CHARLES ELLINGSON

POLLUTION CONTROL HEARINGS BOARD
FOR THE STATE OF WASHINGTON

AIRPORT COMMUNITIES COALITION and CITIZENS AGAINST SEA-TAC EXPANSION, Appellants, v. STATE OF WASHINGTON DEPARTMENT OF ECOLOGY, and THE PORT OF SEATTLE, Respondents.	PCHB No. 01-160 **PREFILED TESTIMONY OF CHARLES ELLINGSON**

Outline of Testimony

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1. I have personal knowledge of the facts stated in this testimony and would be competent to testify to those facts.

BACKGROUND

Current Position

2. I am a principal hydrogeologist at Pacific Groundwater Group (PGG). PGG is a groundwater and environmental consulting firm with offices in Seattle, Tumwater, and Flagstaff, Arizona. My primary consulting responsibilities are managing projects related to groundwater management, supply, and contamination. Many of these projects have included groundwater modeling and other quantitative analyses. I also perform field analysis, reporting, and testimony roles on many projects. I have worked at PGG since co-founding it in 1987. Between 1982 and 1987, I was a project hydrogeologist at Hart Crowser in Seattle. Between 1980 and 1982, I was a staff hydrogeologist at D'Appolonia Consulting Engineers in Denver, Colorado.

3. I received a B.Sc. degree in Geology/Geophysics from the University of Hawaii in 1978. While at UH I worked in a soil physics laboratory and in the field measuring unsaturated flow parameters. I received a M.Sc. degree in Hydrology from the University of Arizona in 1980. While at UA I studied the theory of unsaturated groundwater flow. I have been active in professional organizations and continuing education since finishing school. A copy of my C.V. is attached as **Exhibit A**.

Retention and Scope of Work

4. The Seattle Tacoma International Airport (STIA) third runway project calls for an embankment to be constructed in the Miller Creek and Walker Creek watersheds. PGG was retained to aid in determining the impacts to streamflows in these creeks. Specifically, PGG's role was to model recharge and redistribution of water within the fill embankment. Our work is also applicable to evaluation of wetland hydrology near the embankment. Although the overall project study area includes the Miller Creek and Walker Creek basins, PGG's evaluation was limited to a small portion of these basins wherein new fill is proposed

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to support the third runway. PGG's evaluation was also limited to modeling of post-construction conditions.

5. PGG also assisted in developing responses to conditions that Ecology place on the Water Quality Certification. Specifically, we participated in generating background materials for the Fill Monitoring and Infiltration Contingency Measures Section of the Low Streamflow Analysis and Summer Low Flow Impact Offset Facility Proposal (Parametrix, et al., December 2001), which has been submitted by the Port as an Exhibit. I will refer to the Parametrix report throughout my testimony as the "2001 Low Flow Report."

EMBANKMENT MODELING

Decision to Use Integrated Model Approach

6. In determining the approach to be used to analyze the low flow impacts of the third runway project, I and other hydrologic consultants retained by the Port of Seattle decided to employ a combination of what we determined to be the best and most appropriate tools available for modeling surface and groundwater flows over, through, and beneath the third runway fill embankment area. Because of Hydrologic Simulation Program — FORTRAN's (HSPF's) superior evapotranspiration (ET) and runoff-modeling capabilities, we selected it to model current conditions, which are dominated by runoff and ET, even in the proposed embankment area. We also used HSPF as the "accounting" software for modeling the built condition, including modeling the net effects to flow during the summer low-streamflow periods. HSPF modeling was performed by Aqua Terra Consultants. Because the HSPF models are not capable of accurately simulating groundwater flows of the type anticipated in the built embankment, we selected additional modeling tools, Hydrus and Slice, to more effectively simulate flow through and below the proposed embankment. Specifically, we selected Hydrus to simulate vertical flow through the embankment fill and Slice to simulate flow beneath the embankment fill.

7. The decision to use an integrated model approach uses the optimal model for each simulation. The existing condition is dominated by runoff and evapotranspiration, which

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HSPF simulates especially well. The proposed future condition is dominated by infiltration and deep percolation, which Hydrus/Slice simulate especially well. Therefore, the modeling approach takes advantage of each model's strengths and avoids the limitations of each particular model.

8. ACC's consultant William Rozeboom's assertion in his pre-filed direct examination that a single model should be used to perform all modeling fails to recognize and account for the specific limitations of any one model's ability to simulate the different flows in the current and proposed future conditions. I therefore disagree with Mr. Rozeboom's criticism of our mixed-model approach. For the same reasons, I disagree with ACC's consultant Patrick Lucia's assertion that our integrated approach "adds undesirable complexity" to the analysis. Removing that complexity through the use of a single model would expose the analysis to the limitations of that single model.

Description of Overall Modeling Approach

9. I summarize the overall modeling approach employed for the built condition as follows. Using precipitation records, Aqua Terra calculated embankment runoff and infiltration from the HSPF models using regional parameters. PGG independently checked the infiltration values against the infiltration capacity of the embankment. We then modeled the variably-saturated vertical flow within the embankment fill using Hydrus and modeled saturated, quasi-horizontal flow at the bottom of the embankment using Slice. The Slice results were then integrated across the fill embankment. Aqua Terra incorporated our results back into the built-condition Miller Creek and Walker Creek HSPF models at appropriate times and locations.

10. To complete its work, PGG relied on two data sets provided by Aqua Terra: (1) hourly direct infiltration from incident precipitation into pervious areas of new fill as calculated by HSPF for grass on flat outwash (model parameter "AGWI"); and (2) hourly runoff from runways and taxiways as calculated by HSPF (model parameter "SURO"). We then independently calculated how much of the AGWI and SURO waters would enter the

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embankment or runoff, based on a soil-texture-based infiltration capacity. As part of that infiltration analysis, we accounted for the fact that runoff from the runway will enter pervious filter strips and that much of it will infiltrate. We then used the hourly average infiltration based on the SURO and AGWI input to calculate daily input into the Hydrus model. This process allowed us to simulate vertical water flow through embankment fill 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 and saturated groundwater flow in the shallow aquifer, which is simulated by the Slice model.

11. The data resulting from the application of the Hydrus and Slice models consisted of the timing and magnitude of runoff from the pervious area, water movement through the soils above the till, and downward flow through the till. PGG provided these data to Aqua Terra and Parametrix for their continuing basin-wide simulation and analysis of post-construction conditions.

MODELED FILL AREA AND THICKNESS

12. PGG used existing GIS coverage 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** of PGG's Embankment Fill Modeling in Support of Low-Streamflow Analysis report of November 27, 2001, attached as Appendix B to the 2001 Low Flow Report. Throughout my testimony I will refer to this report as "PGG's November 2001 report." For the Board's convenience, I have attached a copy of **Figure 2-1** as **Exhibit B.**

13. We calculated fill thickness 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** depicts these features. For the purpose of Hydrus

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modeling, fill thickness was descritized into representative values of 10, 20, 30, 50, 70, 90, 110, 130, and 150 feet.

INFILTRATION CALCULATIONS

14. Aqua-Terra used records of hourly precipitation to calculate hourly runoff (SURO) from impervious surfaces (runway and taxiways) and hourly infiltration (AGWI) into pervious areas with a generic application of HSPF. We then performed a separate calculation to independently estimate the extent to which the sum of SURO and AGWI would infiltrate, or conversely, run off, from filter strips. The total amount of infiltration into filter strips (a portion of AGWI and SURO) and other pervious areas (AGWI only) was then used as input to the Hydrus models. Calculated runoff was accounted for but not used in groundwater modeling.

15. To calculate the infiltration capacity, we used a saturated hydraulic conductivity of 1.35×10^{-4} cm/sec for the sandy fill matrix of the embankment, and assumed no flow through the portion of the fill occupied by gravel particles, consistent with assumptions made throughout PGG's involvement with this project. The fill matrix hydraulic conductivity was determined by a computer code called "Rosetta," which I will discuss later in my testimony. During the 11-year modeling period, the total volume of runoff from the filter strips was 28 and 21 percent of the summed AGWI and SURO volumes for Miller and Walker Creek basins, respectively. A small amount of runoff was also calculated for "other pervious areas" (pervious areas that are not filter strips and therefore do not receive runoff) because AGWI exceeded the calculated infiltration capacity of other pervious area on occasions. The total volume of runoff from the other pervious areas was 6 percent of the AGWI volumes for both basins.

