MEMORANDUM

DATE: October 30, 2001

TO: Jim Thomson, HNTB

FROM: Michael Kenrick, Hart Crowser, Inc.

RE: **Wetland Hydrology and the Third Runway Embankment Fill**
4978-06

CC: Elizabeth Leavitt, Port of Seattle

During the course of the Third Runway project, the Port of Seattle and its consultants have evaluated a number of issues that relate to impacts to and preservation of the wetlands and maintaining baseflow to the creeks resulting from construction of the Third Runway Embankment. This memorandum presents the US Army Corps of Engineers (Corps) a summary and guide regarding these studies and how the analyses address key issues of concern regarding long-term protection of wetlands hydrology.

We outline the understanding of current conditions at the Third Runway site, as they relate to the main hydrologic processes that maintain the wetlands and baseflow to Miller and Walker Creeks. We then describe the work done to assess the potential for the Third Runway to affect these hydrologic processes, and how construction of the project is designed to avoid or mitigate adverse effects.

UNDERSTANDING OF EXISTING CONDITIONS

In this section, we answer the question: What are the soil and hydrologic features and characteristics at or near the Third Runway site that maintain wetland hydrology?

Hydrologic and Geologic Setting

The existing conditions at Third Runway site have been documented for both wetlands and hydrology/hydrogeology as part of the *Final Environmental Impact Statement* (FEIS) for the proposed Master Plan Update (FAA/Port of Seattle 1996), of which the Third Runway is a part:

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- Hydrologic conditions in the basins are summarized as part of the *Hydrologic Modeling Study* (Montgomery Water Group 1995) presented in Appendix C (in Volume 3) of the FEIS.

- The original *Wetland Delineation* and *Wetland Function and Values Assessment* for the project were presented in Appendix H-A and H-B (Volume 3) of the FEIS.

- Hydrogeologic conditions at the project site were summarized in the *Baseline Groundwater Study* (AGI 1996), included as Appendix Q-A in Volume 4 of the FEIS.

A schematic cross section showing typical groundwater conditions at the Third Runway project site is shown on Figure 1.

As the project has developed, more detailed studies have been performed. Geotechnical issues related to the filling of wetlands were analyzed by Hart Crowser in its *Geotechnical Engineering Report - 404 Permit Support* (Hart Crowser 1999a). This report contains a summary of existing subsurface conditions (page 3) including soil and groundwater.

The body of work completed through December 1999 has been reviewed and summarized in the *Sea-Tac Runway Fill Hydrologic Studies Report* by the Pacific Groundwater Group (PGG 2000). This work was commissioned by the Washington State Department of Ecology (Ecology) independent of the Port's consultants, under an order of the State Legislature specifically to assess potential hydrologic impacts of the Third Runway project.

Wetland Hydrology

A range of studies performed for the project have provided understanding of the factors which contribute to and sustain the hydrology of hillslope, depression, and riparian wetlands in and adjacent to the Third Runway embankment construction project.

Depression Wetlands. These wetlands generally occur on relatively flat topography and are mostly fed by runoff or interflow draining in from a surface catchment surrounding the depression as a result of recent precipitation events. The depression facilitates ponding of water (if closed) and usually contains fine-grained subsoils. These soils tend to be of low permeability, which helps to sustain shallow saturation for the periods required to qualify as a wetland. During the summer, such wetlands may loose substantial amounts of moisture with soils becoming relatively dry for long periods. Most depression wetlands in the Third Runway project area will be filled as a result of embankment construction.

Slope Wetlands. These wetlands generally occur on sloping land and are mostly fed by surface runoff or interflow draining in from a surrounding catchment as a result of recent precipitation events. Surface topography that is typically concave, or gullied, and/or fine-grained subsoils tend to combine to create the wetland conditions, which provide shallow saturation for the minimal periods required to qualify as a wetland. In dry periods, such wetlands may loose substantial amounts of moisture and suffer long dormant periods in the summer. In some cases, these wetlands may also be fed by the occasional discharge of groundwater from shallow perched water-bearing zones. These are some of the key wetlands that will remain in the Third Runway project area following construction.

