Pacific Groundwater Group

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Port of Seattle
Sea-Tac Third Runway
Embankment Fill Modeling

August 8, 2001

Pacific Groundwater Group
Seattle, Washington

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Sea-Tac Third Runway
Embankment Fill Modeling Report

Prepared for:

Port of Seattle
P.O. Box 68727
Seattle, WA 98168

Prepared by:

Pacific Groundwater Group
2377 Eastlake Avenue East, #200
Seattle, WA 98102
(206) 329-0141
www.pgwg.com

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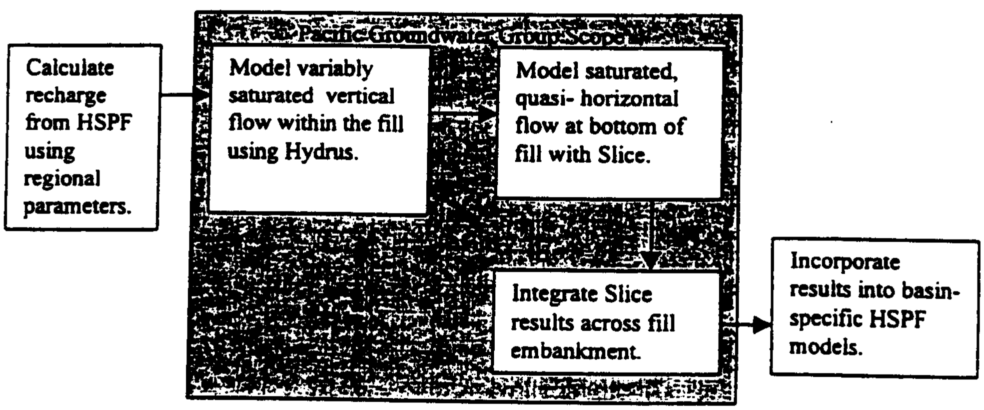
1. Introduction

The Port of Seattle ("the Port") proposes to place a fill embankment in an area west of the existing Sea-Tac Airport complex to build a third runway. Hydrologic and hydrogeologic studies conducted by Earth Tech, Inc., Pacific Groundwater Group (PGG) and others estimated groundwater and low-stream-flow impacts of the proposed fill embankment (Earth Tech, 2000; and Pacific Groundwater Group, 2000). As part of a more detailed study of low flow impacts to streams near the third runway, the Port contracted Parametrix, Earth Tech and PGG to reevaluate low-stream-flow impacts using a more detailed evaluation of hydrogeologic conditions and fill thickness in the embankment area. PGG's role in the more detailed evaluation was to model recharge and redistribution of water within the fill embankment. This is the final report for PGG's portion of that project. The overall project study area includes the Miller Creek and Walker Creek basins, whereas PGG's evaluation was limited to a smaller area of third-runway fill. PGG's evaluation was also limited to post-construction conditions, and did not attempt to simulate existing conditions. PGG's study results were used by the HSPF modeling team to evaluate low-stream-flow impacts in the two basins.

1.1 Scope and Approach

PGG's scope of work was authorized by the Port on May 1, 2001. PGG's scope involved reapplication of previously-developed Hydrus and Slice models to post-construction conditions within the proposed embankment as follows:



Input to the modeling process consisted of estimated daily groundwater recharge derived from precipitation data for a specific area of fill. Output consisted of the timing and magnitude of water movement through the shallow aquifer above the till and through the till for that same specific area. Recharge input was provided by HSPF modelers at AQUA TERRA Consultants ("Aqua Terra"), and output was provided to HSPF modelers at Aqua Terra and Parametrix as part of basin-wide simulations of post-construction conditions.

Output from PGG's combined Hydrus and Slice models ("Hydrus-Slice") was inserted into the regional HSPF simulations to replace HSPF predictions for the runway fill area, because HSPF was deemed incapable of simulating flow within the embankment. A simulation "test period", consisting of water years 1991 through 1994, was established for Hydrus-Slice modeling in discussions between the Port and the Department of Ecology ("Ecology").

The PGG scope consisted of the following tasks:

- Compile model input using existing information including
    - Fill thickness and extent
    - Hydrogeologic data for the fill area
    - Embankment geometries as represented by three (3) hydrogeologic cross sections
- Calculate daily fluxes into the fill based on recharge estimates
- Calculate daily fluxes through the fill using Hydrus models
- Calculate daily flux through the embankment drain layer and the underlying till using Slice models as applied to each basin

The regional water balance was maintained by Hydrus-Slice. Recharge estimation for the Hydrus-Slice approach assumed that runoff from runways and taxiways infiltrated uniformly in the adjacent filter strips and other unpaved portions of the fill.

The work was performed, and this report prepared, in accordance with generally accepted hydrogeologic practices, used at this time and in this vicinity, for sole application to the third runway low-flow assessment project, and for the sole use of the Port of Seattle. This is in lieu of other warrantees, express or implied.

2. Extent of Fill Modeled by Hydrus-Slice

The extent of fill modeled by Hydrus-Slice was defined in a memorandum to the Port of Seattle dated June 25 2001 (Pacific Groundwater Group, 2001a). The modeled fill area (MFA) represents that portion of the embankment within the Walker and Miller creek groundwater basins that would receive precipitation in a post-construction ("built") condition. This area was selected based on discussions with HSPF modelers at the onset of the project. The area was modeled by Hydrus-Slice rather than HSPF for the built condition.

2.1 Geographic Extent of Fill

PGG used existing GIS coverages of pre-fill topography, "built" topography, and third runway pavement distribution to calculate areas for Hydrus-Slice modeling. A graphical approximation of the areas modeled by Hydrus-Slice (and therefore removed from the HSPF model) is shown on **Figure 2-1**. The MFA includes proposed additional runway fill in the Miller and Walker Creek basins minus the steep perimeter slopes along the western and northern edges of the embankment. Steep perimeter slopes were not included in the Hydrus-Slice MFA because surface runoff is assumed to dominate flow in these areas and HSPF is better suited to model these hydrologic conditions. The eastern margin of the MFA is defined by the limit of proposed third runway fill.

2.2 Thickness of Fill

Fill thickness was calculated by subtracting GIS coverages of pre-fill topography from the "built" topography. A fill thickness of up to 160 feet occurs behind the West Mechanically-Stabilized-Earth (MSE) wall with significantly less fill occurring over most of the third runway area (**Figure 2-1**). A fill thickness interval of 20 feet was selected to provide depth discretization for the Hydrus models (Section 4).

2.3 Basin Boundaries and Area Calculations

Groundwater basin boundaries for Miller, Walker and Des Moines Creeks were located for purposes of allocating groundwater flow contributions in the MFA. The groundwater basin boundary of greatest significance in this study is the Miller-Walker divide because these are the receiving basins for fill discharge. A dashed line is drawn on **Figure 2-1** between the Miller and Walker Creek basins. The location of the line is approximately the same as the co-incident surface water and groundwater basin boundaries used in the current-condition HSPF models (Parametrix, 2000, Figure B2-2 of Stormwater Management Plan). The Walker-Des Moines groundwater divide is south of the fill area under the current condition, thus discharge from the fill will not flow to Des Moines Creek under the current or built condition. The fill areas presented in **Table 2-1** are derived from the basin boundary and model area perimeter shown on **Figure 2-1**. Impervious areas comprised 38 percent and 37 percent of the modeled fill areas in the Miller and Walker Creek basins, respectively. The basin areas modeled by Hydrus-Slice are summarized in **Table 2-1**.

Runoff from impervious areas (IA) is assumed to infiltrate in pervious areas (PA). Therefore the IA and PA values presented in **Table 2-1** are used to calculate *effective recharge* on pervious areas (Section 3). IA in Walker Creek consists of only the western half of the third runway because runoff from the eastern half will drain to the east and will not flow onto new third runway fill. Runoff from the eastern half of the third runway in Walker Creek was modeled by HSPF.

3.0 Modeling of Infiltration with Runoff and Evapotranspiration

Precipitation falling on the MFA was used to estimate natural groundwater recharge with a generic application of HSPF that employed regional parameters for grass on flat outwash. This approach was selected, with agreement from Ecology and King County, to take advantage of HSPF's superior evapotranspiration (ET) and runoff-modeling capabilities. The generic HSPF model yielded daily volumes of water that infiltrate beyond the bottom of the root zone and therefore constitute groundwater recharge. A separate calculation factored-in secondary infiltration of runoff from impervious surfaces (secondary recharge). Results were then used as input to the Hydrus models.

3.1 HSPF Results for Grass on Flat Outwash

Aqua Terra accounted for precipitation, runoff, infiltration, and ET on a daily basis between 1984 and 1994 using HSPF and regional parameters for grass on "flat" outwash soils with land slopes of less than five percent (Joe Brascher, personal communication, May 17, 2001). Runoff accounted for a very small proportion of the precipitation. HSPF model output provided daily estimates of recharge (R) below the root zone considering the effects of runoff and evapotranspiration.

3.2 Secondary Recharge

In this study, infiltration of runoff from pavement to pervious areas of the runway fill is called secondary recharge. Earth Tech (2000) calculated that substantial secondary recharge is likely as runoff travels across biofiltration strips and along biofiltration swales to catch basins. Earth Tech's analysis indicates that virtually all runoff from runways should infiltrate in the filter strips. For this reason, recharge used as input to the Hydrus models was increased proportionally by the ratio of impervious area to pervious area occurring in each basin. Effective recharge calculated by the algorithms presented in Section 3.3 below reflects this adjustment for secondary recharge. Effective recharge assumes that water from the impervious areas is distributed evenly over the entire pervious area rather than in the filter strips alone although the secondary recharge analysis of Earth Tech (2000) indicates that the filter strips alone provide sufficient area and infiltration capacity.

The Port collected water stage measurements in a sedimentation pond that collected runoff from Phase I of the third runway fill embankment (Parametrix, 2000). The data are pertinent to this discussion of secondary recharge because runoff defines the amount of water left over for evapotranspiration and recharge. The data were collected over about a one-month period in February 1999 and were later used by Parametrix to derive parameters for HSPF modeling of the fill. The interpretation implies a soil infiltration capacity (related to vertical hydraulic conductivity) that is lower than that of regional HSPF parameters for glacial till. The implied infiltration capacity is also significantly lower than that which was calculated based on average soil texture (Pacific Groundwater Group, 2000). If accurate and representative of the completed fill as a whole, the stage data imply that more runoff and less secondary recharge will occur than predicted by the effective recharge algorithms presented in Section 3.3 to follow. The difference between the observed and predicted runoff may be related to stage measurement or reporting error, stage data interpretation, surface treatments of the Phase I fill that promoted runoff (the fill was bare and compacted at the time), and/or inaccuracies in prediction of hydraulic conductivity based on soil texture. Although prediction of soil properties based on texture is not highly precise, it was the opinion of engineers and hydrogeologists performing these analyses that the fill as a whole is unlikely to exhibit runoff characteristics consistent with the 1999 data. Runoff and secondary recharge more consistent with the soil-texture-based analyses of Earth Tech (2000) and Pacific Groundwater Group (2000) were deemed more likely.

3.3 Effective Recharge

Effective recharge (ER) is the downward groundwater flux, just below the root zone, that includes secondary recharge. It was calculated using the following algorithm:

- Aqua Terra applied daily precipitation (P) between 1984 and 1994 to grass on flat outwash in HSPF using regional parameters to account for runoff and ET
- the resulting daily recharge (R) was increased to account for secondary recharge of runoff from impervious surfaces using the following formula for effective recharge:

$$ER=R+(R*(IA/PA)) \qquad \text{(effective recharge algorithm \#1)}$$

This method uses a lower-end estimate of impervious runoff because impervious runoff is assumed equal to the recharge rate below grass on outwash soils. In actuality, the impervious areas will lose less water to evapotranspiration than would grass areas, and would therefore have more water available for runoff to the pervious areas. The simplifying assumption that impervious runoff equals recharge for pervious areas was adopted to facilitate the timeline of the modeling exercise. Aqua Terra and PGG performed additional analysis on whether an upper-end estimate of runoff from impervious areas was likely to change the effective recharge calculation. Based on conversations with team members, the following alternative algorithm was used in the sensitivity analysis:

- Aqua Terra increased daily precipitation (P) to account for runoff from impervious surfaces to pervious surfaces using the following formula for effective precipitation (EP) on pervious surfaces:

$$EP=P+(P*(IA/PA)) \qquad \text{(effective recharge algorithm \#2)}$$

- Aqua Terra applied daily EP between water years 1984 to 1994 to grass on flat outwash in HSPF (regional parameters) to calculate effective recharge for this alternative algorithm.

The sum of daily effective recharge from algorithm #1 over the 11-year period was 18.7% less than the sum of daily effective recharge from algorithm #2 over the same period. This result suggests algorithm #1 may underestimate actual recharge. All subsequent modeling used recharge calculated by algorithm #1. Walker Creek has a very similar IA/PA ratio and therefore a similar difference in ER estimates.

4.0 Modeling of Vertical Flow Through Embankment Fill

Modeling of downward vertical flow through embankment fill describes water movement in the unsaturated or "vadose" zone between the land surface and the proposed drainage layer at the base of the fill. Downward unsaturated flow is the intermediate step between recharge at the land surface (estimated by HSPF's estimation of daily recharge) and saturated groundwater flow in the shallow aquifer (simulated by the Slice model). An overview of the unsaturated flow modeling completed for this study is presented in the following subsections.