16. ACC's consultant Keith Malcolm Leytham reports that an HSPF model was calibrated to the 1998 runoff data and that an INFILT parameter of 0.02 inches per hour was derived for the 1998 fill. See Dr. Leytham's pre-filed testimony, ¶¶ 38 – 39. He compares that value to our saturated hydraulic conductivity of about 0.08 inches per hour used in the

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calculations, which we derived from the $1.35x10^{-4}$ cm/sec value cited above, and concludes that we have modeled more water moving into the embankment than is likely to occur. In consulting with Joe Brascher, the Port's HSPF modeler, we have concluded that the INFILT parameter cannot be compared directly to saturated hydraulic conductivity as performed by Dr. Leytham. Nonetheless, even assuming the comparison is at least roughly valid, differences of a factor of 4 occur in nature within soil types that may be virtually indistinguishable by other measures. Further, no measures currently exist for determining the ultimate infiltration capacity of the embankment. In my opinion, the Port has properly scheduled further refinement of infiltration capacity knowledge for a time at which it can be measured with greater reliability than the present – that is, during and after construction.

17. Our method of calculating water infiltrating to the pervious areas was compared to a slightly different method performed by Kelly Whiting of King County. I understand that the results of Mr. Whiting's alternative analysis were similar to ours, with our method infiltrating slightly more water than the alternative.

18. Relating to these water balance issues, Mr. Whiting also suggested a modification to Table 3-1 of PGG's November 2001 report, which summarizes water volumes for the test period. Consistent with his recommendations, the revised version of the table only accounts for input water within the water-year 1991 through water-year 1994 (October 1, 1990 through September 30, 1994) test period. Attached as **Exhibit C** is a copy of the modified table. Mr. Whiting also requested that information regarding mass balance, which is discussed in detail in Sections 4 and 5 of PGG's November 2001 report. Attached as **Exhibit D** is a tabular summary of integrated outflows for the 4-year test period.

HYDRUS MODELS
MODELING VERTICAL FLOW THROUGH EMBANKMENT FILL

General Description of Hydrus

19. PGG evaluated vertical flow of recharge between the root zone and the water table within the embankment drainage layer using the model Hydrus-1D, which I refer to as

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"Hydrus." Hydrus simulates the spreading of recharge fronts as they are predicted to move vertically through the embankment fill. Model results describe the lagging and dampening of the recharge pulse for different thicknesses of fill material. Lagging causes 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. Hydrus output was used as recharge input to the Slice models.

20. We used separate Hydrus models to simulate flow through different thicknesses of fill, an approach that has proven to be quick, flexible, and accurate. ACC's consultants GeoSyntec and Patrick Lucia have criticized our use of Hydrus 1-D, asserting that our decision not to utilize Hydrus's two-dimensional capabilities resulted in inaccurate data. However, Dr. Lucia's own two-dimensional analysis of the embankment, as discussed in his pre-filed written direct examination and as shown in GeoSyntec's diagrams depicting that analysis, indicates that the-one dimensional approximation we conducted is quite sound. I refer to Figure 6, Soil Moisture Content, to Dr. Lucia's pre-filed direct examination. This Figure, although based on erroneous initial moisture conditions, indicates that little horizontal flow occurs. The diagram clearly indicates that there is minimal horizontal spreading from the columns of infiltrating water. Thus differences between one-dimensional and two-dimensional modeling are small and effectively insignificant in this case.

Spatial and Temporal Discretization

21. We set up Hydrus models to simulate a total of 12 vertical profiles of varying thicknesses for the proposed embankment. We selected eight profiles for the Miller Creek watershed (using fill thicknesses of 150, 130, 110, 90, 70, 50, 30, and 10 feet) and four for the Walker Creek watershed (using fill thicknesses of 50, 30, 20, and 10 feet). **Figure 2-1** of PGG's November 2001 report depicts the variation of fill thicknesses expected within the embankment, upon which we based the modeled fill thicknesses.

22. We specified that the top of the Hydrus models receive recharge equal to the daily infiltration volumes calculated for the pervious area of the embankment. Discretization

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of the soil profile emphasized detail within the top six inches of the column to accommodate dramatic changes in recharge and flow in responses to changes in the infiltration. Finer detail within this portion of the soil column improved accuracy and model stability. Model timesteps were optimized by Hydrus, and were typically on the order of 0.1 day. The models were run for water-years 1984 through 1994, with only the last four water-years comprising the 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.

Characterization of Fill as Soil

23. We based our calculations of the texture of the modeled fill on specifications for Phase 1 fill installed in 1998 and 1999, on proposed embankment composition, and on the texture of Phase 1 fill measured by 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 PGG's SeaTac Runway Fill Hydrologic Studies Report to the Department of Ecology (2000), which the Port has submitted as an Exhibit.

24. Except for Type 1 soils used as fill in limited areas near the MSE walls and runways, the embankment will be comprised of imported material of several types. We calculated the average properties of the embankment and characterized that material "general fill." We estimated average bulk texture for the general fill to be 55 percent gravel and 45 percent sand-plus-fines matrix. We estimated the sand-plus-fines matrix to be comprised of an average of 63 percent sand and 37 percent silt; clay was assumed to be absent. General fill will not be used as backfill for the MSE walls and under runways where greater compaction and drainage properties are required. In those areas a coarser "Type I" fill will be used.

25. Based on observed deviations of variably saturated flow in very coarse soils from classical flow predicted by computer models, we chose not to attempt a simulation of flow in Type 1 fill. Instead, we assumed Type 1 fill to be infinitely permeable; it therefore provides immediate delivery of recharge to the underlying drain layer. For this reason, Type 1

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soils were not modeled explicitly using Hydrus, although we did consider recharge to the drain layer where Type 1 soils existed in modeled areas.

26. Although we have refrained from modeling Type I fills with Hydrus, GeoSyntec has apparently attempted that modeling, as reported in Dr. Lucia's pre-filed direct examination and GeoSyntec's February 7, 2002, report upon which Dr. Lucia's testimony is based. Because of the fundamental limitations of computer models to simulate variably saturated flow in very coarse soils of this type, we expect Dr. Lucia's Hydrus analysis of flow in Group 1B fill (which is part of Type I fill) to be inaccurate. In my opinion, acknowledging modeling limitations and, where necessary, making appropriate simplifying assumptions with known consequences, results in more reliable results. I maintain that our particular application of the Hydrus models is superior to that proposed by Dr. Lucia.

27. In his pre-filed direct examination, Dr. Lucia criticizes our modeling effort for not addressing the uncertainty resulting from variability of the fill. Although specifications allow for variation in the fill's average unsaturated flow parameters, however, they do not allow for the extremes of variation indicated by Dr. Lucia and GeoSyntec. That is because GeoSyntec has misrepresented the differences between individual fill types as the potential variability of the fill as a whole. See Figures 2, 3a, and 3b to Dr. Lucia's examination. As demonstrated by the analysis of fill texture in PGG's 2000 Hydrologic Studies report, and by Dr. Lucia's own Figures, the soil texture we used for embankment modeling is a good representation of average expected fill texture. GeoSyntec's modeling of individual fill types disregards the fact that the individual fill types are part of a mixed embankment. It therefore overstates potential variability in modeled lag times.

28. The number of factors involved in predicting future low flows is high. I understand that the Port's approach to uncertainty focuses on monitoring the net effects of all factors combined and responding to that real-life data, not assessing the theoretical sensitivity of each individual parameter. It is my opinion that considering a formal sensitivity analysis on

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individual Hydrus/Slice parameters would not have resulted in different conclusions in our low flow assessment.