Riparian Wetlands. These wetlands generally occur on flat or gently sloping land adjacent to stream channels or bodies of open water, and tend to be fed by a shallow water table that is connected with the surface water body. The water table may be an expression of seasonal groundwater discharge from an upslope perched water-bearing zone, may include components of interflow, and/or more sustainable discharge from the water table of the shallow regional aquifer, where this discharges in part through the wetlands, as well as more directly to the adjacent surface water in the form of baseflow. During the summer, the water table typically drops, and surficial soils are no longer saturated. The wetlands do not necessarily dry out because water fluxes through the wetland flora may be sustained via capillary rise and evapotranspiration from the deeper water table. These also include key wetlands that will remain adjacent to the Third Runway project area following construction.

In some locations, very flat topography and constricted outflow points from a depression will create sustained saturation, with some areas of open water. These typically occur in an area of sustained groundwater discharge from the regional shallow aquifer, with water present the year round except during but the driest of years.

The following summary presents an assessment of these factors in the context of the main hydrologic processes that control the supply and abundance of water to the wetlands.

Site Investigations and Modeling

Understanding of the wetland hydrology at the Third Runway is predicated on information collected about the local geology, soils, and groundwater since these play critical roles in the occurrence of wetland conditions. The main factor sustaining wetland hydrology is precipitation. Models used to examine the hydrologic effect the embankment construction simulate the routing of precipitation into its derivative parts (i.e., infiltration, runoff, evapotranspiration, etc.), as those shown for the simple water balance model included on Figure 2. A series of such models has been used to examine specific aspects of the project, as described in the following sections. The main hydrologic studies performed for the project use a computer program called HSPF to develop a comprehensive surface water catchment modeling technique (described below) to simulate the destiny of precipitation at the site under both existing conditions and future post-construction conditions.

HSPF Modeling

One of the main tools used on the project to examine the fate of precipitation at the basin and sub-basin level is the water balance and stormwater modeling performed by Parametrix as part of the *Comprehensive Stormwater Management Plan* (CSMP, Parametric 2000c). This work was implemented using the *Hydrologic Simulation Program - Fortran* (HSPF), a widely recognized computer-modeling tool developed for the EPA (Donigian et al. 1984) and applied locally by King County as the basis for hydrologic analyses that underlie its *Surface Water Design Manual* (King County 1998).

Four years of the precipitation record (Water Years 1991 through 1994) was generally used in HSPF and other project hydrologic modeling. This part of the record is considered representative in that it includes a drought period (1991-93), with 1993 having the third lowest annual rainfall total (28.8 inches). Calibration of the HSPF models for Miller Creek (which includes Walker Creek as a tributary) focuses on this part of the precipitation record as being representative of a reasonably wide range of hydrologic conditions occurring at a time when land use in the basin could be accurately estimated (see Appendix B2 in Volume 3 of the CSMP).

Calibration of the HSPF model at the basin/sub-basin level provides the most defensible understanding and simulation of local hydrology, and forms the baseline for evaluations of changes in basin hydrology as a result of the Third Runway project. The division of the local drainage basins into sub-basins for HSPF modeling is shown on Figure 4-1 (page 4-2) of the CSMP.

The HSPF modeling as presented in the CSMP is the product of a phased development process that is documented on page 4-12 of the CSMP (Parametrix 2000c). Part of this process included an intensive and detailed independent review of the modeling work through the end of 1999, which is summarized in Section 3.6.2.1 (page 44) of the *Sea-Tac Runway Fill Hydrologic Studies Report* (PGG 2000). The review highlighted a number of calibration and simulation issues that led to cooperative work between Parametrix and King County to achieve a mutually agreeable calibration of the ultimate HSPF models, which form the basis of the CSMP (Parametrix 2000c).

Pre-Project Hydrologic Conditions

The following sections summarize our understanding of each aspect of the pre-project local hydrologic conditions with reference to their representation in HSPF and other models, and additional comments as they relate to wetland hydrology, wetland hydrologic functions, and baseflow to the creeks.

Precipitation

The main factor sustaining wetland hydrology is precipitation. The primary precipitation data used on the project for the area of Sea-Tac International Airport (STIA) are the hourly records of precipitation at the SeaTac NOAA Weather Service station, from October 1948 to the present. The average annual rainfall through September 1996 was 38.3 inches. Subsets of these data are used for specific aspects of the various analyses performed. For example, Hart Crowser used daily precipitation data from 1987 through 1997 for infiltration modeling and analysis. The main hydrologic study performed for the project uses a surface water catchment modeling technique to simulate the destiny of precipitation at the site under both existing conditions and future post-construction conditions.