4.1 Summary of Generic Hydrus Model

Vertical flow of effective recharge between the root zone and the water table within the embankment drainage layer was evaluated using the model Hydrus-2D, hereafter called "Hydrus" (Simunek and others, 1999). Hydrus simulates the vertical spreading of recharge fronts as they are predicted to move downward through the proposed embankment fill. Model results describe the lagging and dampening of the recharge pulse for different thicknesses of fill material. Hydrus output was used as recharge input to the Slice models (Section 5).

With the exception of using HSPF-derived daily recharge input values instead of values derived from average monthly rainfall, the modeling approach used in this study was conceptually identical to previous Hydrus simulations completed for the Ecology study (see Appendix C of Pacific Groundwater Group, 2000). Soil characteristics were unchanged. Independent model runs were conducted for the Miller Creek basin using fill thicknesses of 150, 130, 110, 90, 70, 50, 30, and 10 feet. Model runs were conducted for the Walker Creek basin using fill thicknesses of 50, 30, 20, and 10 feet. Hydrus results indicate that substantial lagging and dampening (spreading) of seasonal recharge is likely within the fill, with the amount of lagging and dampening increasing with increasing fill thickness. Discharge at the bottom of the fill is predicted to occur throughout the year.

4.2 Characterization of Fill as Soil

The texture of the modeled fill was calculated based on specifications for Phase 1 fill (installed in 1998 and 1999) and proposed embankment composition described by Hart Crowser (1999). The calculations were also compared to the texture of Phase 1 fill based on soil samples collected by Terra Associates (1998). Details of the characterization of fill texture relative to Hydrus model input is presented in Appendix C of the Ecology study (Pacific Groundwater Group, 2000). The following provides a summary of the two types of fill proposed for use in the embankment and designated in this study.

4.2.1 General Fill

Except for Type 1 soils used as fill in areas near the MSE walls and runways, the embankment will be comprised of imported material termed "general fill." Average bulk texture for the general fill was calculated to be 55 percent gravel and 45 percent sand-plus-fines matrix. The sand-plus-fines matrix was further calculated to be comprised of an average of 63 percent sand and 37 percent silt; clay was assumed to be absent. Soil-moisture characteristic curves and hydraulic conductivity distributions were developed for the Hydrus runs using the U.S. Soil Salinity Laboratory's computer program "Rosetta" based on these estimated grain-size distributions.

4.2.2 Type 1 Fill

According to embankment designs presented by Hart Crowser (1999), Type 1 soils are comprised of sand and gravel; they contain virtually no fines. These materials will be used as backfill for the MSE walls and under runways where greater compaction and drainage properties are required. Type 1 soils were assumed to be infinitely permeable and therefore provide immediate delivery of recharge to the underlying drain layer in the Slice models. Type 1 soils were therefore not modeled explicitly using Hydrus although recharge to the drain layer was considered where Type 1 soils existed in modeled areas.

4.3 Representation of Fill in Hydrus

The sand-plus-silt matrix was modeled as an evenly-distributed 45 percent of the general fill and all water flow was assumed to occur within this active matrix. To maintain a water balance while modeling water flow only through the active matrix, effective recharge values were divided by 0.45 and used as the upper boundary condition flux in Hydrus. This matrix-scaled recharge rate used in Hydrus is called the "effective matrix recharge." Logic for using this rate can be understood by considering that any precipitation falling-on, or percolating-into, clusters of gravel particles is likely to be absorbed by the surrounding sand-plus-silt matrix somewhere within the embankment. The output at the bottom of the Hydrus model was then multiplied by 0.45 to redistribute flux to the bulk fill body and maintain a long-term water flux equal to the grass-on-outwash effective recharge rate.

Modeled hydraulic properties for the active fill matrix were generated with Rosetta, based on the percentages of sand and silt summarized in Section 4.2. Rosetta provides estimates of five parameters used to generate the soil moisture characteristic curve; saturated water content, residual water content, "alpha", "N", and "M" (van Genuchten, 1980). Rosetta also provides an estimate of saturated hydraulic conductivity and a factor "L" used to relate the characteristic curve to the unsaturated hydraulic conductivity curve (Mualem, 1976). A default "L" value of 0.5 was assigned by Rosetta in Hydrus, and was used in this analysis. **Table 4-1** presents the hydraulic parameters generated by Rosetta for the general fill matrix. The saturated hydraulic conductivity calculated by Rosetta was

1.35×10^{-4} cm/sec. This value is near the middle of the range presented in Freeze and Cherry (1979) for silty sand. It is near the high end of the reported glacial till range and lower than the clean sand and gravel ranges reported by the same reference.

Although the actual value(s) of hydraulic conductivity are not known for this proposed future embankment condition, the value calculated by Rosetta is reasonable for the anticipated texture and density of the general fill *matrix*, and is consistent with the active/inactive matrix method of modeling unsaturated flow in the embankment. Experience with testing *saturated* hydraulic conductivity of soils similar in texture to the modeled fill suggests that the Rosetta-calculated value is too low for the bulk (matrix plus gravels) general embankment fill; however, the reason for this discrepancy is the presence of large pores associated with gravels. Large pores associated with gravel deposits dominate saturated flow but can be reasonably assumed inactive under most unsaturated flow conditions because:

- the fill should remain unsaturated except in extreme conditions, and therefore unsaturated flow should predominate,
- large diameter pores associated with gravels will be the first to desaturate as drying occurs,
- over the course of the flow path, water in saturated pores will be absorbed into the finer pores,
- percolation theory (Silliman and Wright, 1988) suggests that continuous paths of finer pores within the matrix will exist throughout the embankment at the modeled texture (it also predicts continuous coarse pore paths which would be predominant in saturated flow),
- it was not feasible for this project to characterize soil moisture retention characteristics of gravels

This representation should be accurate for classical unsaturated flow modeling used by Hydrus and for nearly all other unsaturated flow prediction methods. However, it does not account for the observation that "fingering" of flow can occur in coarse soils under very wet conditions. Fingering occurs when saturation builds-up at one location and then rapidly drains downward through large connected pores in a saturated finger. Such fingering flow will only occur during recharge events when the ground surface, or a subsurface soil zone, becomes saturated. If fingering flow occurs in the fill, the Hydrus model will overestimate groundwater travel times between ground surface and the water table.

4.4 Spatial Discretization of Hydrus Models

As described in Section 4.1, Hydrus models were set up to simulate a total of twelve vertical profiles for the proposed fill. Eight different thickness simulations were run for Miller Creek fill and four different thickness simulations were run for Walker Creek fill. Model runs for a given basin differ in fill thickness only. Separate runs were required for the two basins because slightly different IA/PA ratios led to different effective matrix recharge rates.

The analyses required only a one-dimensional simulation, and Hydrus-2D's finite element grid was set up to most closely approximate a purely 1-D solution. Two columns of nodes were specified with a horizontal separation of 15 cm (6 inches). The upper and lower 150 cm (6 feet) of the profile were assigned relatively detailed nodal definition, with vertical nodal spacings gradually increasing from 1 cm (0.4 inches) at the land surface and water table to 5 cm (2 inches). Between these high-definition top and bottom zones, vertical spacings transitioned to a maximum value of 15 cm (6 inches). Nodes representing the land surface were specified flux boundaries. The bottom two nodes were assigned the "water table" boundary condition, which is a constant head boundary equal to elevation head, simulating saturated conditions beneath the embankment fill. "Observation nodes" were specified every 50 feet in the vertical profile, from which hydrographs of water content (or head) versus time could be extracted. Time-series data for volumetric flow rates exiting the bottom of the model domain at the water table boundary nodes were extracted and used as input to the Slice models.

4.5 Temporal Discretization

Daily stress periods were used, and daily effective matrix recharge estimates were applied to the top of each model. Model timesteps were automatically optimized by Hydrus, and were typically on the order of 0.10 days. The models were run for water years 1984 through 1994, with only the last four water years comprising the critical test period. Output from the initial six years was examined visually to assure that residual effects from the initial conditions (uniform moisture) were not present during the 1991-1994 test period. The fluxes at the water tables were multiplied by 0.45 to maintain mass balance (Section 4.3), and exported to the finite difference Slice models (Section 5).

4.6 Results

Figure 4-1 shows daily effective recharge (input to the bulk soil column in the Hydrus models) and eight daily outflow hydrographs for the Miller Creek basin fill over the test period. The effective recharge plot represents the daily average flow of water into fill soils immediately below the root zone. The outflow graphs represent the daily average flow of water to the embankment drain layer (or the water table within the drain) for any one of eight modeled fill thickness intervals. **Figure 4-2** presents comparable results for the Walker Creek fill. Fill thickness intervals correspond with the range of fill geometries occurring in each basin as presented in **Figure 2-1.**

Quality assurance review included comparison of total outflow between runs, and comparison of total inflow to the average total outflow. All model runs had the same total outflow to within 3 percent and 1 percent, respectively, for Miller and Walker Creek Hydrus models. For the Miller Creek models, total effective recharge was about 2 percent less than the average total outflow, likely as a result of lower storage at the end of the simulation than at the beginning. For the Walker Creek Hydrus models, total effective recharge was about 0.7 percent less than the average total outflow (for the same reason).

Figures 4-1 and 4-2 show that the seasonal recharge pulse (ER) introduced below the root zone is predicted to be lagged and dampened as a function of the thickness of the fill. Lagging causes the arrival of the recharge pulse to be delayed from its introduction at the land surface to its arrival at the bottom of the fill. Dampening causes a reduction in the overall range of flux in the deeper fill. Lagging and dampening both increase with increasing fill thickness and decrease with increasing annual recharge. These effects on the timing of recharge will impact the arrival of flow to the top of the slice model (i.e., to the water table in the embankment drainage layer), and ultimately the arrival of baseflow to streams bordering the study area.

5. Modeling Saturated Flow Beneath the Embankment Fill

Three simple finite difference slice models were developed to simulate horizontal and vertical groundwater flow within the drain layer and existing soils below the embankment. Slice configurations were based on subsurface data described in available geotechnical and hydrogeologic reports and from the pre-fill and "built" topography of the third runway area as supplied by Parametrix and the Port. Slice alignments were located based on the availability of subsurface data while describing the range of hydrogeologic and fill conditions that exist in the embankment area.

The slice models were used to accumulate recharge in the shallow water table aquifer and move it downgradient to the Miller Creek or Walker Creek wetlands under "built" conditions. Slice 1 was originally developed for the Ecology study (Pacific Groundwater Group, 2000). It was re-applied for this low-flow analysis using daily recharge data for 1984 through 1994 and a more representative runway configuration, but otherwise remained unchanged. Slices 2 and 3 were developed for this analysis using new interpretations of existing hydrogeologic and fill data. The three different versions of the model were constructed to represent a range of conditions that exist within the fill embankment. The slice models are a simplification of subsurface conditions within each hydrogeologic cross section. **Figures 5-1 through 5-3** present simplified cross sections of the slice models used in this study. Slice locations are shown on **Figure 2-1**.

The slice models are based on a quasi-two-dimensional finite-difference formulation of the partial differential equation describing transient groundwater flow through a saturated medium. Model cells were only connected to laterally adjacent neighbors as opposed to overlying or underlying cells – thus the quasi-two-dimensional nature of the model. Each model cell can contain up to three different "soil layers", differing in thickness and hydraulic conductivity. The bottom elevation of each cell is defined by the top of the till layer, and downward flow through the till was simulated. For each cell, the model also specified a uniform specific yield of 30 percent. Recharge for each stress period (day) was derived for each cell from Hydrus output for the appropriate overlying fill thickness.

The model assumes unconfined flow (variable transmissivity) under horizontal gradients defined by head differences between adjacent cells. The model was implemented in a Microsoft Excel spreadsheet, using direct (explicit) methods to solve the finite-difference equation. Details of the slice model input and functions are described further in Appendix E of the Ecology study report (Pacific Groundwater Group, 2000).

Downward flow through till was calculated using Darcy's equation, a uniform hydraulic conductivity of $4x10^{-3}$ ft/day ($1.4x10^{-6}$ cm/sec), a uniform thickness of 10 feet, and a model-calculated gradient. To calculate the gradient, the head of groundwater above the till was calculated by the model, and head at the bottom of the till was considered to be one of three values. Groundwater head at the bottom of the till was assumed equal to the elevation of that contact where groundwater in the underlying Qva aquifer was expected to be unconfined (see **Figures 5-1 through 5-3**). This condition prevailed in the eastern portions of Slices 1 and 2, and throughout Slice 3. Groundwater head below the till was considered to be equal to groundwater head above the till where the conceptual model predicted highly confined conditions. This "no vertical flow" condition was actually implemented in the model by assigning a zero hydraulic conductivity to the till where highly confined conditions were expected. That condition prevailed in the western lowland portions of Slices 1 and 2. Groundwater head at the bottom of the till, in locations of intermediate confinement of Qva groundwater, was assigned a value equal to the elevation of the mid-point of the till.

5.1 Cross Section 1 and Slice 1

This cross section is located through the thickest portion of the fill embankment with a fill thickness of up to 160 feet (**Figure 2-1**). A simplified cross section showing Slice 1 is presented in **Figure 5-1**. Slice 1 is located at the same location as the original slice model developed by PGG in the Ecology study. Hydrogeologic conditions were defined by eight subsurface explorations located along the 1,320-foot slice alignment. Fill located behind the West MSE wall was modeled using Slice 1.

The geometry and material types represented in the cross section of **Figure 5-1** were used to construct the Slice 1 model. **Tables 5-1 and 5-2** present Slice 1 model cell parameters. Because the removed portion of the HSPF model does not include the steep slopes of the embankment fill, results from Slice 1 were extracted from the portion east of cell 43 ("active model cells").