Representation of Fill in Hydrus

29. As stated previously, we modeled the sand-plus-silt matrix as an evenly-distributed 45 percent of the general fill and assumed all water flow to occur within this active matrix. To maintain a water balance while modeling water flow, we divided effective recharge values by 0.45 and used the resulting figure as input to the top of Hydrus. This matrix-scaled recharge rate used in Hydrus is called the "effective matrix recharge." Our 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. For this reason, we treated the gravel fraction of the general fill as inactive. 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 recharge rate effective for the entire embankment fill.

30. While PGG's approach explicitly dictates that infiltrated water can only flow through the non-gravel portions of the embankment (e.g. 45% of the total embankment volume), GeoSyntec's approach, as discussed by Dr. Lucia in his pre-filed direct examination, allows infiltrated water to flow through the entire embankment volume, including gravel portions. Dr. Lucia wrongly asserts that PGG has "ignored" gravel content in its analysis. This is simply not the case. For infiltration calculations, we adjusted hydraulic conductivity using a well-accepted gravel-correction approach. Our infiltration calculations therefore account for gravel content through adjustment of input flux to Hydrus, whereas Dr. Lucia's approach changes the hydraulic properties of the embankment fill so that they are consistent with flow limited to the non-gravel portions of the embankment. Both approaches are, therefore, designed around the same assumption, that vertically downward saturated flow occurs predominantly in the matrix of the embankment fill rather than through gravel. As a consequence, we see no fundamental disagreement between the two conceptual models.

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31. Modeled hydraulic properties for the active fill matrix were generated with the U.S. Soil Salinity Laboratory's computer model and database called "Rosetta." Rosetta provided estimates of parameters used to describe the relationship between soil moisture, soil tension (suction), and soil hydraulic conductivity. Although the actual value(s) of hydraulic conductivity are not known for the proposed future embankment, the value calculated by Rosetta provides a reasonable estimation 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.

32. Dr. Lucia notes that uncertainty results from our use of Rosetta. However, such uncertainty is inherent in all groundwater modeling, particularly in modeling of variably-saturated flow, because the ability to determine actual parameters that control flow is limited even when fill texture is known. It is limited theoretically because physically-based computer models do not predict all types of flow and do not perfectly model the types of flow they attempt to address. It is limited practically because the plans and specifications can not predict precisely what the future fill texture will be, much less the unsaturated flow parameters. Although Dr. Lucia asserts that these uncertainties will result in inaccurate data and therefore unreliable conclusions, it should be understood that an order of magnitude (10x) is an often-cited range of certainty applied to groundwater calculations.

Initial Moisture Conditions in Hydrus

33. We modeled a total of 11 years of daily precipitation within Hydrus and Slice, and exported only the last four years back to HSPF for low flow assessment. The long pre-test period was performed to assure that data used in the low flow assessment was not influenced by artifacts of initial model conditions. In contrast to our careful consideration of model initial conditions, GeoSyntec has drawn extensive conclusions about groundwater lag times based on faulty initial conditions and a flawed conceptual model.

34. Dr. Lucia has criticized our low flow modeling through the embankment, asserting that we have erroneously concluded that "the discharge of water from the

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embankment will occur immediately after the completion of construction with no regard for the ability of the embankment to store water prior to discharging water into the gravel drain." Dr. Lucia's pre-filed direct examination, ¶ 20. His concerns can be easily dismissed. Dr. Lucia has incorrectly assumed that fill will be placed dry and will remain dry despite exposure to rainfall. He has also assumed that all construction will be completed instantaneously.

35. Our modeling, in contrast, recognizes that soils will be excavated from borrow sources at moisture contents reflecting roughly normal, in-situ conditions in the region. In other words, the moisture content of fill used will be in rough equilibrium with long-term conditions in the area. In addition, moisture-conditioning of the fill to attain proper densities (within 95 percent of maximum bulk density) will result in degrees of saturation that are typically between 60 and 80 percent. Moreover, our modeling account for the exposure of these soils to rainfall during the six-year period of construction. This precipitation will presumably maintain normal moisture content and water movement through the fill. In short, Dr. Lucia's assumptions regarding initial moisture content and the duration of embankment construction do not reflect actual and probable conditions. Consequently, they lead Dr. Lucia to erroneous and invalid conclusions about extensive delays or initial lag time in the seepage flows from the embankment.

Results of Hydrus Modeling

36. Our Hydrus models indicate that the recharge below the root zone will be lagged and dampened as a function of the thickness of the fill. As I discussed previously, lagging delays the arrival of the recharge pulse from its introduction at the land surface to the bottom of the fill, while dampening reduces the overall range of flux in the deeper fill. Lagging and dampening both increase with increasing fill thickness and decrease with increasing annual recharge. The outflow graphs for the Miller Creek basin 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. These outflow graphs for the Miller Creek basin are depicted in **Figure 4-1** of PGG'S December 2001 report. Results for Walker Creek, depicted in

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Figure 4-2, are very similar. For the Board's convenience, these Figures are attached as **Exhibit E**.

37. For quality assurance, we compared total outflow between runs, and total inflow to the average total outflow. Results indicated that, within close tolerances, the same amount of water came out of Hydrus as went in. For the 11-year modeling period, all model runs had the same total outflow to within 3 percent and 1.6 percent, respectively, for Miller Creek and Walker Creek Hydrus models. For the Miller Creek models, total effective recharge was about 1.4 percent less than the average total outflow. For the Walker Creek Hydrus models, total effective recharge was about 0.1 percent less than the average total outflow. These small discrepancies were likely a result of lower storage at the end of the simulation than at the beginning. **Exhibit D** presents additional mass balance information from model output, and is specific to the 4-year test period.

SLICE MODELS
MODELING FLOW BENEATH EMBANKMENT FILL

General Description of Slice Models

38. We developed three finite-difference Slice models to simulate groundwater flow within the embankment drain layer and existing soils below the embankment. Slice configurations were based on subsurface data contained in available geotechnical and hydrogeologic reports and from pre-fill and "built" topography of the third runway area. The Slice models were used to accumulate flows from the embankment (Hydrus output) and move it laterally and vertically to the Miller Creek or Walker Creek wetlands under post-construction conditions. We incorporated these flow rates into overall low flow predictions. ACC's consultant William Rozeboom's generalized criticisms that the construction materials may "accelerate groundwater velocities" are therefore not very meaningful, as whatever effect these materials have has been quantitatively accounted for.

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Slices 1, 2 & 3

39. PGG originally developed Slice 1 for the Ecology study. We reapplied the model for this low-flow analysis using daily recharge data for 1984 through 1994 and a more representative runway configuration, but the model otherwise remained unchanged. Slice 1 is located through the thickest portion of the fill embankment, with a fill thickness of up to 160 feet. A simplified cross section showing Slice 1 is presented in **Figure 5-1** of PGG's November 2001 report. For the Board's convenience, Figures 5-1, 5-2, and 5-3 are attached collectively as **Exhibit F**.

40. We developed Slices 2 and 3 for the low flow analysis using new interpretations of existing hydrogeologic and fill data. Slice 2 is located through the northern portion of the fill embankment near the northern end of the third runway. **Figure 5-2** of PGG's November 2001 report presents a simplified cross section showing Slice 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.

41. Slice 3 is located in the Walker Creek basin immediately north of the South MSE wall. See **Figure 5-3** of PGG's November 2001 report, presenting a simplified cross section. A fill thickness of up to 40 feet occurs in the western end of this slice. **Figure 2-1** of PGG's November 2001 report (Exhibit B to my testimony) shows the locations of all the Slices.

Results of Slice Modeling

42. The results of the three Slice models indicate that a complex set of factors control the relationship between input (recharge to the drain) and output (Qvr/drain outflow and downward flow through till). As we expected, the timing of recharge to the drain layer is controlled by the type and thickness of fill in the Slice. More uniform fill thickness in Slice 3 results in more seasonal variability of recharge to the drain layer compared to Slices 1 and 2. We also observed that the presence of Type 1 fill causes output to be nearly as variable as input on Slice 1, and to be smoother for the other slices where Type 1 fill is not proposed. I

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have consulted with Kelly Whiting of King County regarding his concerns about the variability ("spikiness") of the Slice 1 output and my belief that this variability resulted from the assumption of infinite permeability for Type 1 fill and did not constitute a modeling error. Mr. Whiting and I agreed that actual outflow is likely to be smoother than modeled at Slice 1.

