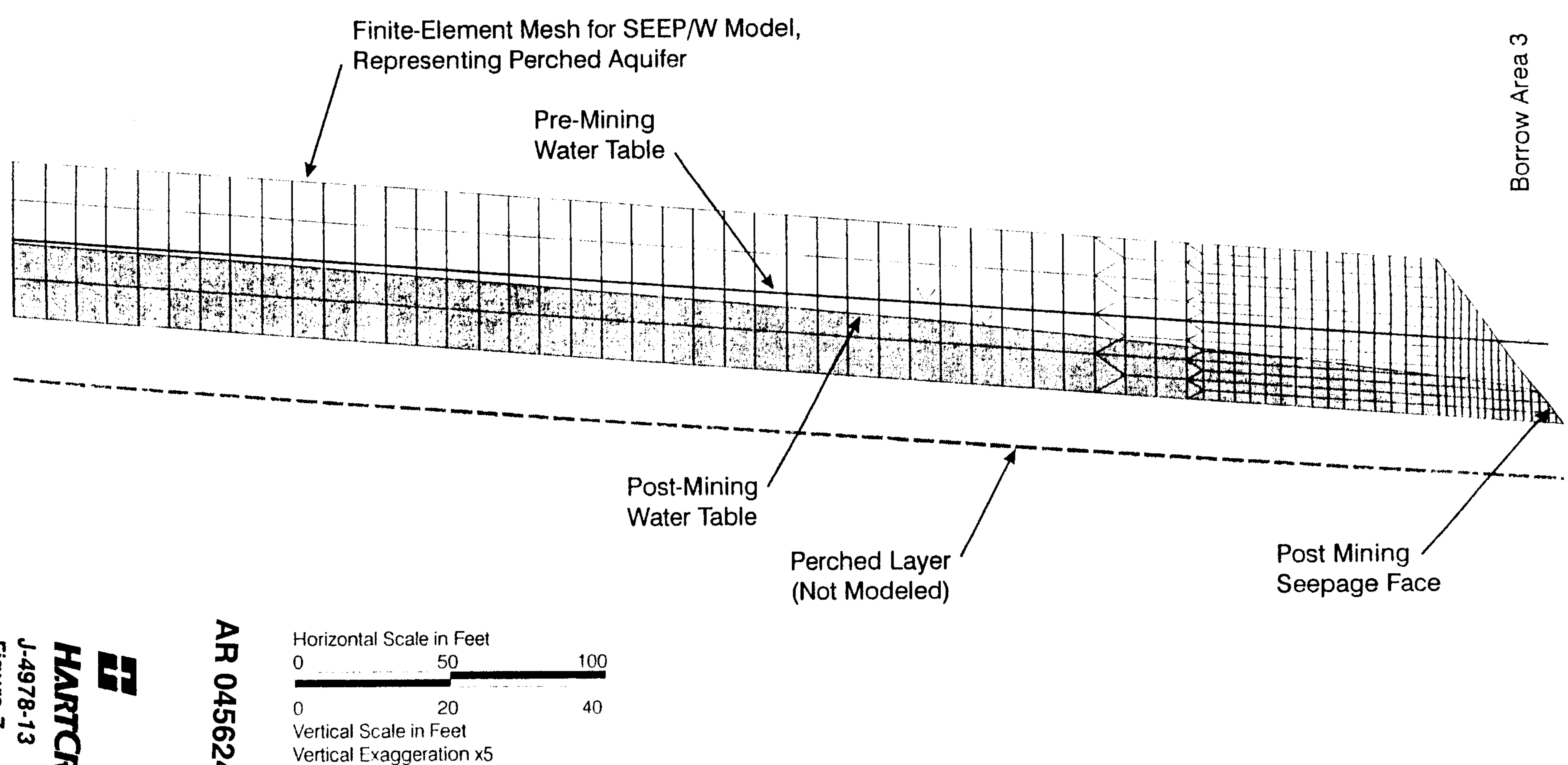
Figure 6

DJH 8/9/00 1=1 (xref)see drawing file/charlie.pc2
49781303

Development of Seepage Face
Borrow Area 3 Perched Zone



AR 045624

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Figure 7

DJH 8/9/00 497813B.cdr