5.2 Cross Section 2 and Slice 2

Slice 2 is located through the northern portion of the fill embankment near the northern end of the third runway (**Figure 2-1**). A simplified cross section showing Slice 2 is presented in **Figure 5-2**. The slice is located to represent an intermediate fill thickness of up to 100 feet thick and crosses one taxiway in addition to the third runway. Slice 2 was developed from a generalized hydrogeologic cross section originally created by Hart Crowser through the northern toe of the fill embankment (see Section A-A' of Hart

Crowser, 1999a) with supplemental information from more recent borings and shallow test pits (Hart Crowser, 2000a). The slice location is based on availability of suitable subsurface data with seven explorations located near the 1,420-foot slice alignment. Slice 2 represents subsurface conditions for the bulk of Miller Creek embankment fill.

The geometry and material types represented in the cross section of **Figure 5-2** were used to construct the Slice 2 model. **Tables 5-3 and 5-4** present Slice 2 model cell parameters. Because the removed portion of the HSPF model does not include the steep slopes of the embankment fill, results from Slice 1 were extracted from the portion east of cell 38 ("active model cells").

5.3 Cross Section 3 and Slice 3

Slice 3 is located immediately north of the South MSE wall (**Figure 2-1**). A simplified cross section showing Slice 3 is presented in **Figure 5-3**. A fill thickness of up to 40 feet occurs in the western end of this slice.. The slice location was chosen through fill of intermediate thickness for the Walker Creek fill and minimal thickness for the Miller Creek fill. Although this slice does not completely describe the variety of fill thicknesses in Walker Creek basin, the thicker portion of the fill is of small areal extent and does not justify an additional slice model. Slice 3 is partially based on a generalized hydrogeologic cross section originally created by Hart Crowser through the northern end of the South MSE wall study area (see Section E-E' of Hart Crowser, 2000b). The hydrogeologic interpretation for this slice has been modified using geotechnical data (Hart Crowser, 2000a), existing and "built" topography, and available till mapping data (AESI, 1999). Eight subsurface explorations occur along the 625-foot slice alignment.

The geometry and material types represented in the cross section of **Figure 5-3** were used to construct the Slice 3 model. **Tables 5-5 and 5-6** present Slice 3 model cell parameters. Because the removed portion of the HSPF model does not include the steep slopes of the embankment fill, results from Slice 1 were extracted from the portion east of cell 25 ("active model cells").

5.4 Individual Slice Model Results

Figures 5-4 through 5-6 present individual Slice model results for Slices 1 through 3 (respectively) for water years 1991 through 1994. Results are presented as daily time series plots for three model terms: drain outflow, till seepage, and recharge. The drain outflow term is actually a combination of horizontal groundwater flow at the western edge of the fill embankment through the shallow (Qvr) aquifer and the constructed drain layer. The drain outflow term is extracted from the western-most "active" cell in the slice, and represents subsurface flow towards downgradient receiving waters. Till seepage and recharge are summed daily for all active cells in the slice. Till seepage represents vertical drainage to the deeper (Qva) aquifer below the till. Recharge to the drain layer at the bottom of the fill is obtained from Hydrus output, and varies along the slice due to the varying thickness of overlying fill. Model results represent flow for a one-foot-wide slice of the embankment with units reported in cubic feet per day, per foot of width (cfd/f).

Model results show that the lagtime (seasonal delay) between drain recharge peaks and drain outflow peaks is controlled by the lateral extent (width) of fill along the groundwater flowpath represented by the slice, and are also likely influenced by the varying spatial distribution and timing of recharge inflow along the slice. Increased lateral distances are related to increased travel times within the aquifer. For example, the lagtime in Slice 3 is relatively small, on the order of a few weeks to two months depending on the year considered (**Figure 5-6**). The small delay is a function of the relatively narrow width of fill modeled by this slice. Limited fill width creates a shorter and therefore more rapid horizontal flow path above the till. By contrast, lagtime in Slice 1 ranges between about two to five months depending on the year considered (**Figure 5-4**). Longer lag times reflect longer flow paths above the till. In comparing Slice 1 and Slice 2, differences in the timing of recharge inflow versus drain outflow may be more influenced by differences in the spatial and temporal distribution of recharge inflows.[PNS2]

Quality assurance review included comparison of total inflow, outflow and change in storage between runs. In all cases, the mass balance error in this comparison was significantly less than one percent. However, model predictions of storage did vary on a year-to-year basis due to varying annual recharge inflows.

5.5 Method for Integrating Slice Results Over Entire Fill Areas

Groundwater discharge quantities for Miller and Walker Creeks were calculated by multiplying unit-width flow quantities from representative Slice model output by an effective basin length (EBL). This process integrates the slice model results over the entire basin. The EBL represents an idealized length over which groundwater within the embankment will discharge to the respective downgradient receiving waters. EBLs were measured (or calculated) parallel to the long axis of embankment fill, an orientation perpendicular to expected groundwater flow lines. EBLs are associated with each Slice model and depend on the length of the basin with characteristics similar to the Slice (i.e., thickness and lateral extent). For instance, the entire Walker Creek basin is best represented only by Slice 3 because the embankment fill in this basin is relatively narrow and has limited thickness variation (typically less than 40 feet thick). Walker Creek is therefore modeled by Slice 3 only and the results are integrated over the basin using a single EBL. In contrast, Miller Creek is represented by a combination of Slices 1, 2, and 3 because of variable fill geometries that occur in this basin (fill thickness ranging up to 160 feet over a variety of fill widths). **Figure 2-1** presents the reaches of the Miller and Walker Creek basins that are represented by each of the Slice models. A summary of effective basin lengths is presented in **Table 5-7**.

The derivation of EBLs is discussed in the following sections followed by a summary of the integrated flow results for each basin.

5.6 Effective Basin Length for Walker Creek

The EBL for Walker Creek basin was calculated to maintain a water balance for the modeled fill area (MFA) measured for the basin, where MFA=IA+PA as defined in Section 2.3. Maintaining a water balance means that the integrated area of the slice models equals the total area of the basin. When this condition is met, effective recharge for the basin is equal to the effective recharge of the integrated slice model results. In the Walker Creek Basin, an EBL of 2,032 feet was calculated based on a Slice 3 width of 350 feet and an MFA of 711,373 square feet.

5.7 Effective Basin Length for Miller Creek

The total EBL for Miller Creek basin is comprised of four reach segments that are represented by Slices 1, 2 and 3 (**Figure 2-1**). Multiple slices were used to describe groundwater flow to Miller Creek because of the variable fill width and fill thickness in this basin. Similar to Walker Creek, the EBL for Miller Creek was adjusted to maintain a water balance for the MFA measured previously for the basin. That is, the Miller Creek basin fill area (and therefore basin recharge area) defined by the calculated total EBL was the same as the MFA used for Hydrus and Slice modeling. Because the actual fill width is considerably less than the Slice 2 modeled fill width used to represent the north and south ends of the basin, the Slice 2 EBL was reduced to achieve the desired MFA.

The EBL for the segment represented by Slice 1 adjacent to the West MSE wall was assigned a value of 1,600 feet based on map measurements (**Figure 2-1**). The fill width over this reach is relatively uniform at approximately 1,000 feet and is very close to the 1,050-foot Slice 1 model width. The map-measured length was therefore considered representative for this reach of the basin and the map length was adopted as the EBL.

The Miller Creek basin reach located north of the West MSE wall is represented by Slice 2. The northeastern corner of the runway fill has an irregular shape where the actual fill width is less than the Slice 2 model width. The basin reach immediately south of the West MSE wall is also represented by Slice 2. The combined map length of the two Miller Creek reaches represented by Slice 2 is approximately 3,700 feet. However, to maintain a water balance for the basin, the combined EBL for Slice 2 reaches was reduced relative to map lengths shown on **Figure 2-1**. The combined EBL for Slice 2 reaches was adjusted to 2,576 feet to maintain the water balance. By adjusting the Slice 2 EBL in this manner, an MFA of 4,864,548 square feet (and thus recharge area) was maintained between Hydrus, Slice and the integrated basin flow estimates described in Section 5.8.

The southern reach of the Miller Creek basin is represented by Slice 3 where the fill is relatively thin and narrow. The EBL for this reach of Miller Creek was assigned as the map-measured length 930 feet. The actual fill width of 340 feet is closely approximated by the modeled slice width of 350 feet. The map-measured EBL is therefore considered representative for this reach of the basin as mass balance is maintained.

5.8 Integrated Flow Estimates for Walker Creek Fill

Integrated estimates of drain flow and till seepage for the Walker Creek fill area for water years 1991 through 1994 are presented in **Figure 5-7**. Integrated flows are the product of the 2,032-ft EBL discussed in Section 5.6 and the model results for Slice discussed in Section 5.4. **Figure 5-7** shows that the timing and magnitude of horizontal drain outflow is variable depending on the amount of recharge received though the fill. Estimated annual maximum drain outflows through the fill range between about 6,300 cubic feet per day (cfd) in water year 1991 with a peak flow predicted in late April, and about 730 cfd in 1994 with a peak flow predicted in late July. Estimated annual minimum groundwater flows are predicted to occur between December and March.

Integrated till seepage rates for the Walker Creek basin fill are relatively constant regardless of annual and seasonal variations in recharge. The condition of unconfined groundwater everywhere in the Qva and the relatively flat section contribute to the relatively steady till seepage. Groundwater gradients (and till/drain slopes) are relatively low in this area. These conditions result in slower groundwater travel times and a steadier seepage rates through the till compared to high gradient areas depicted in Slices 2 and 3. Seepage through the till is estimated to occur at a rate of about 2,000 cfd for the four year period shown in **Figure 5-7**.

Quality assurance review included comparison of total inflow to total outflow. For Walker Creek, integrated outflow was about 5 percent greater than total effective recharge for the 4-year test period, likely as a result of lower groundwater storage at the end of the simulation than at the beginning.

5.9 Integrated Flow Estimates for Miller Creek Fill

Integrated estimates of drain outflow and till seepage for the Miller Creek Fill area for water years 1991 through 1994 are presented in **Figure 5-8**. Integrated flows are the product of a combined 5,106-foot basin length discussed in Section 5.7 and the combined model results for Slices 1, 2, and 3 presented in Section 5.4. **Figure 5-8** shows that considerable seasonal and annual differences may exist in drain outflow rates from the Miller Creek fill embankment. Estimated annual maximum flows range from about 19,000 cfd in mid-July of 1991 to about 6,200 cfd in late-July of 1994 following a year of low recharge. Annual minimum drain outflows are predicted to occur between February and June.

Integrated till seepage rates for the Miller Creek basin fill show greater seasonal and year-to-year variations than do Walker Creek fill results for the same time period. The increased variability probably relates to the longer and steeper fill sections in the Miller Creek basin as well as variations in hydraulic head simulated for the lower till boundary condition.

Quality assurance review included comparison of total inflow to total outflow. For Miller Creek, integrated outflow was 3.5 percent greater than total effective recharge for the 4-year test period, likely as a result of lower groundwater storage at the end of the simulation than at the beginning.

5.10 Use of Integrated Flow Estimates

Integrated flow estimates for Miller and Walker Creek basins for water years 1991 through 1994 were transmitted to Parametrix and Aqua Terra on June 27 2001 for use in HSPF models of Miller and Walker Creeks. Time series of total daily discharge (volume per day) from above the till (drain outflow), and total daily discharge through the till (till seepage) were provided for the MFAs within the Miller Creek and Walker Creek basins. Parametrix and Aqua Terra used the flow estimates developed in this modeling study as part of a low-stream-flow impact evaluation.

7. References

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Table 2-1
Summary of Areas Modeled by Hydrus-Slice

	Miller Creek Basin	Walker Creek Basin
Pervious Fill Area (PA)	3,030,620	450,630
Runway and Taxiway Impervious Area (IA)	1,833,928	260,743
Total Modeled Fill Area (MFA) in Basin	4,864,548	711,373

Note: All areas in square feet as calculated by GIS using Parametrix data

5575,921 ft by Joe for remodel

5,575,921 above

Table 4-1
Summary of Hydraulic Parameters Used for Fill Matrix in the Hydrus-2D Model

Sand Fraction of matrix	63%
Silt Fraction of matrix	37%
Clay Fraction of matrix	0
Saturated Volumetric Water Content of matrix	0.25
Residual Volumetric Water Content of matrix	0.02
"alpha" (1/cm)	0.088
"N"	1.35
Saturated Hydraulic Conductivity (cm/sec) of matrix	1.35×10^{-4}

Table 5-1

Slice 1 Model Parameters for Different Cell Types

Model Parameters for Cells Types	Cell Type 1	Cell Type 2	Cell Type 5
Surficial Soil	removed	removed	removed
Aquifer Materials	fill	outwash stringers	peat & outwash
Land Cover	embankment	embankment	embankment
Wetland/Upland	upland	upland	wetland
Bottom Layer Hydraulic Conductivity (ft/d)	300	6	2.7
Top of Bottom Layer (ft above till)	4	7.5	7.5
Middle Layer Hydraulic Conductivity (ft/d)		300	300
Top of Middle Layer (ft above till)		11.5	11.5
Upper Layer Hydraulic Conductivity (ft/d)			
Top of Upper Layer (ft above till)			
Maximum Saturated Thickness (ft)	4	11.5	11.5
Gradient of Top of Till (ft/ft)	18.8%	18.8%	3.6%
Full Thickness Hydraulic Conductivity (ft/d)	300	108.2608696	106.076087
Maximum Subsurface Flow (cfd)	225.0	233.4	43.9
Maximum Downgradient Flow (cfd)	233.4	43.9	0.0
Cell Length (ft)	25	25	25
Specific Yield	30%	30%	30%
Maximum Storage (cubic ft)	30	86.25	86.25
Bottom Layer Storage (cubic ft)	30	56.25	56.25
Till Thickness (ft)			

Model Constants	
Till Thickness (ft)	10
Till Permeability Beneath Uplands (ft/d)	0.004
Till Permeability Beneath Wetlands (ft/d)	0
Outwash Permeability (ft/d)	6
Peat Permeability (ft/d)	1
Percent Outwash in Peaty Aquifer	33%
Peaty Aquifer Permeability (ft/d)	2.65
Drain Material Permeability (ft/d)	300
Till Derived Soil Permeability (ft/d)	4
Outwash Derived Soil Permeability (ft/d)	4
Wetland Surficial Soil Permeability (ft/d)	1
Minimum Saturation Considered for h and T (ft)	0.0001

Time Stepping	
user defined model timestep (d)	0.10

(from Anderson & Woesner, 1982: dt <= 0.5*S*"delta X"^2/T

NOTE: All values are for a vertical slice of 1-foot width.