43. The results also indicate that downward flow through the till is seasonal due to changes in aquifer saturation. Downward flow through till is also greater on average than Qvr/drain outflow, and is sensitive to till permeability. **Figure 5-4** of PGG's November 2001 report shows the results of the Slice 1 model.

Integration of Slice Results Over Entire Fill Areas

44. The Slice model output is two-dimensional. We calculated three-dimensional groundwater discharge quantities for Miller and Walker Creeks by multiplying the unit-width flow quantities from representative Slice model output by effective basin widths. This process integrated the Slice model results over the entire embankment and ensured that approximate mass balance was maintained. The resulting three-dimensional flows are called "integrated flows," as described below.

INTEGRATED FLOW ESTIMATES

Walker Creek Fill

45. For the Walker Creek fill area, the timing and magnitude of Qvr/drain outflow varies seasonally. The model predicts maximum flows during spring or early summer and minimum flows during winter. Estimated annual maximum Qvr/drain outflows through the fill range between approximately 3,500 cubic feet per day (cfd) in water year 1991, with a peak flow predicted in late March, and about 1500 cfd in 1994, with a peak flow predicted in late April. We predict annual minimum Qvr/drain outflows to occur between October and December, with some years experiencing a period of no flow from the Qvr/drain. Integrated estimates of Qvr/drain outflow and downward flow through till for the Walker Creek fill area for water years 1991 through 1994 are presented in **Figure 5-7** of PGG's November 2001 report.

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Miller Creek Fill

46. Qvr/drain outflow rates from the Miller Creek fill embankment are relatively constant, but with a smooth seasonal pattern. These outflow rates are punctuated by spikes during rainstorms, which we believe to be a modeling artifact of the infinite permeability assumed for Type 1 fill. We expect that actual flow rates will likely be steadier. Estimated annual maximum Qvr/drain outflows range from about 18,000 cfd in April of 1991 to about 8,000 cfd in late-July of 1994 following a year of low recharge. Integrated estimates of Qvr/drain outflow and downward flow through till for the Miller Creek Fill area for water years 1991 through 1994 are presented in **Figure 5-8** of PGG's November 2001 report.

USE OF INTEGRATED FLOW ESTIMATES

For Low Streamflow Modeling

47. We transmitted our integrated flow estimates for Miller Creek and Walker Creek basins to Parametrix and Aqua Terra for use in HSPF models of Miller and Walker Creeks. Specifically, we provided time series of total daily discharge from above the till (Qvr/drain outflow), and total daily discharge through the till (downward flow through the till).

48. Embankment model results used in low-flow calculations are consistent with moisture conditions that will prevail over the long term. Also, results reasonably approximate moisture conditions that will prevail during and soon after construction, because construction will occur over several years, and moisture will likely be added to allow compaction. There will therefore be no long-term lag time between construction and initial discharges from the embankment as predicted by Dr. Lucia. The fact that groundwater already discharges from the base of the 1998 fill supports our conclusion on this issue.

For Wetland Hydrology Assessment

49. The embankment modeling results, and the hydrogeologic characterization that supports the modeling, can be used to assess possible construction effects on wetlands near the embankment.

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50. Water levels in wells completed in wetland soils and the underlying Qva aquifer are near land surface in the riparian wetlands of Miller and Walker Creeks. **Figure 5-1** of PGG's November 2001 report depicts these features. The Qva aquifer is a regional groundwater body that will be quite insensitive to local construction. As a result, changes to Qva water levels, and their support of wetland moisture conditions, are not likely to change significantly as a result of embankment construction. Water tables below fills typically rise as a result of longer groundwater travel paths.

51. The Hydrus and Slice modeling PGG conducted for the Ecology project suggests that wetlands will likely remain wetter further into the dry season under proposed conditions compared to current conditions because of the longer travel times of groundwater from recharge locations to the drain and underlying Qvr at the downstream end of the embankment. Direct comparison of pre- and post-development conditions are possible using the results from the Ecology project because Hydrus and Slice were used to model both current and proposed conditions.

52. Although no such direct comparison is possible using the Hydrus and Slice modeling results conducted for the low flow assessment, the modeling for low flow issues indicates that drain/Qvr discharges will occur to the wetlands throughout the dry summer months under proposed future conditions. In particular, as indicated in **Figure 5-8** of PGG's November 2001 report, drain/Qvr discharges are predicted to be rather constant in the Miller Creek drainage. As **Figure 5-7** indicates, we predict that drain/Qvr discharges will be more seasonal in Walker Creek, but the low discharge season is likely to be after the onset of fall rains.

FILL INFILTRATION TESTING

53. In response to the Department of Ecology's request, PGG researched available means of measuring infiltration capacity on the completed embankment. We recommended numerous large-scale "pilot infiltration tests," as sanctioned by the Department of Ecology in its Stormwater Management Manual for Western Washington, and a statistical means of

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assessing whether the field results differed significantly from modeled values. The tests were specified for the various fill types comprising the near surface of the embankment. These recommendations were adopted as part of the Fill Monitoring and Infiltration Contingency Measures Section of the December 2001 Low Flow report.

54. The infiltration tests are designed to measure the saturated vertical hydraulic conductivity of the near-surface embankment. That parameter can be related to the infiltration capacity of the embankment as we calculated it for modeling. Contrary to Dr. Leytham's assertion that these tests cannot be used to assess infiltration capacity of the embankment, the relationship between saturated hydraulic conductivity and infiltration characteristics is well understood. These tests can indeed be used for that purpose. Dr. Leytham's recommendation that a surface water-based water balance be measured for a section of completed fill would develop data for HSPF or a similar surface water model calibration, but would not directly measure infiltration capacity as would infiltration tests. Although monitoring of the major surface water paths on a section of completed embankment might provide useful complementary data, I disagree that this procedure is necessary to meet the Department of Ecology's objective for assessment of the groundwater model variable.

CONCLUSION

55. I am familiar with every aspect of PGG's involvement with assessing hydrologic impacts of the proposed construction of the third runway at STIA. Our results were developed by groundwater specialists using reliable concepts and tools, and provide sound input to low flow modeling and wetland impacts. Of course, our results are subject to the types of uncertainties as are any analyses of variably-saturated groundwater flow. I believe, however, that the Port's plan to address a primary current uncertainty by measuring infiltration capacity of the fill when it is available for measurement will address the prime uncertainty. The measurement results will be tested against modeling assumptions, and contingency actions are identified in case the modeling assumptions are shown to deviate significantly from field measurements. I also concur with the Port's plan to monitor wetland

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conditions and streamflows to measure the bottom-line on hydrologic effects. In short, I believe the Port's approach of design based on sophisticated modeling, coupled with construction and post-construction monitoring, represents the best possible approach.

I declare under penalty of perjury under the laws of the State of Washington that the foregoing is true and correct.

Executed at Seattle, Washington, this 6 day of March 2002.