The last 10 years of the precipitation record were generally used in HSPF and other project hydrologic modeling. This record is considered representative in that it includes a drought period (1991-93), with 1993 having the third lowest annual rainfall total (28.8 inches), as well as some abnormally wet years, e.g., 1996 had the second-highest annual rainfall total (50.7 inches).

Evapotranspiration

Potential evapotranspiration is provided as an input stream of daily or monthly values for hydrologic simulations, based on local measurements of pan evaporation from the Washington State Research and Extension Center in Puyallup. Actual evaporation is calculated from these potential values within HSPF, depending on land use, soil type, and vegetation cover as described below.

Evapotranspiration rates vary with these different land segments; most occur from saturated soils, with forested soils generating more than grassland soils, with very little coming from impervious areas. Actual evapotranspiration is also restricted by the amount of water available in the shallow soil zone, and declines rapidly in late summer as shallow soils dry out. These natural mechanisms are represented in the HSPF models.

Runoff

Runoff is a function of rainfall frequency, intensity, and duration. These aspects are integrated in the HSPF model by use of continuous hydrologic simulation applied to analyze hourly precipitation data, with the model itself operating on a 15-minute time-step throughout the selected simulation periods. Runoff is also dependent on land use and soil type, especially as these relate to vegetation and slope. These factors are represented in HSPF by specifying parameters for elements in the model called permeable land segments (PERLNDs).

Each sub-basin represented in HSPF is made up of different PERLND specifications for broad categories of existing soil type, slope, and vegetation, including a separate category for wetlands or saturated soils. The PERLND specifications are in the form of a set of parameter values, as listed for example in Table B2-2 (page B2-5) in Appendix B (Volume 3) of the CSMP (Parametrix 2000c). These PERLNDs control the behavior of HSPF to best represent the hydrologic response of each of the following soil/vegetation combinations:

- **TFM.** Glacial **T**ill soils supporting **F**orest vegetation on a **M**oderate slope;
- **TGM.** Glacial **T**ill soils supporting **G**rassland vegetation on a **M**oderate slope;
- **OF.** Glacial **O**utwash soils supporting **F**orest vegetation;
- **OG.** Glacial **O**utwash soils supporting **G**rassland vegetation;
- **SAT.** Wetlands and **SAT**urated soils.

The hydrologic meaning and applicable regional values of various PERLND HSPF parameters are provided in Dinicola (1990).

Another critical factor controlling runoff is the proportion or area of each basin or sub-basin that is composed of impervious surfaces (roads, roofs, parking lots, runways, taxiways). These areas are represented directly in HSPF, as listed in Table 4-1 (page 4-4) of the CSMP (Parametrix 2000c).

Wetlands are represented in HSPF through specified PERLND segments representing the appropriate proportion of each modeled sub-basin that is composed of saturated soils (wetlands). See, for example, Table B2-4 (pages B2-7 through B2-14) in Appendix B (Volume 3) of the CSMP (Parametrix 2000c). This table shows the amounts of each sub-basin represented as effective impervious area (EIA) using impermeable land segments (IMPLND) in the HSPF model.

Runoff is generated in HSPF primarily from the impermeable land segments for each storm event, with some contribution coming from areas of till soil, depending on soil-moisture conditions, and antecedent and current precipitation characteristics. Runoff accumulating as streamflow at key points in the model simulation allows direct comparison with streamflow records for the creeks, which are represented in the model.

The HSPF model is calibrated for known conditions by making careful adjustments to model parameters, as described for example on page B2-28 in Appendix B (Volume 3) of the CSMP (Parametrix 2000c), such that the best match is achieved between simulated and real hydrographs of basin runoff. See, for example Figures B2-4 though B2-21 (pages B2-32 ff) in Appendix B (Volume 3) of the CSMP (Parametrix 2000c).

Infiltration

Infiltration occurs when surficial soils are unsaturated and extra moisture is available from precipitation. The type of soil (e.g., outwash or till) strongly influences the rate and amount of infiltration that can occur; other variable factors also control the rate of infiltration on a daily or hourly basis, including the changing rates of precipitation, evapotranspiration (driven by solar and other radiation), and runoff.