Table 5-2
Slice 1 Model Cell Parameters

Cell ID	Distance from Outlet	Top of Till Elevation	Cell Length (ft)	Cell Type	Till Perme-ability (ft/d)	Head at Bottom of Till	Maximum Subsurface Outflow (cfd)	Specific Yield	Maximum Storage (cf)	Fill Material	Embankment Thickness (ft)	Modeled "Effective" Embankment Thickness (ft)	
1	1137.5	385.0	25	1	0.004	375.0	225.0	30%	30.0	Type 2	3	0	
2	1112.5	380.4	25	1	0.004	370.4	225.0	30%	30.0	Type 2	7	10	
3	1087.5	375.7	25	1	0.004	365.7	225.0	30%	30.0	Type 2	11	10	
4	1062.5	371.0	25	1	0.004	361.0	225.0	30%	30.0	Type 2	14	-99	taxiway, no recharge
5	1037.5	366.3	25	1	0.004	356.3	225.0	30%	30.0	Type 2	19	10	
6	1012.5	361.6	25	1	0.004	351.6	225.0	30%	30.0	Type 2	24	-99	taxiway, no recharge
7	987.5	356.9	25	1	0.004	346.9	225.0	30%	30.0	Type 2	27	30	
8	962.5	352.2	25	1	0.004	342.2	225.0	30%	30.0	Type 2	32	-99	taxiway, no recharge
9	937.5	347.5	25	1	0.004	337.5	225.0	30%	30.0	Type 2	35	30	
10	912.5	342.9	25	1	0.004	332.9	225.0	30%	30.0	Type 2	40	-99	taxiway, no recharge
11	887.5	338.2	25	1	0.004	328.2	225.0	30%	30.0	Type 2	44	50	
12	862.5	333.5	25	1	0.004	323.5	225.0	30%	30.0	Type 2	49	-99	taxiway, no recharge
13	837.5	328.8	25	1	0.004	318.8	225.0	30%	30.0	Type 2	54	50	
14	812.5	324.1	25	1	0.004	314.1	225.0	30%	30.0	Type 2	57	-99	taxiway, no recharge
15	787.5	319.4	25	1	0.004	309.4	225.0	30%	30.0	Type 2	60	50	
16	762.5	314.7	25	2	0.004	304.7	233.4	30%	86.3	Type 2	64	-99	taxiway, no recharge
17	737.5	310.0	25	2	0.004	300.0	233.4	30%	86.3	Type 2	69	70	
18	712.5	305.4	25	2	0.004	295.4	233.4	30%	86.3	Type 2	74	70	
19	687.5	300.7	25	2	0.004	290.7	233.4	30%	86.3	Type 2	78	70	
20	662.5	296.0	25	2	0.004	286.0	233.4	30%	86.3	Type 2	84	90	
21	637.5	291.3	25	2	0.004	281.3	233.4	30%	86.3	Type 2	90	90	
22	612.5	286.6	25	2	0.004	276.6	233.4	30%	86.3	Type 2	96	90	
23	587.5	281.9	25	2	0.004	271.9	233.4	30%	86.3	Type 2	101	110	
24	562.5	277.2	25	2	0.004	267.2	233.4	30%	86.3	Type 2	105	110	
25	537.5	272.5	25	2	0.004	267.5	233.4	30%	86.3	Type 2	111	110	
26	512.5	267.9	25	2	0.004	262.9	233.4	30%	86.3	Type 2	116	-99	runway, no recharge
27	487.5	263.2	25	2	0.004	258.2	233.4	30%	86.3	Type 2	120	-99	runway, no recharge
28	462.5	258.5	25	2	0.004	253.5	233.4	30%	86.3	Type 2	125	-99	runway, no recharge
29	437.5	253.8	25	2	0.004	248.8	233.4	30%	86.3	Type 2	128	-99	runway, no recharge
30	412.5	249.1	25	2	0.004	244.1	233.4	30%	86.3	Type 2	132	-99	runway, no recharge
31	387.5	244.4	25	2	0.004	239.4	233.4	30%	86.3	Type 2	138	-99	runway, no recharge
32	362.5	239.7	25	2	0.004	234.7	233.4	30%	86.3	Type 2	142	-99	runway, no recharge
33	337.5	235.0	25	2	0.004	230.0	43.9	30%	86.3	Type 2	147	-99	runway, no recharge
34	312.5	232.3	25	5	0	222.3	43.9	30%	86.3	Type 2	148	-99	runway, no recharge
35	287.5	231.4	25	5	0	221.4	43.9	30%	86.3	Type 2	148	150	
36	262.5	230.5	25	5	0	220.5	43.9	30%	86.3	Type 2	148	150	
37	237.5	229.6	25	5	0	219.6	43.9	30%	86.3	Type 2	148	150	
38	212.5	228.7	25	5	0	218.7	43.9	30%	86.3	Type 2	148	150	
39	187.5	227.8	25	5	0	217.8	43.9	30%	86.3	Type 2	148	150	
40	162.5	226.9	25	5	0	216.9	43.9	30%	86.3	Type 1	148	0	
41	137.5	226.0	25	5	0	216.0	43.9	30%	86.3	Type 1	146	0	
42	112.5	225.1	25	5	0	215.1	43.9	30%	86.3	Type 1	145	0	
43	87.5	224.2	25	5	0	214.2	43.9	30%	86.3	Type 1	115	0	not included in mass balance
44	62.5	223.3	25	5	0	213.3	43.9	30%	86.3	Type 1	35	0	not included in mass balance
45	37.5	222.4	25	5	0	212.4	43.9	30%	86.3	Type 1	7	0	not included in mass balance
46	12.5	221.5	25	5	0	211.5	9999	30%	86.3	Type 1	0	0	not included in mass balance

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Table 5-3
Slice 2 Model Parameters for Different Cell Types

Model Parameters for Cells Types	cells 1-3, 8-9 **Cell Type 1**	cells 4-7 **Cell Type 2**	cells 10-13 **Cell Type 3**	cells 14-28 **Cell Type 4**	cells 29-43 **Cell Type 5**	cells 44-46 **Cell Type 6**
Surficial Soil	removed	removed	removed	removed	removed	removed
Aquifer Materials	utwash stringer	outwash stringers	outwash stringers	outwash stringers	outwash stringers	outwash stringers
Land Cover	embankment	embankment	embankment	embankment	embankment	embankment
Wetland/Upland	upland	upland	upland	upland	upland	upland
Bottom Layer Hydraulic Conductivity (ft/d)	6	6	6	6	6	6
Top of Bottom Layer (ft above till)	39.5	45	28.25	15	15	15
Middle Layer Hydraulic Conductivity (ft/d)	300	300	300	300	300	300
Top of Middle Layer (ft above till)	43.5	49	32.25	19	19	19
Upper Layer Hydraulic Conductivity (ft/d)						
Top of Upper Layer (ft above till)						
Maximum Saturated Thickness (ft)	43.5	49	32.25	19	19	19
Gradient of Top of Till (ft/ft)	9.1%	9.1%	9.1%	9.1%	5.1%	1.7%
Full Thickness Hydraulic Conductivity (ft/d)	33.0	30.0	42.5	67.9	67.9	67.9
Maximum Subsurface Flow (cfd)	130.5	133.5	124.4	117.1	65.4	21.3
Maximum Downgradient Flow (cfd)	133.5	65.4	21.3	117.1	65.4	21.3
Cell Length (ft)	30	30	30	30	30	30
Specific Yield	30%	30%	30%	30%	30%	30%
Maximum Storage (cubic ft)	391.5	441	290.25	171	171	171
Bottom Layer Storage (cubic ft)	355.5	405	254.25	135	135	135

Model Constants	
Till Thickness (ft)	10
Till Permeability Beneath Uplands (ft/d)	0.004
Till Permeability Beneath Wetlands (ft/d)	0
Outwash Permeability (ft/d)	6
Peat Permeability (ft/d)	1
Percent Outwash in Peaty Aquifer	33%
Peaty Aquifer Permeability (ft/d)	2.65
Drain Material Permeability (ft/d)	300
Till Derived Soil Permeability (ft/d)	4
Outwash Derived Soil Permeability (ft/d)	4
Wetland Surficial Soil Permeability (ft/d)	1
Minimum Saturation Considered for h and T (ft)	0.0001
Time Stepping	
user defined model timestep (d)	0.10

(from Anderson & Woesner, 1982: dt <= 0.5*S**delta X^2/T
Note that the maximum timestep above (dt) is for full saturation of the drain, which will not occur.

NOTE: All values are for a vertical slice of 1-foot width.

Table 5-4
Slice 2 Model Cell Parameters

Cell ID	Distance from Outlet	Top of Till Elevation	Cell Length (ft)	Cell Type	Till Permeability (ft/d)	Head at Bottom of Till	Maximum Subsurface Outflow (cfd)	Specific Yield	Maximum Storage (cf)	Fill Material	Embankment Thickness (ft)	Modeled "Effective" Embankment Thickness (ft)	
1	1365	372.0	30	1	0.004	362.0	130.5	30%	391.5	Type1	0.0	0	drain only, no overlying fill
2	1335	369.1	30	1	0.004	359.1	130.5	30%	391.5	Type1	0.0	0	drain only, no overlying fill
3	1305	366.2	30	1	0.004	356.2	130.5	30%	391.5	Type 2	0.5	0	
4	1275	363.3	30	2	0.004	353.3	133.5	30%	441.0	Type 2	1.4	-99	taxiway/unspec., no recharge
5	1245	360.4	30	2	0.004	350.4	133.5	30%	441.0	Type 2	2.2	-99	taxiway/unspec., no recharge
6	1215	357.5	30	2	0.004	347.5	133.5	30%	441.0	Type 2	3.0	-99	taxiway/unspec., no recharge
7	1185	354.6	30	2	0.004	344.6	133.5	30%	441.0	Type 2	5.7	-99	taxiway/unspec., no recharge
8	1155	351.7	30	1	0.004	341.7	130.5	30%	391.5	Type 2	12.0	-99	taxiway/unspec., no recharge
9	1125	348.8	30	1	0.004	338.8	130.5	30%	391.5	Type 2	18.4	-99	taxiway/unspec., no recharge
10	1095	345.9	30	3	0.004	335.9	124.4	30%	290.3	Type 2	24.7	20	
11	1065	343.0	30	3	0.004	333.0	124.4	30%	290.3	Type 2	30.6	30	
12	1035	340.1	30	3	0.004	330.1	124.4	30%	290.3	Type 2	36.4	30	
13	1005	337.2	30	3	0.004	327.2	124.4	30%	290.3	Type 2	42.3	50	
14	975	334.2	30	4	0.004	324.2	117.1	30%	171.0	Type 2	48.1	50	
15	945	331.3	30	4	0.004	321.3	117.1	30%	171.0	Type 2	53.9	50	
16	915	328.4	30	4	0.004	318.4	117.1	30%	171.0	Type 2	57.1	50	
17	885	325.5	30	4	0.004	315.5	117.1	30%	171.0	Type 2	59.7	50	
18	855	322.5	30	4	0.004	312.5	117.1	30%	171.0	Type 2	62.7	70	
19	825	320.1	30	4	0.004	310.1	117.1	30%	171.0	Type 2	66.6	70	
20	795	317.7	30	4	0.004	307.7	117.1	30%	171.0	Type 2	70.5	70	
21	765	315.2	30	4	0.004	305.2	117.1	30%	171.0	Type 2	74.4	70	
22	735	312.8	30	4	0.004	307.8	117.1	30%	171.0	Type 2	77.9	-99	runway, no recharge
23	705	310.4	30	4	0.004	305.4	117.1	30%	171.0	Type 2	81.0	-99	runway, no recharge
24	675	308.0	30	4	0.004	303.0	117.1	30%	171.0	Type 2	84.1	-99	runway, no recharge
25	645	305.5	30	4	0.004	300.5	117.1	30%	171.0	Type 2	86.9	-99	runway, no recharge
26	615	303.1	30	4	0.004	298.1	117.1	30%	171.0	Type 2	89.3	-99	runway, no recharge
27	585	300.7	30	4	0.004	295.7	117.1	30%	171.0	Type 2	91.2	-99	runway, no recharge
28	555	298.4	30	4	0.004	293.4	117.1	30%	171.0	Type 2	92.3	-99	runway, no recharge
29	525	296.9	30	5	0	286.9	65.4	30%	171.0	Type 2	92.7	-99	runway, no recharge
30	495	295.4	30	5	0	285.4	65.4	30%	171.0	Type 2	93.2	90	
31	465	293.9	30	5	0	283.9	65.4	30%	171.0	Type 2	93.7	90	
32	435	292.3	30	5	0	282.3	65.4	30%	171.0	Type 2	94.3	90	
33	405	290.8	30	5	0	280.8	65.4	30%	171.0	Type 2	94.9	90	
34	375	289.3	30	5	0	279.3	65.4	30%	171.0	Type 2	95.1	90	
35	345	287.8	30	5	0	277.8	65.4	30%	171.0	Type 2	95.1	90	
36	315	286.3	30	5	0	276.3	65.4	30%	171.0	Type 2	95.0	90	
37	285	284.7	30	5	0	274.7	65.4	30%	171.0	Type 2	94.9	90	top of embankment and western
38	255	283.2	30	5	0	273.2	65.4	30%	171.0	Type 2	83.3	-99	no recharge
39	225	281.7	30	5	0	271.7	65.4	30%	171.0	Type 2	71.7	-99	no recharge
40	195	280.2	30	5	0	270.2	65.4	30%	171.0	Type 2	60.1	-99	no recharge
41	165	278.7	30	5	0	268.7	65.4	30%	171.0	Type 2	48.5	-99	no recharge
42	135	277.1	30	5	0	267.1	65.4	30%	171.0	Type 2	37.7	-99	no recharge
43	105	275.6	30	5	0	265.6	65.4	30%	171.0	Type 2	27.0	-99	no recharge
44	75	274.8	30	6	0	264.8	21.3	30%	171.0	Type 2	16.4	-99	no recharge
45	45	274.3	30	6	0	264.3	21.3	30%	171.0	Type 2	5.6	-99	no recharge
46	15	273.8	30	6	0	263.8	21.3	30%	171.0	Type 2	0.0	-99	no recharge