Charles Ellingson

AR 016315

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PRE-FILED TESTIMONY OF CHARLES ELLINGSON

EXHIBITS

A	Resume
B	Figure 2-1 of PGG's Embankment Fill Modeling in Support of Low-Streamflow Analysis report of November 27, 2001
C	Modified Table 3-1 of PGG's November 2001 report
D	Tabular Summary of Integrated Outflows
E	Figures 4-1 and 4-2 of PGG's December 2001 Report
F	Figures 5-1, 5-2 and 5-3 of PGG's November 2001 Report

A

Charles T. Ellingson, RPG, CGWP
Principal Hydrogeologist

Education and Other Qualifications

M.S. Hydrology, 1980, University of Arizona
B.S. Geology/Geophysics, 1978, University of Hawaii
Registered Professional Geologist, 1990, State of Oregon
Certified Groundwater Professional, 1990, Association of Groundwater Scientists and Engineers

Professional Experience

Mr. Ellingson is a co-founder and principal hydrogeologist of Pacific Groundwater Group, bringing to the firm 22 years of consulting experience in aquifer protection, contaminant hydrogeology, basin hydrology, and water supply. His educational background in groundwater hydraulics complements his experience exploring, testing, and modeling a wide variety of groundwater regimes: single- and multi-aquifer systems, unsaturated soils, fractured aquifers, and two-phase flow systems. He has directed groundwater development projects that have involved evaluating regional aquifers, siting and designing wells and well fields, and analyzing impacts to surface water. Mr. Ellingson's other areas of expertise include groundwater management, contaminant assessment, design of remedial measures, and modeling the hydrologic effects of land development. He was an invited participant in the State's technical advisory committee on hydraulic continuity and co-authored *Report of the Technical Advisory Committee on the Capture of Surface Water by Wells,* produced for Ecology in 1998. Mr. Ellingson's recent activities involving land development include management of the multi-disciplinary team to independently assess hydrologic effects from construction of the SeaTac third runway, evaluating potential impacts to ground and surface water from a rezone proposal in Thurston County, and leading the groundwater efforts necessary to develop a basin plan focused on flood mitigation for Salmon Creek in Thurston County.

Representative Project Experience

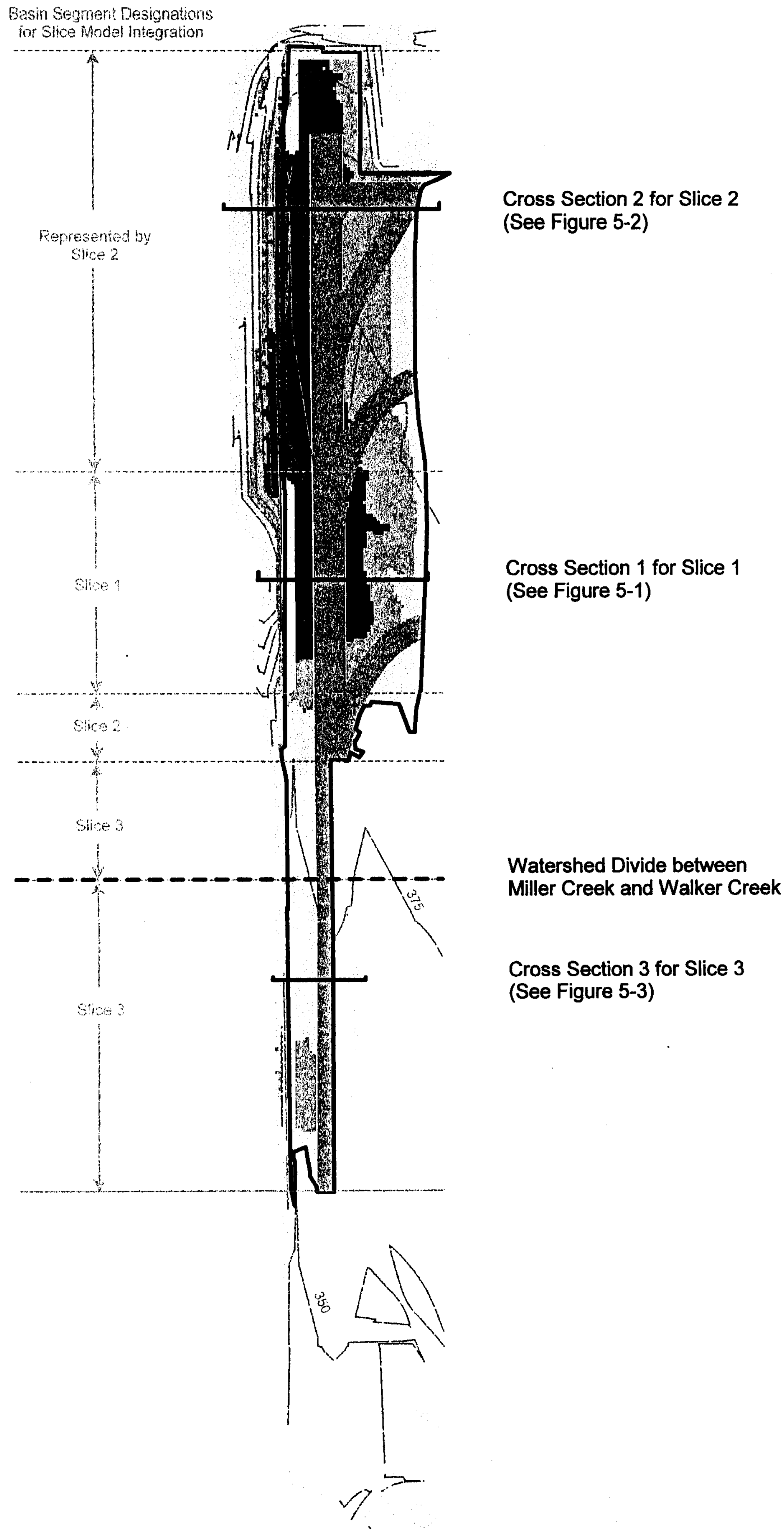
- Predicted groundwater flooding severity and return periods as part of basin planning in the Salmon Creek Basin in Thurston County. Statistical methods and GIS were used to characterize the shallow groundwater regime and flooding potential on a detailed scale. Specified groundwater modeling requirements as part of land development standards used by Thurston County.
- Project manager of team of surface water, fisheries, wetlands, and groundwater specialists required to assess hydrologic impacts from construction of the SeaTac third runway. Worked closely with Port of Seattle, King County, public, and Ecology personnel to develop and implement this highly sensitive project. Assessed results of various existing surface water and groundwater models, and developed new models to complement the others.

- Identified water supply options and water right requirements for a proposed natural gas/steam power plant in Wallula, Washington requiring up to 9,500 gpm of supply.
- Assisted with the planning and development of the City of Tumwater's groundwater supply. The project required wellhead protection planning and drilling multiple test and production wells.
- Completed the hydrogeologic portions of a RCRA Part B Permit application. Characterized the groundwater migration paths in an extremely variable glacial regime.
- Brought five solid-waste landfills into compliance with the Washington State groundwater monitoring regulations.
- Characterized the site of a proposed dangerous waste landfill in Grant County, Washington, for a RCRA Part B Proposed Permit. The project required evaluating tests conducted in hard-rock aquifers and soils.
- Analyzed regional hydrogeologic data to develop a groundwater-surface water model of Renton Cedar River aquifer. The model required short- and long-term transient calibrations that considered recharge from the river and influx from groundwater. It was used to optimize aquifer management despite groundwater contamination problems and required in-stream flows.
- Conducted a MTCA Remedial Investigation at a bulk petroleum plant in the Port of Tacoma.
- Analyzed regional hydrogeologic data to evaluate groundwater resources in Kitsap County, Washington. The project required assessing the impacts of development on other wells and surface waters and assessing the impacts of on-site septic drain fields on water quality.
- Conducted a Remedial Investigation/Feasibility Study for the Tacoma Landfill. The project required defining the groundwater flow regime, modeling contaminant transport, and designing and installing a groundwater extraction system.
- Assisted a municipal water purveyor in Pierce County, Washington, in developing its groundwater supplies. The project required evaluating groundwater resources, recommending well locations, and designing a 2,000-gpm well.
- Designed, installed, and tested wells for a 1,000-gpm water supply at uranium mill in Central Wyoming.
- Characterized the vadose zone beneath a proposed liquid waste impoundment in eastern Washington; modeled potential impacts to the vadose zone and aquifer under various release scenarios.
- Assessed the suitability of siting a landfill over an environmentally sensitive aquifer in Whidbey Island, Washington.