Models such as HSPF simulate the amount of infiltration occurring into different pervious land segments. The models track continually changing variables such as precipitation, evapotranspiration, and runoff through simulations based on months or years of real data. The models also determine the portion of infiltration that becomes available for shallow interflow or becomes deeper percolation that recharges the groundwater system.

Existing rates of infiltration into wetlands and the various soil types/vegetation combinations at the Third Runway site were also studied independently as reported in the *Sea-Tac Runway Fill Hydrologic Studies Report* (PGG 2000). Examples of water balance calculations for monthly average infiltration to estimate groundwater recharge rates are presented in Appendix B (Tables B-5 through B-13) of that report. Specifically, average monthly water balances for wetland soils are presented in Tables B-5 through B-7.

Interflow/Perched Groundwater

Interflow, defined as shallow lateral subsurface flow that occurs on sloping land over a period of hours to days after individual storm events, represents an important component of wetland hydrology for slope and depression wetlands at the Third Runway site, and can also play a role in the supply of water to riparian wetlands. HSPF takes account of interflow and represents its contribution at the sub-basin scale (although not on the level of individual wetlands).

A portion of interflow likely contributes to or derives from shallow perched groundwater beneath sloping land at the Third Runway site, where a veneer of relatively permeable surficial soils commonly overlies less-permeable glacial till at shallow depths (typically 5 to 10 feet). The conditions are described on page 5 of the *Geotechnical Engineering Report - 404 Permit Support* (Hart Crowser 1999a). Shallow flows in these soils contribute significantly to the hydrology of slope wetlands and will be sensitive to changes in vegetation or land use that may occur in the small upslope drainage areas associated with most slope wetlands.

As part of the geotechnical investigations for the Third Runway, Hart Crowser has installed approximately 77 shallow monitoring wells, the majority of which monitor water levels in the shallow perched water-bearing zone beneath the proposed embankment. These data are contained in the following *Subsurface Conditions Data Reports* issued for specific sections of the proposed construction area:

- Subsurface Conditions D*ata Report - 404 Permit Support* (Hart Crowser 1999b);
- Subsurface Conditions Data Report - *Phase 3 Fill* (Hart Crowser 1999c);
- Subsurface Conditions Data Report - *North Safety Area* (Hart Crowser 2000a);
- Subsurface Conditions Data Report - *South MSE Wall and Adjacent Embankment* (Hart Crowser 2000b);
- Subsurface Conditions Data Report - *West MSE Wall* (Hart Crowser 2000c);
- Subsurface Conditions Data Report - *Additional Field Explorations and Advanced Testing* (Hart Crowser 2000d);
- Subsurface Conditions Data Report - *Phase 4 Fill* (Hart Crowser 2000f); and
- Subsurface Conditions Data Report - *Phase 5 Fill and Subgrade Improvement* (Hart Crowser 2001b).

The reports also contain boring logs, test pit logs, and the results of laboratory tests among other geotechnical data collected for the project.

Baseflow/Groundwater Recharge

Underlying the glacial till beneath the Third Runway site is the shallow regional aquifer, which exists primarily within the advance outwash deposits of the Vashon glaciation that occurred during the Quaternary period (Qva). Information on the Qva aquifer has been collected over a broad area surrounding STIA as part of an ongoing groundwater study being performed for the Port of Seattle by Associated Earth Sciences Inc (AESI). Based on these data, groundwater elevations and implied flow directions throughout the airport area have been mapped by AESI; see Figure B1-3 (page B1-6) in Appendix B1 (Volume 3) of the CSMP (Parametrix 2000c).

AESI has also prepared a hydrogeologic cross section through the southcentral portion of the airport that extends westward to include part of the Third Runway site. This is presented in a memorandum entitled *Analysis of Preferential Ground Water Flow Paths Relative to Proposed Third Runway* (AESI 2001).

Groundwater elevations in the portions of the Qva aquifer near the creeks show close association with Miller Creek and Des Moines Creek, indicating that these are generally gaining streams supplied by baseflow contributions from the aquifer. The occurrence of this baseflow contribution is reflected by water table elevations adjacent to the creek that are typically somewhat higher than corresponding creek levels (a necessary requirement for baseflow to occur). Depending on surface topography adjacent to the creek, these conditions help to create and sustain riparian wetlands that are fed in part by the shallow groundwater table.