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Table 5-5
Slice 3 Model Parameters for Different Cell Types

Model Parameters for Cells Types	Cell Type 1	Cell Type 2	Cell Type 3
Surficial Soil	removed	removed	removed
Aquifer Materials	outwash stringers	outwash stringers	outwash stringers
Land Cover	embankment	embankment	embankment
Wetland/Upland	upland	upland	upland
Bottom Layer Hydraulic Conductivity (ft/d)	6	6	6
Top of Bottom Layer (ft above till)	2.5	2.5	4.75
Middle Layer Hydraulic Conductivity (ft/d)	300	300	300
Top of Middle Layer (ft above till)	3	6.5	8.75
Upper Layer Hydraulic Conductivity (ft/d)			
Top of Upper Layer (ft above till)			
Maximum Saturated Thickness (ft)	3	6.5	8.75
Gradient of Top of Till (ft/ft)	17.1%	5.2%	5.2%
Full Thickness Hydraulic Conductivity (ft/d)	55.0	186.9	140.4
Maximum Subsurface Flow (cfd)	28.2	62.9	63.6
Maximum Downgradient Flow (cfd)	28.2	62.9	63.6
Cell Length (ft)	25	25	25
Specific Yield	30%	30%	30%
Maximum Storage (cubic ft)	22.50	48.75	65.63
Bottom Layer Storage (cubic ft)	18.75	18.75	35.63

Model Constants	
Till Thickness (ft)	10
Till Permeability Beneath Uplands (ft/d)	0.004
Till Permeability Beneath Wetlands (ft/d)	0
Outwash Permeability (ft/d)	6
Peat Permeability (ft/d)	1
Percent Outwash in Peaty Aquifer	33%
Peaty Aquifer Permeability (ft/d)	2.65
Drain Material Permeability (ft/d)	300
Till Derived Soil Permeability (ft/d)	4
Outwash Derived Soil Permeability (ft/d)	4
Wetland Surficial Soil Permeability (ft/d)	1
Minimum Saturation Considered for h and T (ft)	0.0001

Time Stepping	
user defined model timestep (d)	0.10

(from Anderson & Woesner, 1982: dt <= 0.5*S*"delta X"^2/T
Note that the maximum timestep above (dt) is for full saturation of the drain, which will not occur.

NOTE: All values are for a vertical slice of 1-foot width.

Table 5-6
Slice 3 Model Cell Parameters

Cell ID	Distance from Outlet	Top of Till Elevation	Cell Length (ft)	Cell Type	Till Permeability (ft/d)	Head at Bottom of Till	Maximum Subsurface Outflow (cfd)	Specific Yield	Maximum Storage (cf)	Fill Material	Embankment Thickness (ft)	Modeled "Effective" Embankment Thickness (ft)	
1	612.5	368.8	25	1	0.004	358.8	28.2	30%	22.5	Type 2	0.0	-99	drain only, no overlying fill, excluded from model via zero recharge
2	587.5	366.3	25	1	0.004	356.3	28.2	30%	22.5	Type 2	0.0	-99	drain only, no overlying fill, excluded from model via zero recharge
3	562.5	364.0	25	2	0.004	354.0	62.9	30%	48.8	Type 2	0.0	-99	drain only, no overlying fill, excluded from model via zero recharge
4	537.5	362.7	25	2	0.004	352.7	62.9	30%	48.8	Type 2	0.9	-99	excluded from model via zero recharge
5	512.5	361.4	25	2	0.004	351.4	62.9	30%	48.8	Type 2	2.2	-99	excluded from model via zero recharge
6	487.5	360.1	25	2	0.004	350.1	62.9	30%	48.8	Type 2	3.6	-99	runway, no recharge
7	462.5	358.8	25	2	0.004	348.8	62.9	30%	48.8	Type 2	5.3	-99	runway, no recharge
8	437.5	357.5	25	2	0.004	347.5	62.9	30%	48.8	Type 2	7.1	-99	runway, no recharge
9	412.5	356.2	25	2	0.004	346.2	62.9	30%	48.8	Type 2	8.8	-99	runway, no recharge
10	387.5	354.9	25	2	0.004	344.9	62.9	30%	48.8	Type 2	10.5	-99	runway, no recharge
11	362.5	353.6	25	2	0.004	343.6	62.9	30%	48.8	Type 2	11.9	-99	runway, no recharge
12	337.5	352.3	25	2	0.004	342.3	62.9	30%	48.8	Type 2	12.8	-99	runway, no recharge
13	312.5	351.0	25	2	0.004	341.0	62.9	30%	48.8	Type 2	13.6	-99	runway, no recharge
14	287.5	349.7	25	2	0.004	339.7	62.9	30%	48.8	Type 2	14.4	-99	runway, no recharge
15	262.5	348.4	25	2	0.004	338.4	62.9	30%	48.8	Type 2	15.2	-99	runway, no recharge
16	237.5	347.1	25	2	0.004	337.1	62.9	30%	48.8	Type 2	15.8	20	
17	212.5	345.8	25	2	0.004	335.8	62.9	30%	48.8	Type 2	16.1	20	
18	187.5	344.6	25	2	0.004	334.6	62.9	30%	48.8	Type 2	16.5	20	
19	162.5	343.3	25	2	0.004	333.3	62.9	30%	48.8	Type 2	16.9	20	
20	137.5	342.0	25	2	0.004	332.0	62.9	30%	48.8	Type 2	17.3	20	
21	112.5	340.7	25	2	0.004	330.7	62.9	30%	48.8	Type 2	17.7	20	
22	87.5	339.4	25	2	0.004	329.4	62.9	30%	48.8	Type 2	18.1	20	
23	62.5	338.1	25	3	0.004	328.1	63.6	30%	65.6	Type 2	18.1	20	
24	37.5	336.8	25	3	0.004	326.8	63.6	30%	65.6	Type 2	17.4	20	top of embankment and western edge of area receiving recharge in this cell
25	12.5	335.5	25	3	0.004	325.5	63.6	30%	65.6	Type 2	6.6	-99	no recharge

Table 5-7
Summary of Effective Basin Lengths for Walker and Miller Creek Flow Estimates

Basin & Slice Representation	Impermeable Area, IA (sf)	Permeable Area, PA (sf)	Modeled Fill Area (MFA) = IA+PA (sf)	Slice Active Cell Count	Slice Model Cell Width (ft)	Active Slice Width (ASW, ft)	Effective Basin Length (EBL, ft)	Mapped Basin Length (MBL, ft)	Fraction of MBL	Fraction of EBL
Walker Creek	260,743	450,630	711,373							
Slice 3				14	25	350	2,032	2,250	100.0%	100.0%
Miller Creek	1,833,928	3,030,620	4,864,548				5,106	6,230		
Slice 1				42	25	1,050	1,600	1,600	25.7%	31.3%
Slice 2				37	30	1,110	2,576	3,700	59.4%	50.4%
Slice 3				14	25	350	930	930	14.9%	18.2%

MFA ÷ ASW

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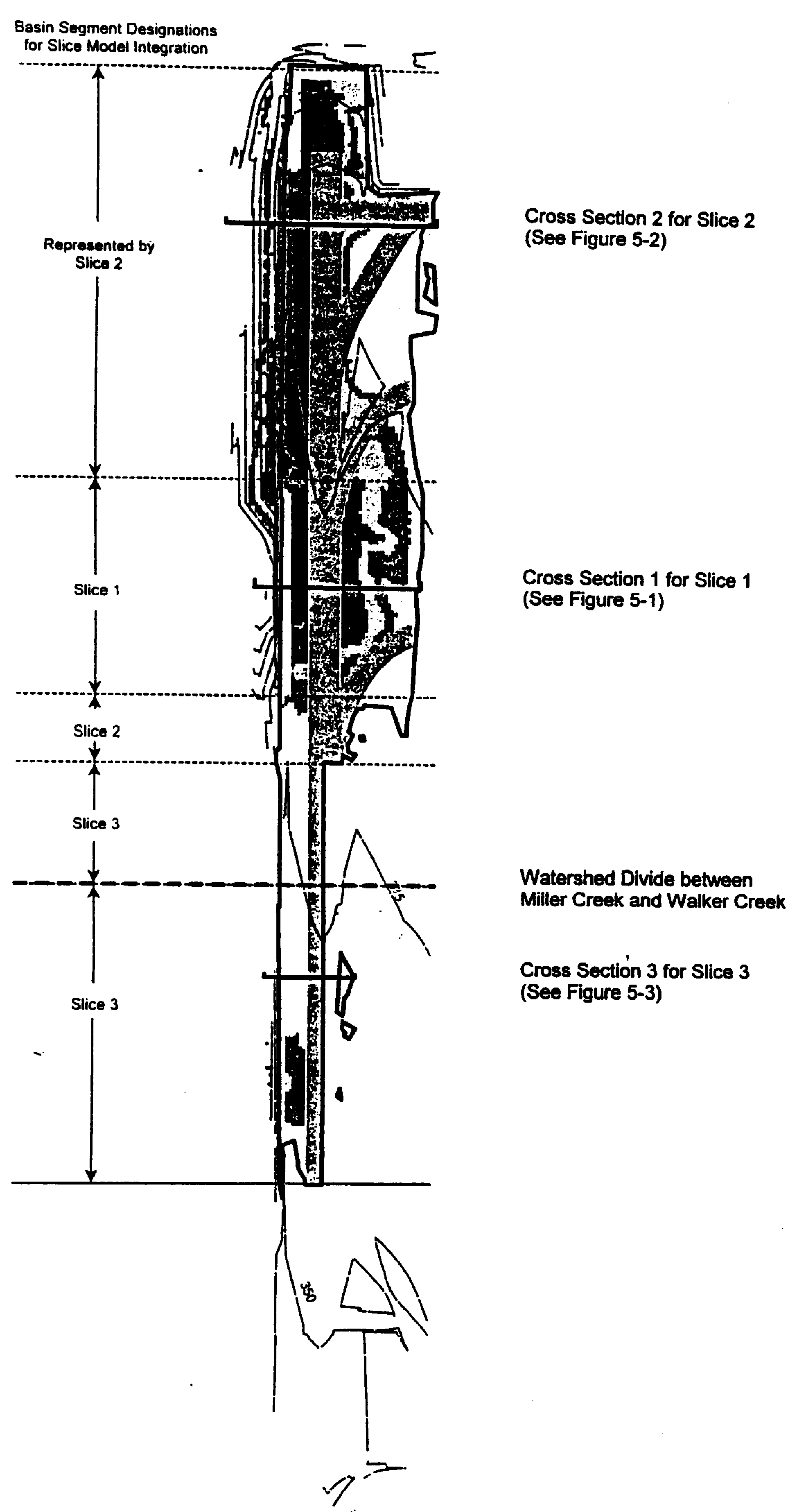
Figures



Depth of Fill (feet)

- 0 - 20
- 21 - 40
- 41 - 60
- 61 - 80
- 81 - 100
- 101 - 120
- 121 - 140
- 141 - 160

Approximate Area Modeled by Hydrus and Slice (Clipped from HSPF)*

Impervious Area

"Built" Elevation Contours (25 ft interval)