Publications and Presentations

- Invited speaker and participant in regional workshops addressing groundwater protection from land uses (storm water, septage) and industrial elements (pipes, tanks) in Renton, Washington.
- Invited by Ecology to participate in the Technical Advisory Committee on the Capture of Surface Water by Wells, a committee formed to help regulators evaluate impacts that may result from issuing additional water rights in Washington State. Key participant in Report.
- "Brine Reservoirs in the Castile Formation, Southeastern New Mexico", by R.S. Popielak, R.L. Beauheim, S.R. Black, W.E. Coons, C.T. Ellingson, and R.L. Olsen, TME 3153, Technical Support Contract to U.S. Department of Energy, Waste Isolation Pilot Plant, Albuquerque, New Mexico, 1983.
- "When is Modeling Necessary for Problem Solving?", by C.T. Ellingson; abstract and lecture for short course titled "Practical Applications of Groundwater Flow and Contaminant Transport Models", August, 1985, University of Washington, Seattle, Washington.
- "Grant County Waste Management Facility", by G.W. Smedes and C.T. Ellingson; abstract of presentation given at the 1985 Pacific Northwest Pollution Control Association Convention - Hazardous Waste Management Session, October, 1985.
- "Irrigation Impact Issues at the Proposed Grant County Dangerous Waste Management Site", by C.T. Ellingson; In: Proceedings of the Focus Conference on Northwestern Ground Water Issues, May 1987; National Water Well Association, 6375 Riverside Dr., Dublin, OH 43017.
- "Interesting Issues: Tacoma Landfill Hydrogeology", by Charles Ellingson and Russell Prior, at Washington Hydrologic Society Meeting, November 18, 1993.
- "Development and Implementation of a Comprehensive Aquifer Protection Program for the City of Renton", by Carolyn Boatsman, Michael Warfel, Charles Ellingson, and Geoff Clayton; In: First Symposium on the Hydrogeology of Washington State, August 1995.

B



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

Figure 2-1

Site Features for Hydrus-Slice Modeling

SeaTac Third Runway Embankment Fill Modeling JE0105

Pacific Groundwater Group

AR 016322

k:/pony/seatac_ii/3rdrunway_depthofill/3rdrunway_010511.apr (figure 2-1), 11/15/01

C

Table 3-1
Summary of Water Volumes for Test Period

	Water Available to Filer Strip	Water Available to OPA	Runoff from Filter Strip (RO1)	Runoff from Other Pervious Area (RO2)	Water excluded by Hydrus (RO3)	Water artificially removed from Hydrus to promote stability (RO4)	Total Runoff	Total Infiltration
Miller Creek Modeled Fill Area								
Water Volume (ft3)	24,615,402	10,539,200	6,950,896	624,474	110,293	0	7,685,662	27,468,939
Percent of total water	70%	30%	20%	2%	0%	0%	22%	78%
Percent of water to filter strip			28%					
Percent of water to other pervious area				6%				
Walker Creek Modeled Fill Area								
Water Volume (ft3)	4,569,798	599,425	933,633	35,517	20,046	8,686	997,882	4,171,340
Percent of total water	88%	12%	18%	1%	0%	0%	19%	81%
Percent of water to filter strip			20%					
Percent of water to other pervious area				6%				

Test period is Oct 1 1990 through Sept 30 1994.

D

Summary of Modeled Water Volumes for the 4-Year Test Period

	Total Infiltration From Recharge Analysis	Hydrus Input	Hydrus Output Note 1	Integrated Outflows from Slice Models
Miller Creek Modeled Fill Area				
Water Volume (ft3)	27,468,939	27,522,016	27,314,383	28,571,973
Percent of Total Infiltration	100%	100%	99%	104%
Walker Creek Modeled Fill Area				
Water Volume (ft3)	4,171,340	4,176,446	4,111,325	4,292,734
Percent of Total Infiltration	100%	100%	99%	103%

Note 1: The Hydrus output volumes are the means of the various Hydrus models for different fill thicknesses.
The standard deviation of output from the individual Hydrus runs is 0.8% to 0.9% of the mean.