During periods of flooding, water levels in the creeks may briefly exceed the levels of groundwater in the adjacent aquifer, and may flood the riparian wetlands, temporarily reversing the baseflow and mobilizing bank storage within sediments and geologic deposits alongside the creek.

Post-Construction Conditions

The second part of this memorandum addresses the analysis and evaluation of potential hydrologic effects to wetlands and creeks that may occur as a result of Third Runway embankment construction. Specifically, how will the Third Runway embankment and its MSE Walls affect the long-term hydrology of the wetlands?

Embankment Construction

The proposed Third Runway will be constructed on native soils and an embankment of compacted earth fill, so that the new runway level meets the existing airfield level, as shown schematically on Figure 3. To accommodate the slope of the existing terrain, the new embankment will vary up to a maximum fill height of about 165 feet. The new embankment is being constructed as a zoned fill, with specific types of soil materials and compaction requirements used in different areas to provide necessary stability and settlement characteristics. Overall, the new embankment will include about 17,000,000 cubic yards of compacted earth fill.

The new embankment will be constructed on the west side of the existing airfield. The embankment side slopes will have an average inclination of 2H:1V. Three high retaining walls will be used to limit the extent of embankment slope from impacting sensitive portions of Miller Creek and adjacent wetlands. Mechanically stabilized earth (MSE) technology will be used to construct the retaining walls. The specific type of MSE walls being designed for Sea-Tac utilize strips of steel layered in the compacted soil fill, and a relatively thin reinforced concrete facing to form a near vertical retaining wall face.

The foundation soils for the MSE walls and parts of the main embankment require additional measures to improve their performance and to limit the potential effects of liquefaction during a major earthquake (see also the *Geotechnical Design Summary Report*, Hart Crowser 2001d). This includes the excavation of unsuitable foundation soils (typically peat, soft clay, and loose silty sands) and replacement with compacted sand and gravel fill material.

Post-Construction Hydrologic Conditions

Precipitation

Precipitation inputs to HSPF for the modeling of future (post-construction) conditions use the same period of record as described above for existing conditions. This allows comparisons between pre- and post-construction analyses to focus on potential construction effects manifested under comparable precipitation patterns as have occurred in the recent past.

Predictive modeling of post-construction conditions using HSPF allows the overall impact of land use changes at the sub-basin level (including the filling of impacted wetland acreage) to be assessed. This analysis is presented in Appendix A (Volume 2) of the CSMP (Parametrix

2000c). Summaries of this and other related hydrology work are presented below, with references to the corresponding reports containing the detailed work.

Evapotranspiration

Site clearing required for the construction of the Third Runway includes the removal of forested slopes and the filling of wetlands, both of which represent significant sources of water loss to evapotranspiration in the local basins. These changes are simulated at the sub-basin level by defined inputs to the HSPF model, with most of the embankment fill surface that is not impermeable represented as outwash with grass vegetation. As a result, the amount of water available post-construction for the remaining hydrologic processes (runoff, infiltration, interflow, baseflow) is increased at the Third Runway site.

Runoff

Changes in land use that directly affect soil type, vegetation, wetlands, and impervious areas are predicted using HSPF to increase surface runoff from the project area. This is primarily related to the net increase in effective impervious area as a result of runway and taxiway construction that exceeds the removal of existing impervious surfaces (i.e., roads and roofs).

HSPF was used as a key tool in developing the management strategy for stormwater routing, sizing for stormwater facilities, and discharge of stormwater within the requirements of King County's best management practices (BMPs) for surface water (King County 1998). The post-construction HSPF model includes the generation of **all** runoff from new impervious surfaces (runways and taxiways), ignoring the potential for secondary infiltration of runoff into permeable filter-strip soils adjacent to impervious runway/taxiway areas, which is very conservative (see below).

Some of the runoff generated from the face of the embankment will occur at elevations that are below the level that allows free gravity drainage to stormwater ponds. This limited volume of stormwater will be collected in swales and distributed to downslope wetlands via flow dispersal trenches, as shown in Exhibit C-115 of Appendix Q (Volume 4) of the CSMP (Parametrix 2000c).

Infiltration

The Third Runway embankment will be composed of fill material that is moderately permeable and allows the infiltration of water at its surface. Water that has infiltrated the fill surface and is not consumed by evapotranspiration through surface plants (primarily grass) will be available to percolate downward through the embankment under the influence of gravity.