N

0 1000 Feet

1:12,000

**Perimeter boundary is a simplification of the line used for area calculations and should not be used quantitatively.*

Figure 2-1

Site Features for Hydrus-Slice Modeling

SeaTac Third Runway
Embankment Fill Modeling
JE0106

Pacific Groundwater Group

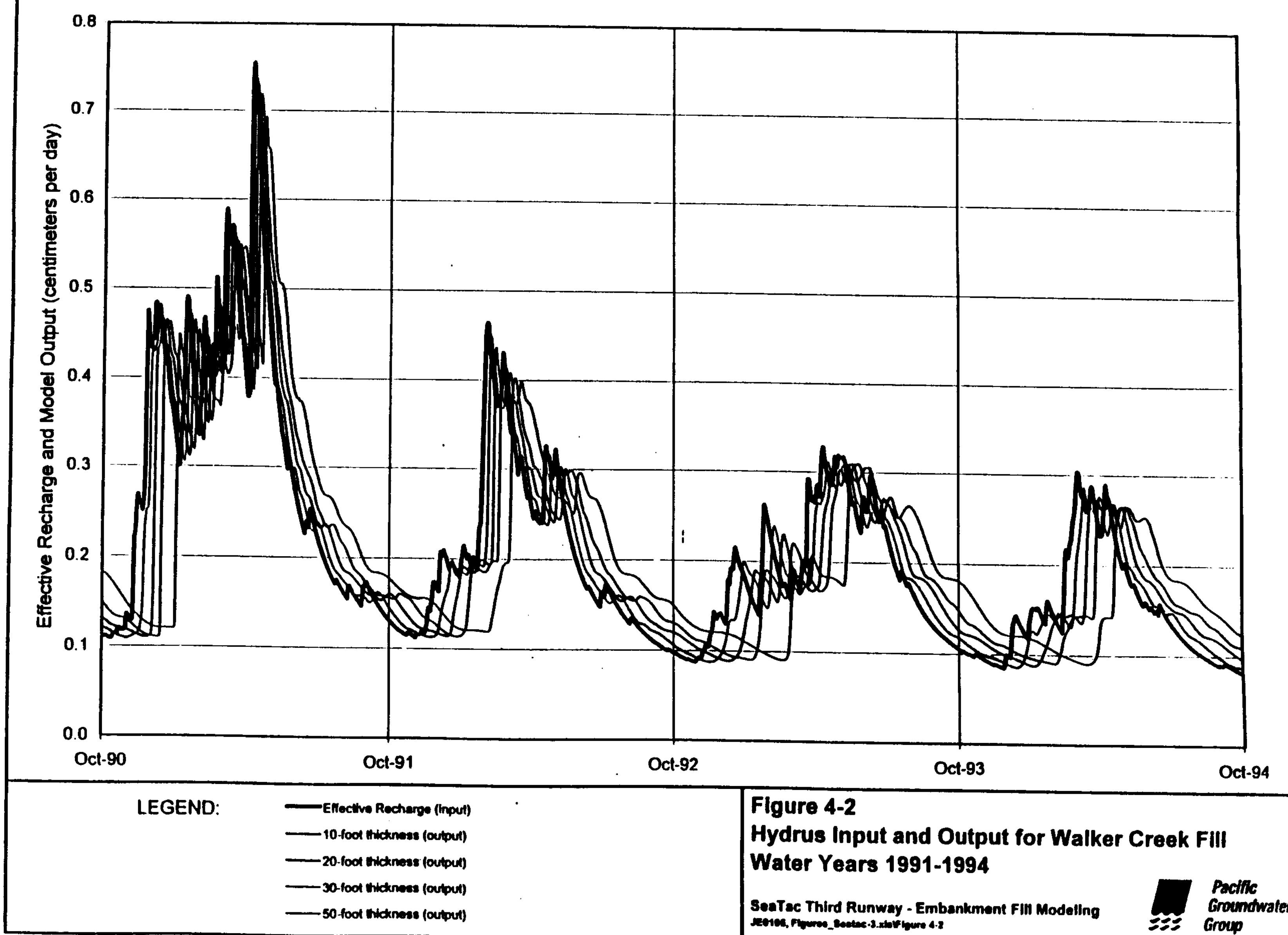


Figure 4-2
Hydrus Input and Output for Walker Creek Fill Water Years 1991-1994

SeaTac Third Runway - Embankment Fill Modeling
JE0106, Figures_Seatac-3.xls\Figure 4-2

Pacific Groundwater Group

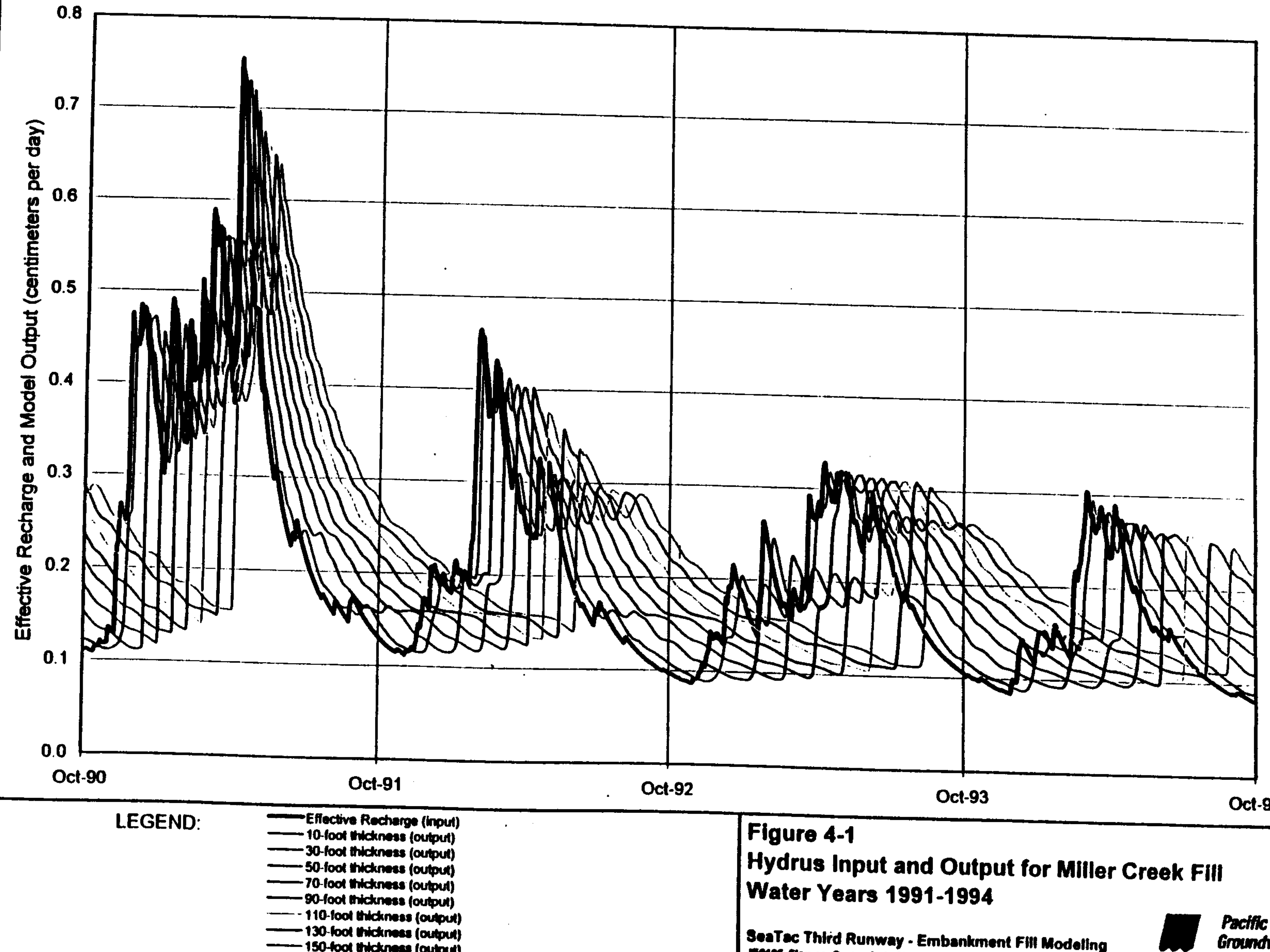
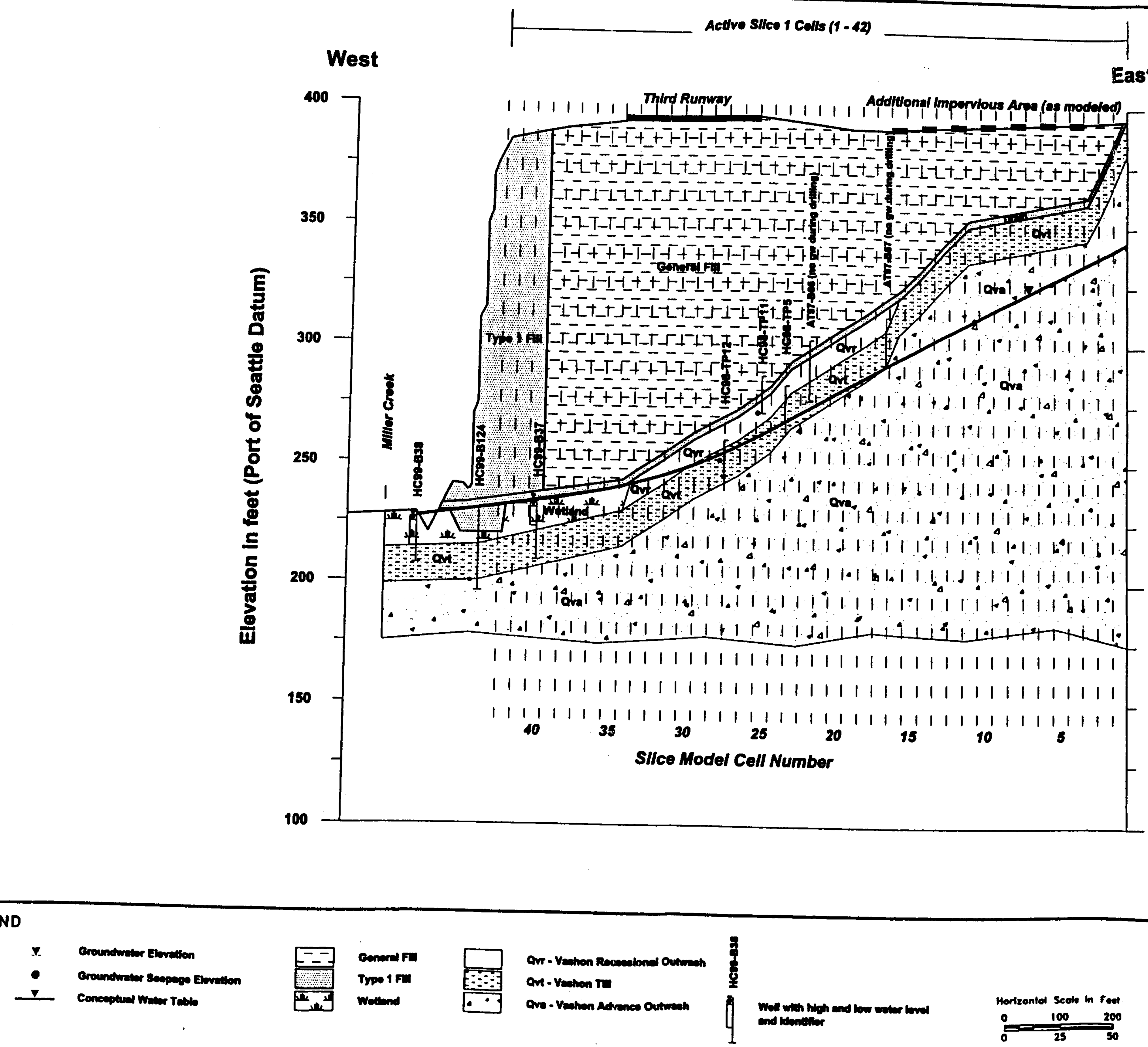


Figure 4-1
Hydrus Input and Output for Miller Creek Fill Water Years 1991-1994

SeaTac Third Runway - Embankment Fill Modeling
JE0106, Figures_Seatac-3.xls\Figure 4-1