E

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

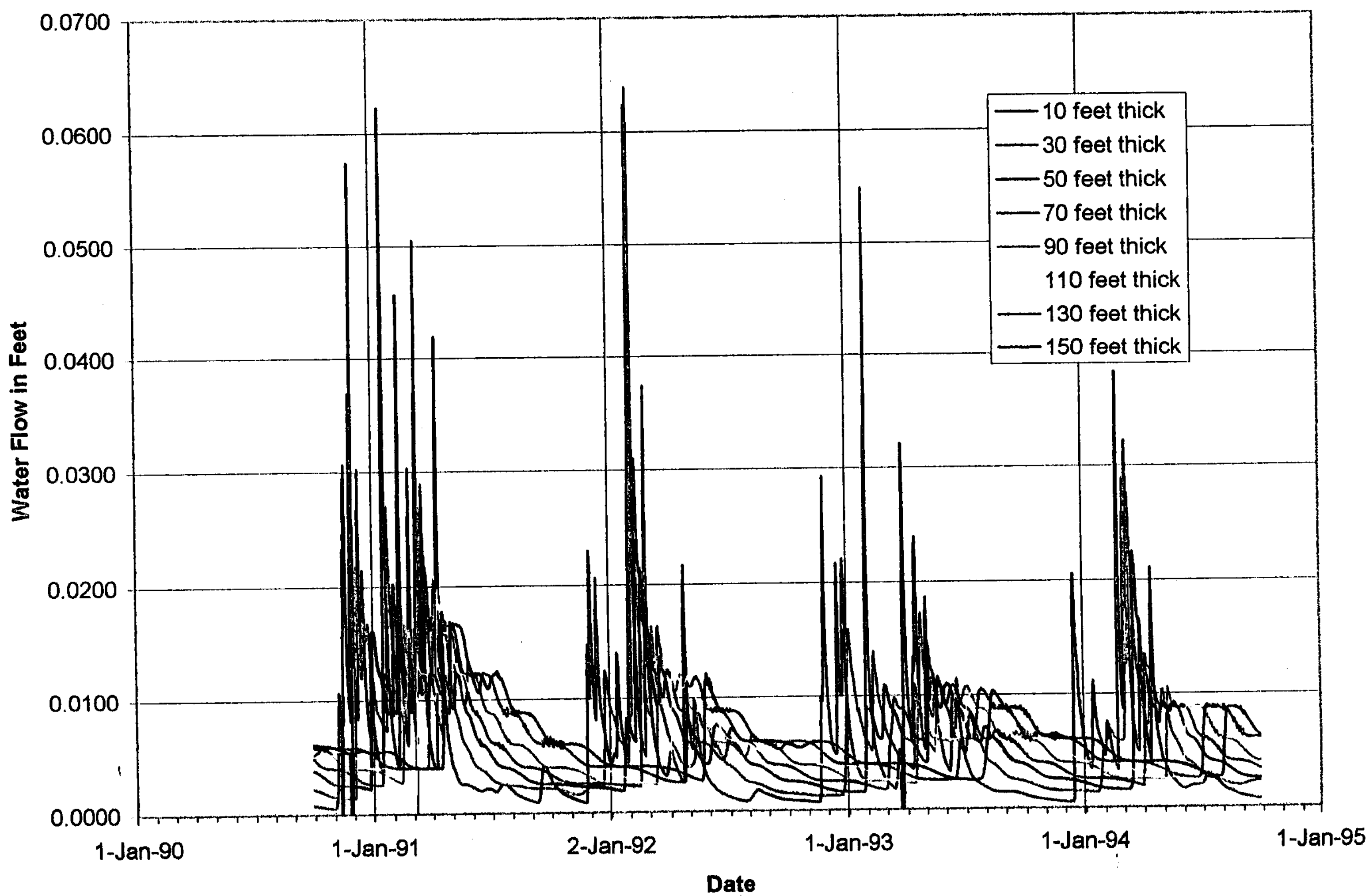
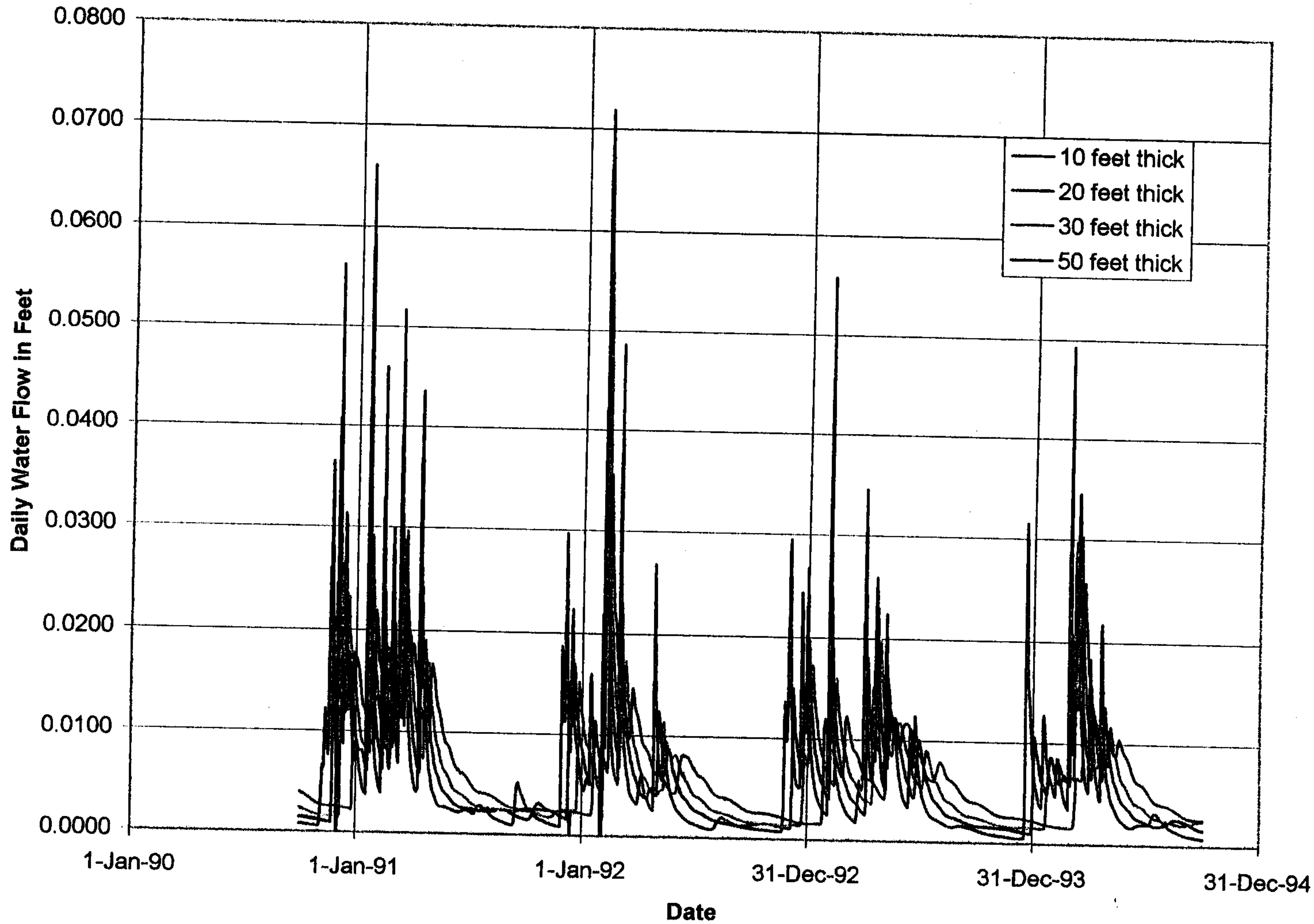
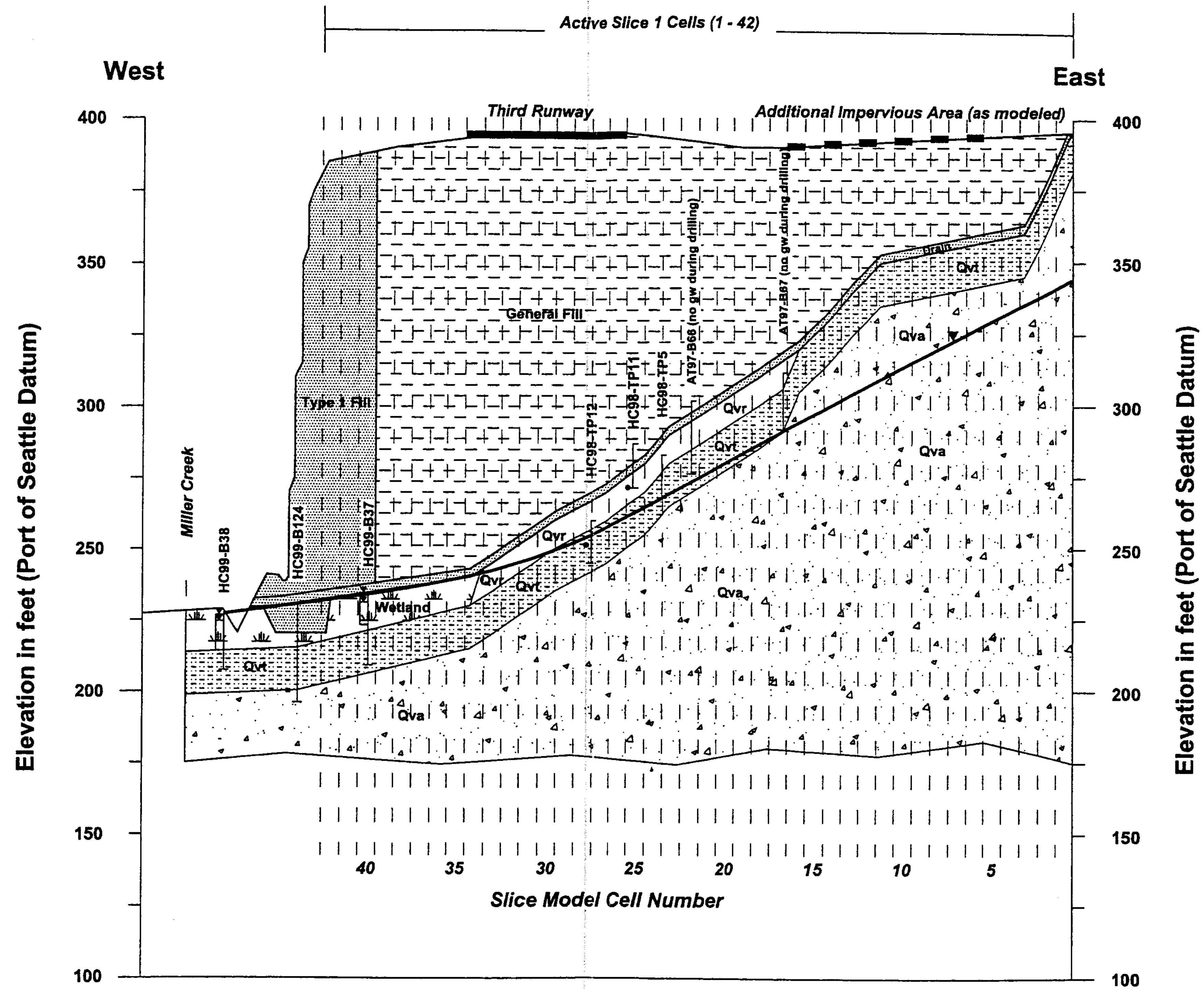