Deep percolation and seepage through the embankment were initially analyzed using a simple block-flow water balance model for two representative cross sections, as described in Appendix B of *Geotechnical Engineering Report - 404 Permit Support* (Hart Crowser 1999a).

A more rigorous analysis of infiltration and seepage, taking into account unsaturated groundwater flow was developed using the US Army Corps of Engineers *Hydrologic Evaluation of Landfill Performance (HELP) model* (Schroeder et al. 1994), as described in Appendix C of *Geotechnical Engineering Analyses and Recommendations* (Hart Crowser 2000g). This work was independently verified by additional modeling prepared as part of the *Sea-Tac Runway Fill Hydrologic Studies Report* (PGG 2000) for one cross section or slice through the future embankment, located at the western MSE wall. In its *Sea-Tac Runway Fill Hydrologic Studies Report* (PGG 2000), PGG used a three-part modeling approach to evaluate the percolation and seepage of water through the completed embankment:

- Infiltration was calculated using a proprietary water balance model to estimate monthly average values of recharge from the surface of the fill, as described in Appendix B of PGG (2000);

- Percolation through various thicknesses of the fill material was simulated using an unsaturated seepage model called Hydrus-2D, as described in Appendix C of PGG (2000); and

- The accumulation of percolating water with shallow groundwater flow and drainage layer flow at the base of the embankment was modeled using a proprietary one-dimensional finite-difference numerical groundwater flow model, called Slice, as described in Appendix E of PGG (2000).

Additional modeling of embankment infiltration and seepage was performed by PGG in support of the *Low-Flow Analysis (Flow Impact Offset Facility Proposal)* prepared by Parametrix (2001). This work included seepage analysis for two additional slices located north and south of the western MSE wall, as shown in Figure 2-1 of the *Sea-Tac Third Runway - Embankment Fill Modeling* report (PGG 2001). The same modeling approach as above was used except that infiltration rates into the surface of the embankment slices were not calculated using PGG's monthly average water balance/recharge model. Rather, to ensure compatibility with HSPF, a series of daily (rather than monthly) values were derived from HSPF, covering four years of simulation based on the conversion of actual precipitation to infiltration on outwash with grass cover. The seepage analysis also included representation of secondary infiltration where stormwater runoff from the runways infiltrates into the embankment fill via permeable filter strips constructed alongside runways and taxiways. Design details for the filter strips are included in Appendix H (Volume 4) of the CSMP (Parametrix 2000c).

Additionally, the seepage and recharge rates calculated by PGG for the three slices were aggregated over the full area of the Third Runway embankment, based on fill thickness, and the corresponding recharge flows were used in HSPF to provide improved representation of seepage through the new embankment and its effect on baseflow/groundwater recharge.

Interflow

Interflow in the area of the Third Runway embankment will occur within the sloping face of the embankment. As shown on Figure 3, the outer shell of the embankment (a 20-foot-wide zone that runs the full height of the main embankment's 2H:1V slope) will be formed of relatively permeable Group 1B material. The grain size envelope specified for Group 1B material is as shown on Figure C-5 (Appendix C) of *Geotechnical Engineering Analyses and Recommendations* (Hart Crowser 2000g). This material will allow more infiltration than would typically occur with the common embankment fill. Most of this infiltration will become interflow that percolates down the sloping interface between Group 1B and common fill material forming the body of the embankment, to enter the drainage layer.

Flow from the drainage layer will in general replace the pre-project interflow, but will provide a much more consistent source of water to the downslope wetlands because of the buffering effect created by storage of pore water within the body of the embankment. This effect is described on page 51 of PGG (2000). The result will be a significant attenuation in peak flows and improved timing in terms of extended periods of flow and of increased flow during the late summer periods. This is demonstrated on Figures 5-4 through 5-6 of PGG (2001).

The main discharge points for flow from the drainage layer beneath most of the completed embankment are expected to be the topographic low spots along the final toe of the embankment. These are expected in some cases to coincide with current wetland locations. Drainage layer flows will be collected and redistributed to the downslope portions of the wetlands that remain following construction, using flow dispersal trenches as shown, for example, in Exhibit C-115 of Appendix Q (Volume 4) of the CSMP (Parametrix 2000c). If excess flows are deemed to be occurring based on monitoring of the wetlands, some of the flow can then be diverted away from the wetland and directed to stormwater ponds for detention and subsequent discharge to the creeks. Conversely, if there is not enough flow to sustain the wetlands, treated stormwater discharges can be diverted to flow through the wetlands.