Pacific Groundwater Group

AR 050992

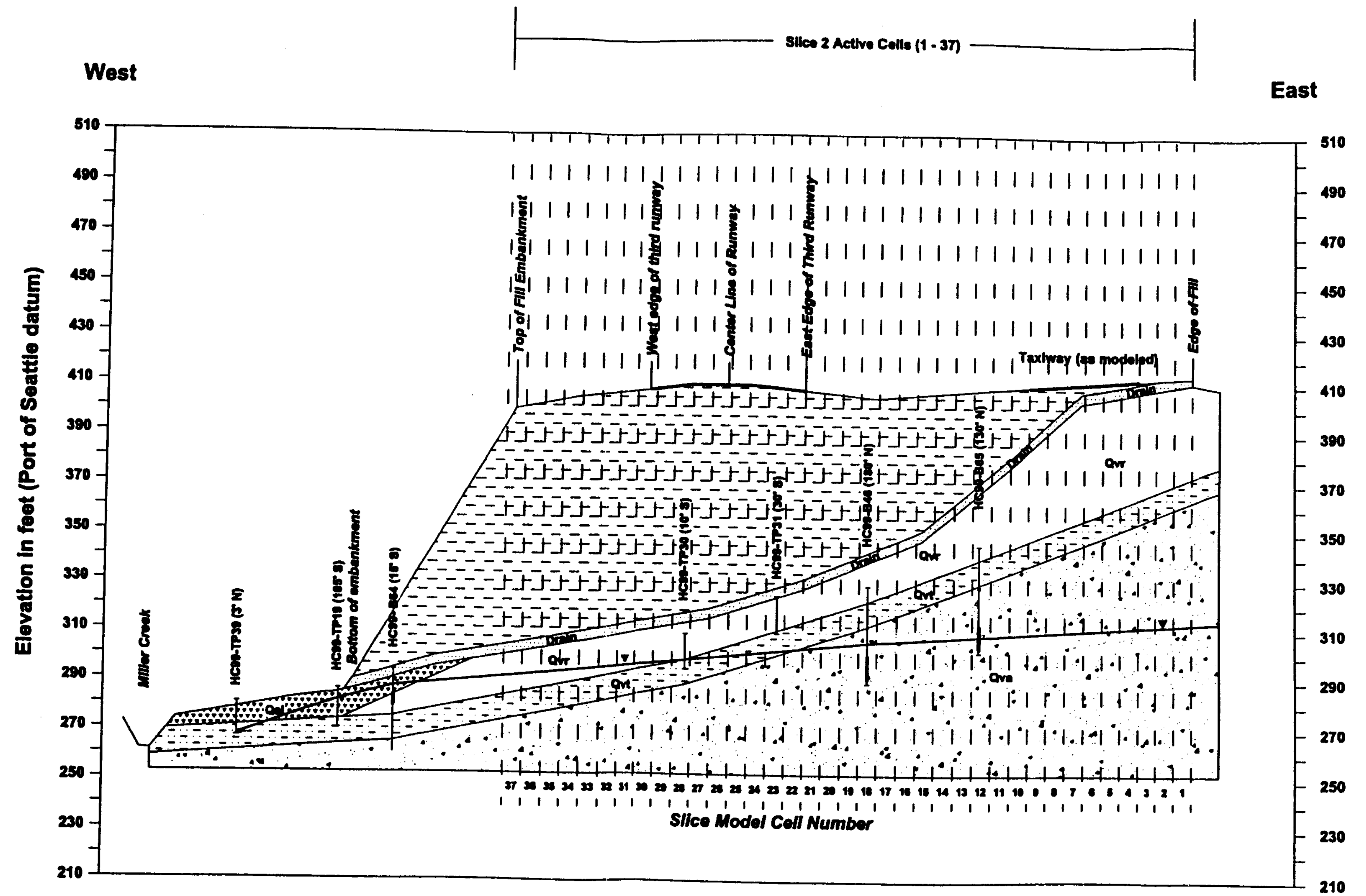


AR 050993

FIGURE 5-1
Simplified Cross Section for Slice 1

SeaTac Third Runway
Embankment Fill Modeling

Pacific Groundwater Group



AR 050994

LEGEND

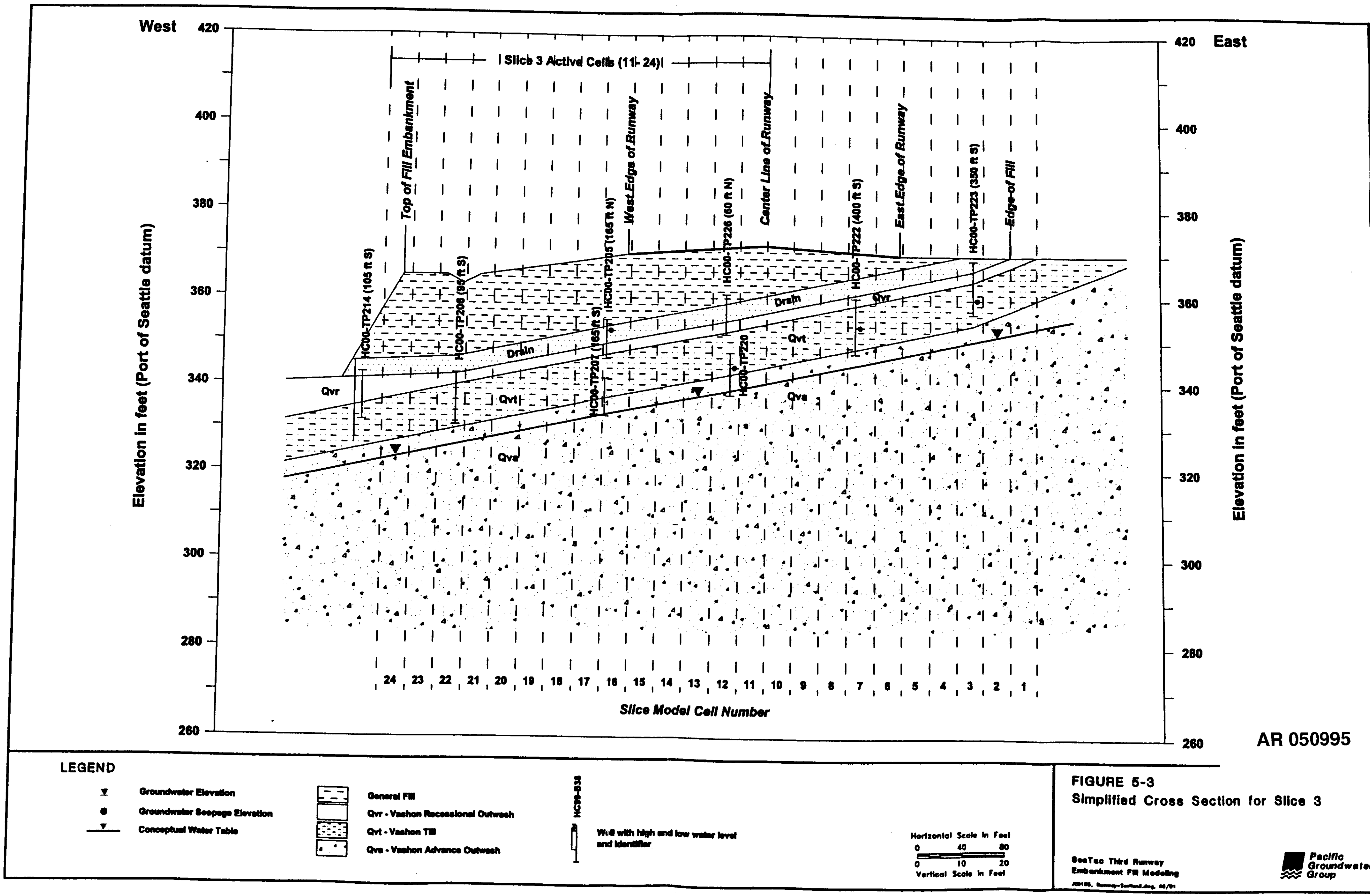
- Groundwater Elevation
- Groundwater Seepage Elevation
- Conceptual Water Table
- General Fill
- Qvr - Vashon Recessional Outwash
- Qvt - Vashon Till
- Qva - Vashon Advance Outwash
- Qal - Recent Alluvium
- HC99-B38 — Well with high and low water level and identifier