Figure 4-2 - Hydrus Model Output for Walker Creek Fill - Water Years 1991 - 1994



F



AR 016331

LEGEND

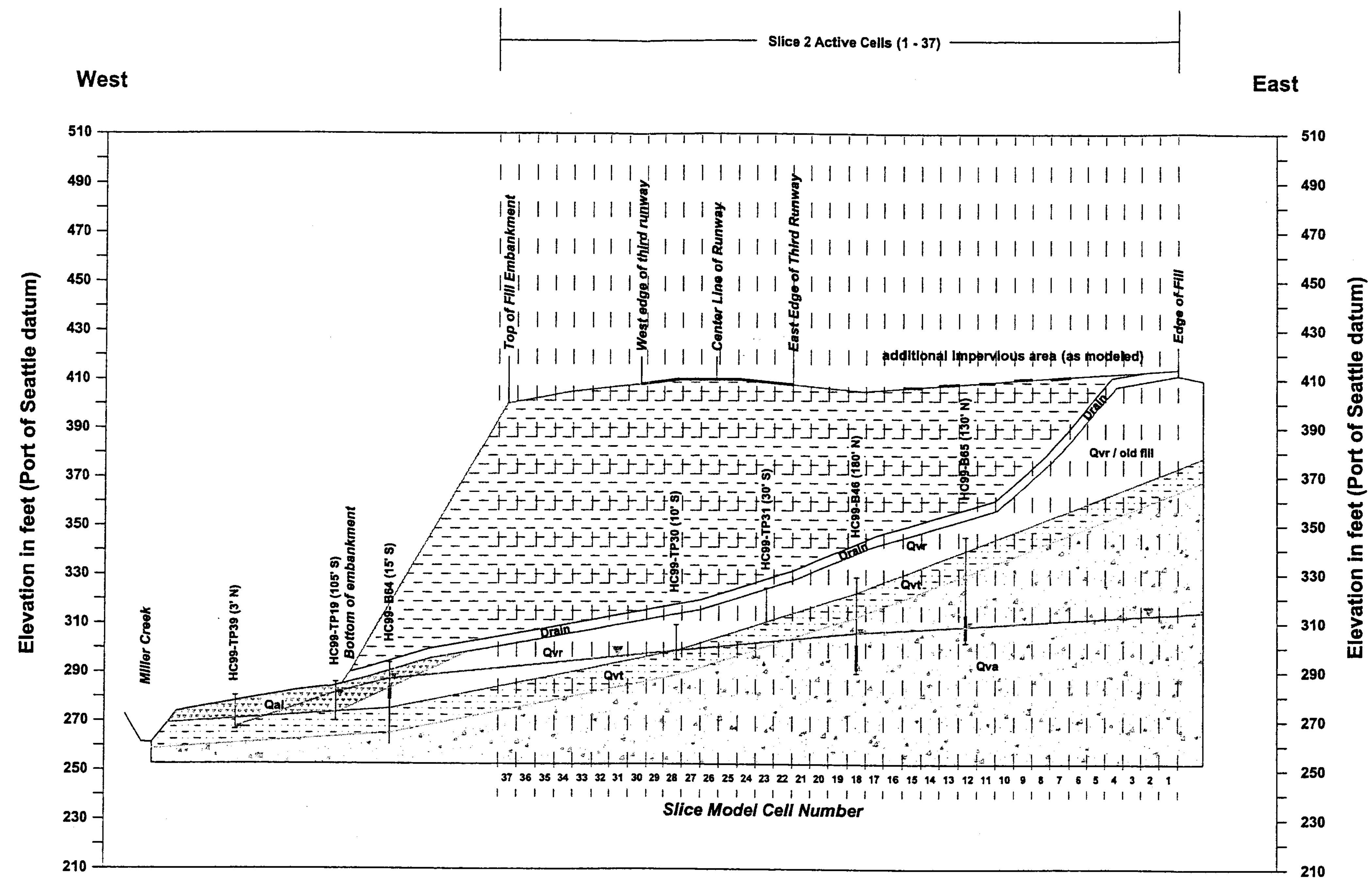
Groundwater Elevation
Groundwater Seepage Elevation
Conceptual Water Table
General Fill
Type 1 Fill
Wetland
Qvr - Vashon Recessional Outwash
Qvt - Vashon Till
Qva - Vashon Advance Outwash
HC99-B38 Well with high and low water level and identifier

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

FIGURE 5-1
Simplified Cross Section for Slice 1

SeaTac Third Runway
Embankment Fill Modeling
JE0105, Runway-Section1.dwg, 11/01

Pacific Groundwater Group



AR 016332

LEGEND

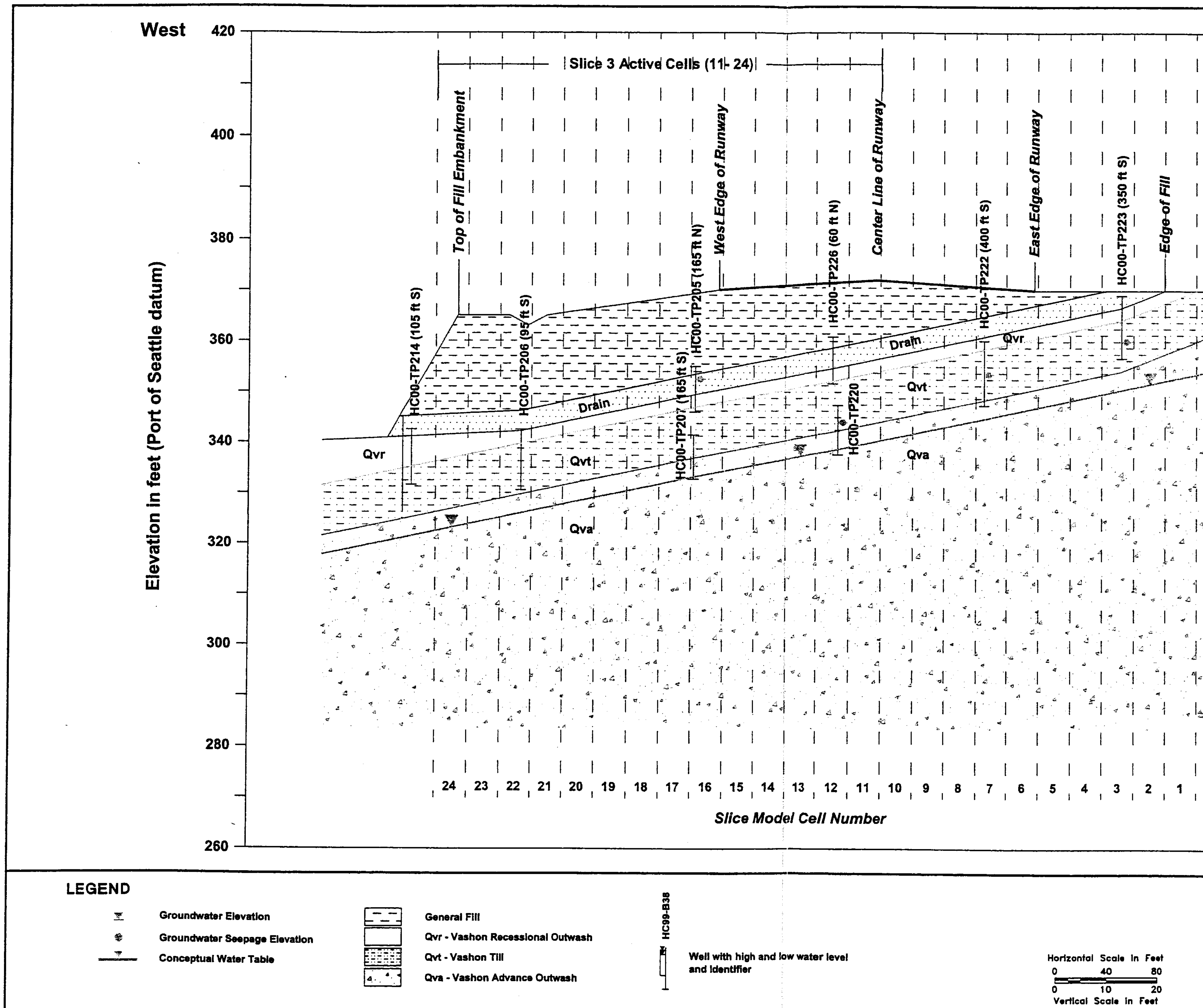
- Groundwater Elevation
- Groundwater Seepage Elevation
- Conceptual Water Table
- General Fill
- Qvr - Vashon Recessional Outwash
- Qvt - Vashon Till
- Qva - Vashon Advance Outwash
- Qal - Recent Alluvium
- HC99-B38 — Well with high and low water level and identifier

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
JD105, Runway-Section2.dwg, 08/01

Pacific Groundwater Group



AR 016333

FIGURE 5-3
Simplified Cross Section for Slice 3

SeaTac Third Runway
Embankment Fill Modeling

Pacific Groundwater Group