DJH 8/9/00 1=1 charlie.pc2 49781305

Modeled Post-Mining Conditions

Borrow Area 3 Perched Zone

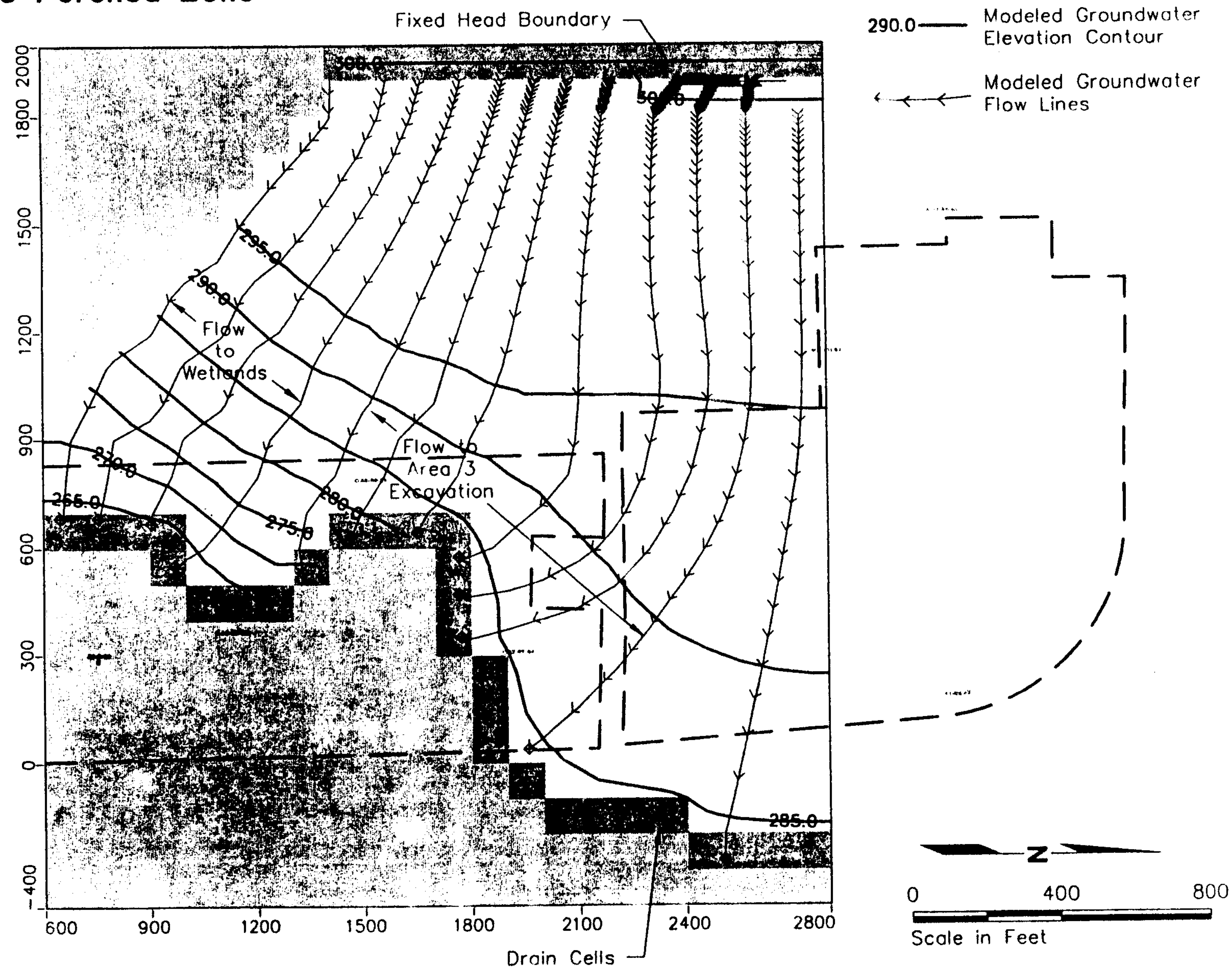

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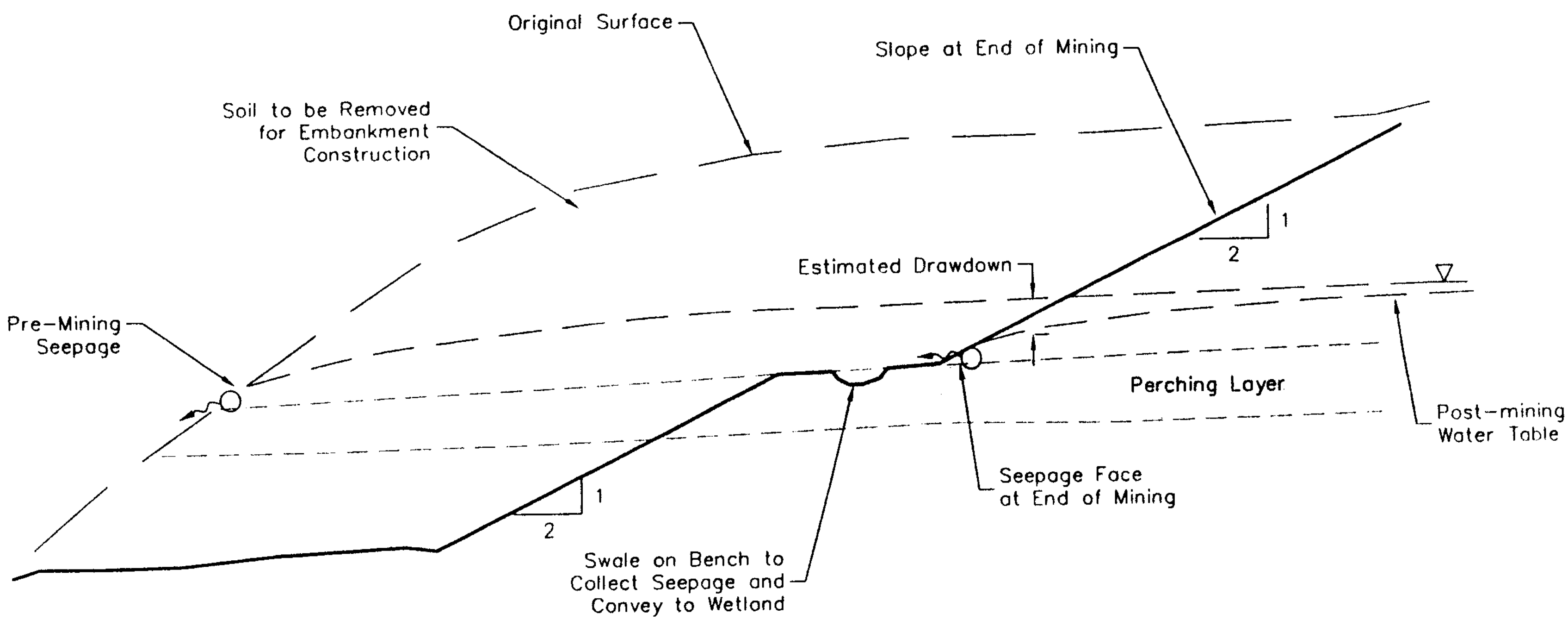
Figure 8

AR 045625

DJH 8/9/00 1=1 charlie-8.pc2 49781307.dwg

Swale to Collect Perched Zone Seepage (Cross Section B-B')

Borrow Area 3 Perched Zone



Not to Scale

AR 045626

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Figure 9

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