Horizontal Scale in Feet: 0 100 200
Vertical Scale in Feet: 0 25 50

FIGURE 5-2
Simplified Cross Section for Slice 2

SeaTac Third Runway
Embankment Fill Modeling

Pacific Groundwater Group



AR 050995

FIGURE 5-3
Simplified Cross Section for Slice 3

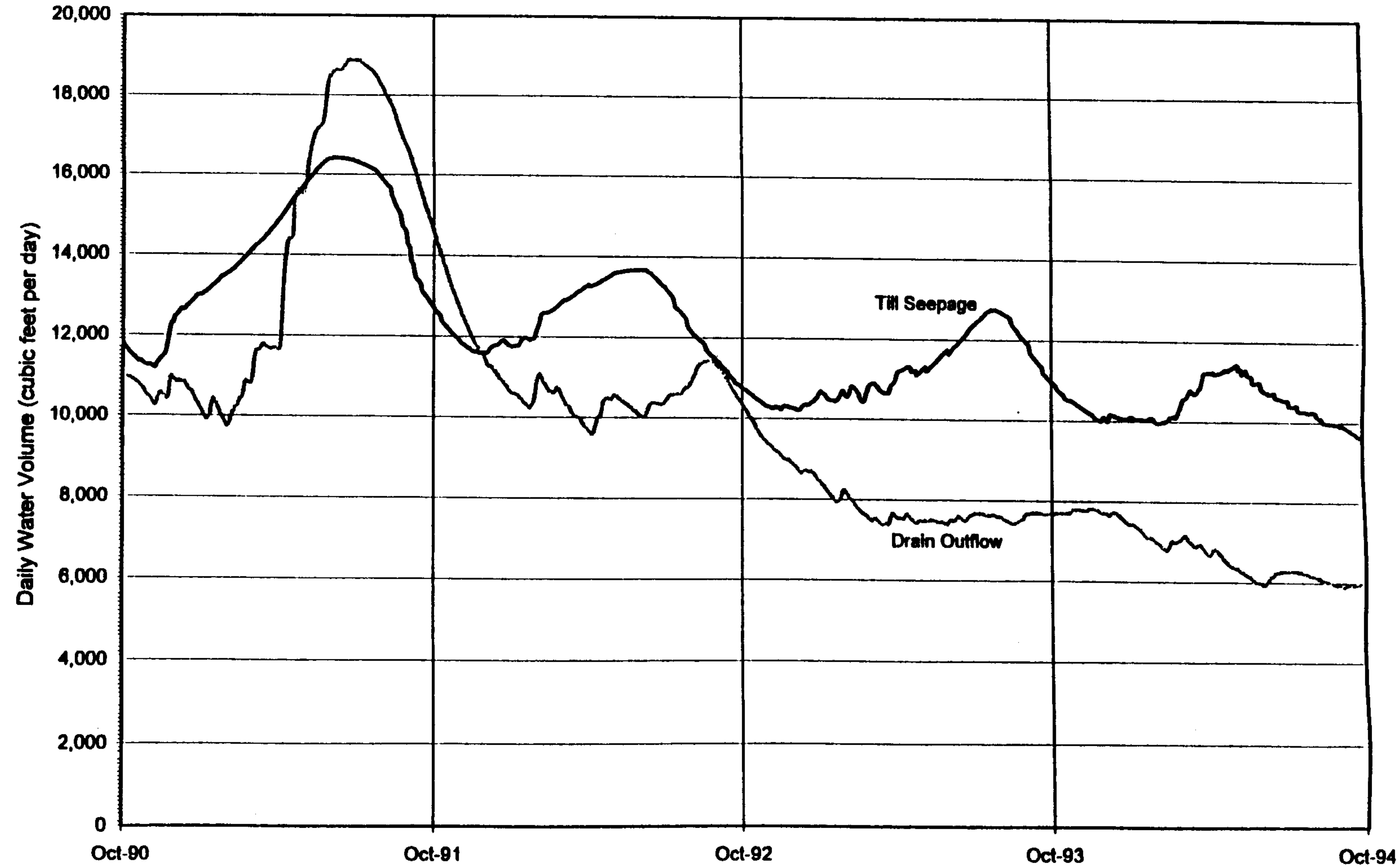


Figure 5-8
Integrated Outflows for Miller Creek Fill
Water Years 1991-1994

SeaTac Third Runway - Embankment Fill Modeling

Pacific Groundwater Group

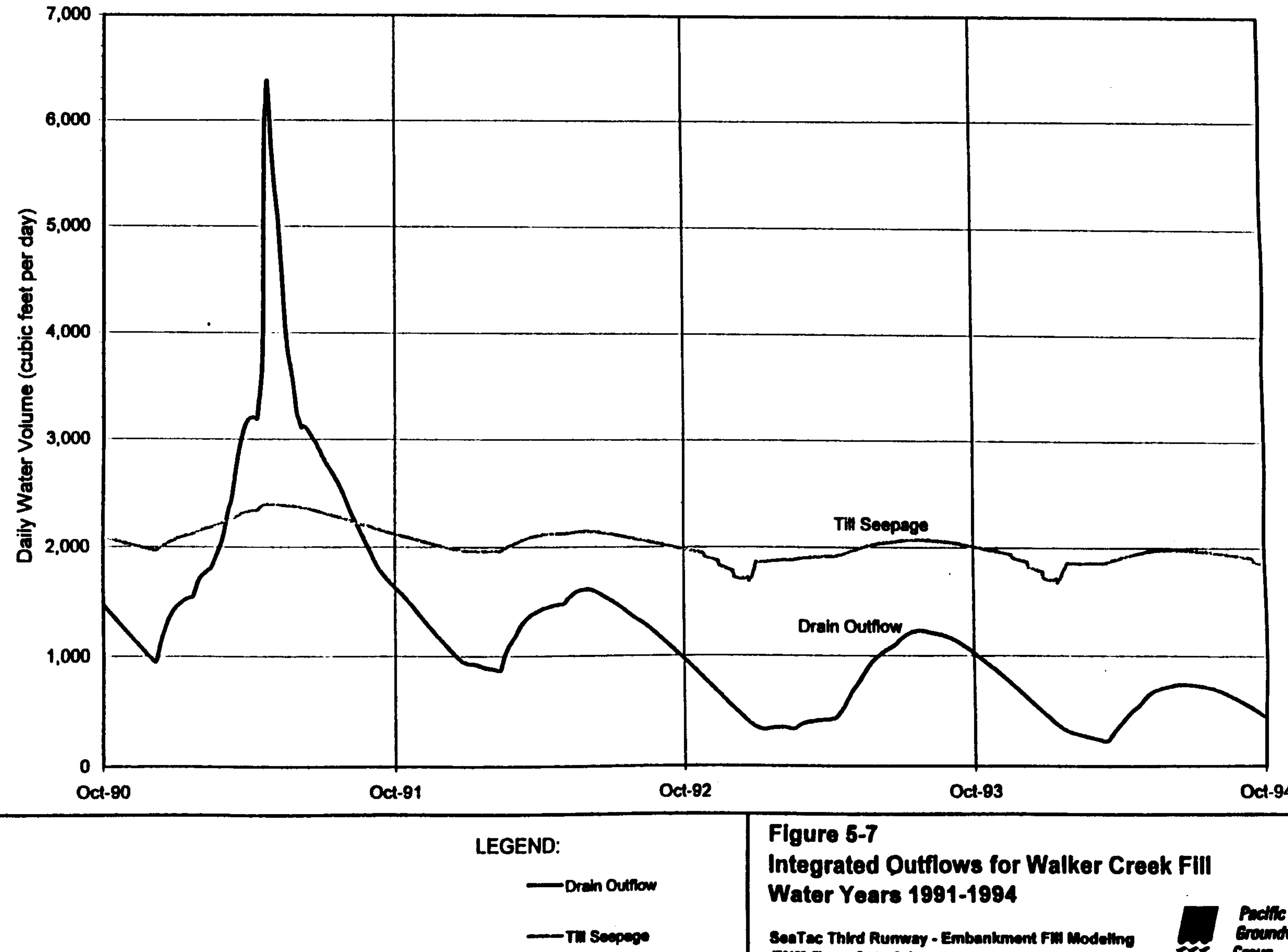


Figure 5-7
Integrated Outflows for Walker Creek Fill
Water Years 1991-1994

SeaTac Third Runway - Embankment Fill Modeling

Pacific Groundwater Group

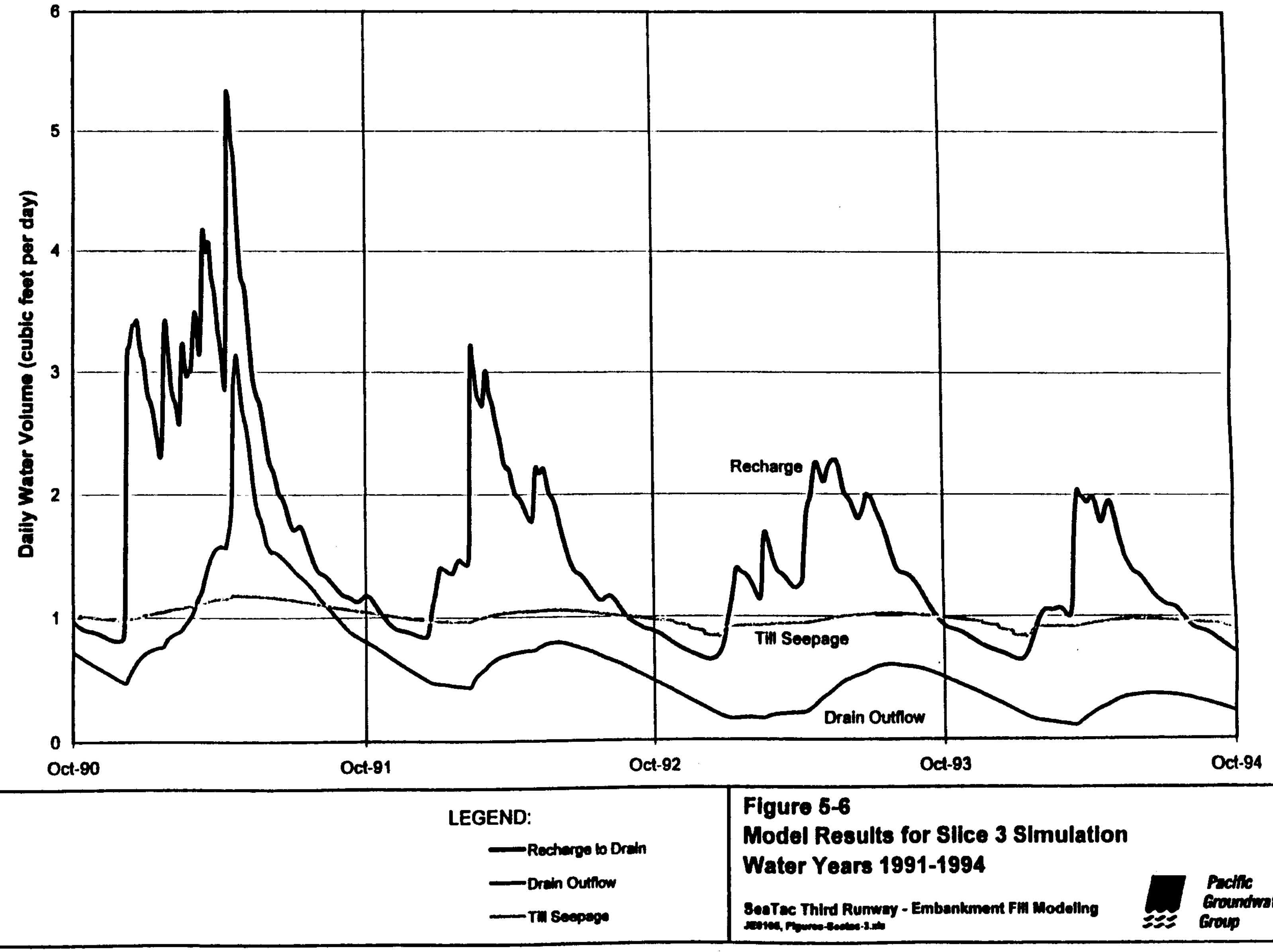


Figure 5-6
Model Results for Slice 3 Simulation
Water Years 1991-1994

SeaTac Third Runway - Embankment Fill Modeling

Pacific Groundwater Group

AR 050998

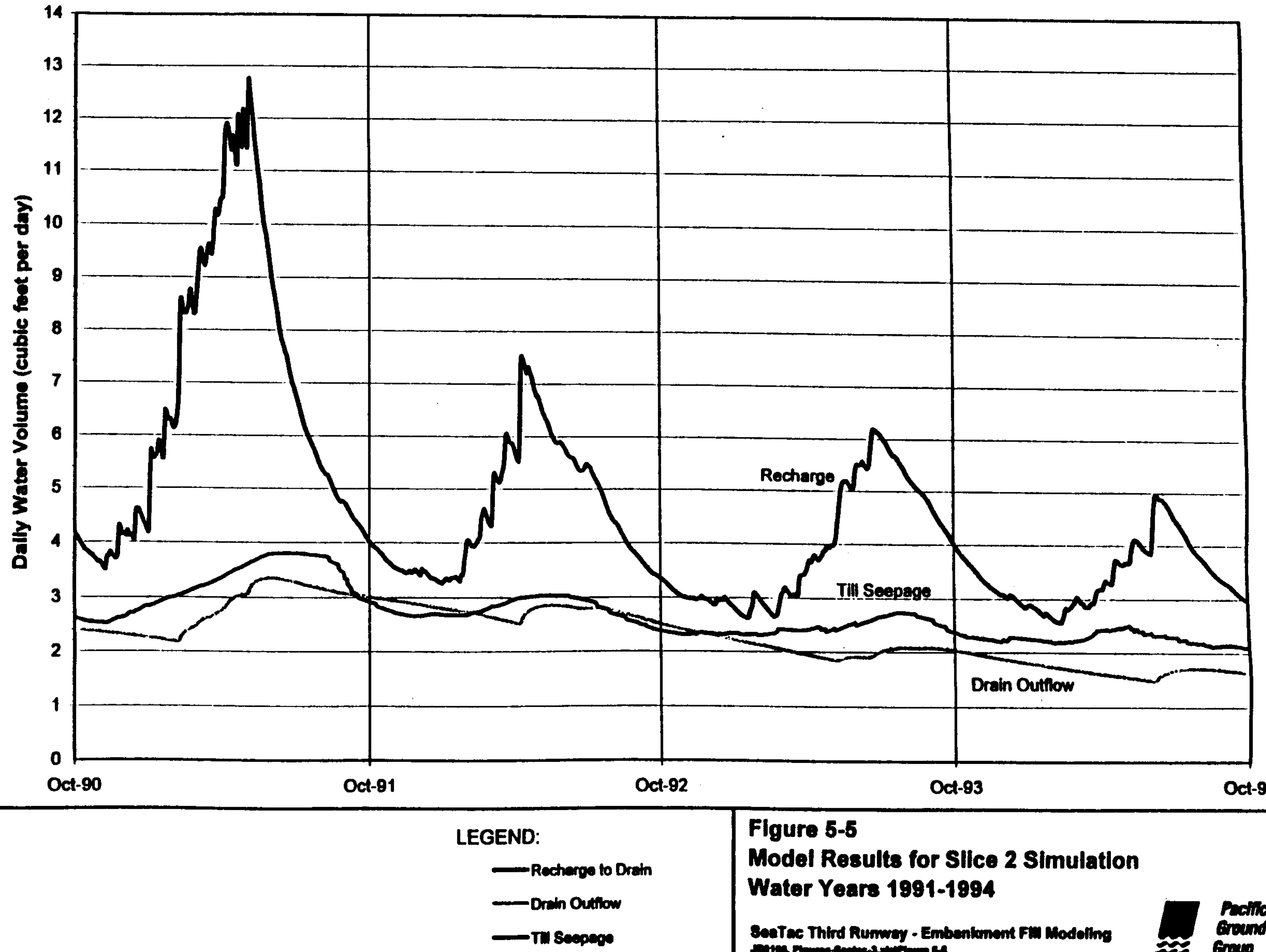
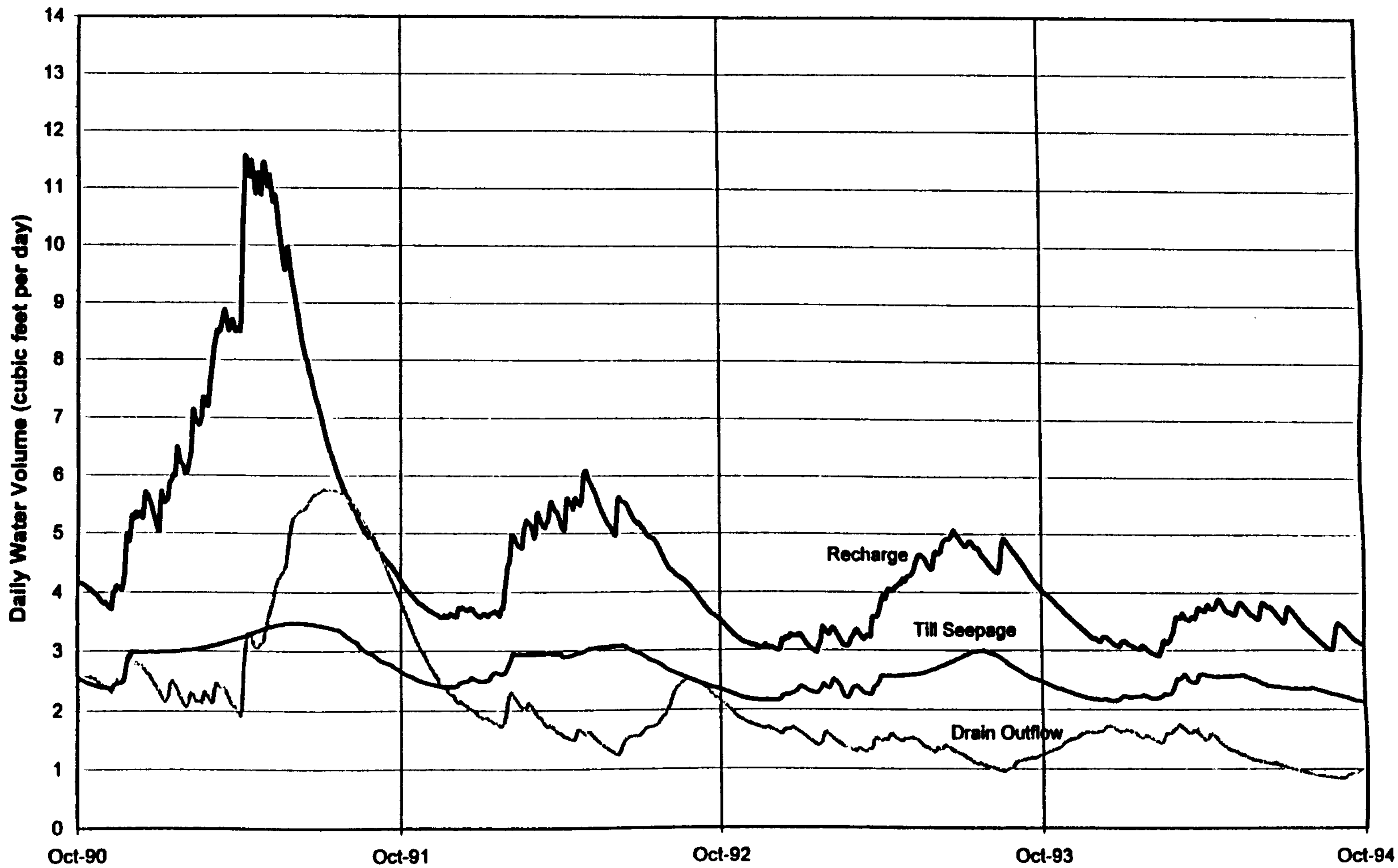


Figure 5-5
Model Results for Slice 2 Simulation
Water Years 1991-1994

SeaTac Third Runway - Embankment Fill Modeling

Pacific Groundwater Group

AR 050999



LEGEND:

- Recharge to Drain
- Drain Outflow
- Till Seepage

Figure 5-4
Model Results for Slice 1 Simulation
Water Years 1991-1994

SeaTac Third Runway - Embankment Fill Modeling
JE0106, Figures_Seatac-3.xls\Figure 5-4

Pacific Groundwater Group