At the toe of the embankment in the area beneath the West MSE wall, collection swales will not flow by gravity to the stormwater ponds, due to elevation constraints. In this area, a system of replacement channels has been designed (in part to mitigate the burial of drainage channels beneath the embankment) which will carry drainage layer discharges and redistribute flows to the downslope portions of the riparian wetlands that remain following construction. The replacement channels are shown in Appendix D of the NRMP (Parametrix 2000a).

Baseflow/Groundwater Recharge

Beneath most of the embankment, the existing groundwater flowpaths will largely be maintained and unaffected by construction. This includes:

- The shallow soils directly beneath the embankment that contain groundwater perched above the glacial till;
- The underlying shallow outwash aquifer which discharges as baseflow to the creeks and helps sustain the riparian and slope wetlands; and
- The deeper regional aquifers that play an important role in local water supplies.

In particular, seepage and groundwater flow through surficial soils at and below the toe of the embankment will continue to supply water to riparian wetlands and the associated creeks.

Subgrade Improvement

In limited areas of the embankment associated with MSE wall construction, some of the shallow soils are unsuitable as foundation materials and must be strengthened or replaced, as described on page 24 of the *Geotechnical Engineering Report - 404 Permit Support* (Hart Crowser 1999a) and on pages 2 through 12 of the *Preliminary Stability and Settlement Analyses, Subgrade Improvements, MSE Wall Support* (Hart Crowser 2000e). Other sections of the Third Runway embankment foundation may be subject to liquefaction during certain earthquake conditions; strengthening or replacement of subgrade materials will also be implemented in these area, as described on page 4 of *Geotechnical Engineering Analyses and Recommendations* (Hart Crowser 2000g).

Selection of a method for subgrade improvement was strongly influenced by the need to avoid permanent impacts on baseflow to downgradient wetlands. After considering eight alternative methods, two approaches (stone columns; and removal and replacement of native soils) were selected for final design analysis:

- Subgrade strengthening may be achieved by a method such as the installation of stone columns into the foundation soils. These methods are designed to increase soil strength by displacing weak soils with columns of gravel placed in the ground. Stone column installation densifies adjacent sand and gravel soils but provides little or no compaction of silt and clay soils. There is no evidence of stone columns impeding groundwater flow (see *Proposed MSE Wall Subgrade Improvements*, Hart Crowser 2000h) and permeability may increase where silt and clay soils are disturbed. To the extent that recharge area and rates remain unchanged, the amount of groundwater flowing through the area will not change, although water levels and hydraulic gradients may adjust to convey this water through, around, or over the area where stone columns are installed. Increases in water level will be limited by the presence of the drainage layer (see below), which will act as an overflow conduit, preventing water levels from rising much above the original ground level beneath the embankment.

- Another alternative is the excavation of weak, unsuitable soils (to depths ranging typically from 10 to 20 feet, down to a dense bearing layer, such as glacial till), and replacement with compacted free-draining granular fill material, as described on page 25 of *Geotechnical Engineering Report - 404 Permit Support* (Hart Crowser 1999a) and in Appendix C of *Geotechnical Engineering Analyses and Recommendations* (Hart Crowser 2000g). This backfill material will typically be more permeable than the soils it replaces, and becoming saturated below the water table, will conduct groundwater flow from upslope to downslope soils, with flowrates controlled by the hydraulic conductivity of the adjacent native soils.

The second alternative, the removal and replacement of unsuitable soils, has been selected as the best approach for construction by the Port of Seattle following pilot testing of stone columns.

Drainage Layer

Embankment construction includes the placement of a drainage layer beneath sections of the fill that will be 50 feet or more in height. A drainage layer will also be used beneath less tall sections of the embankment where existing or inferred potential seepage could occur into the new fill. The drainage layer will form a blanket with a minimum thickness of 3 feet, laid mainly over the existing ground surface (see Figure 3) and will consist of sand and gravel (designated Group 1A material). The grain size envelope specified for Group 1A material is as shown on Figure C-5 (Appendix C) of *Geotechnical Engineering Analyses and Recommendations* (Hart Crowser 2000g). The drainage layer will be relatively permeable and will provide a somewhat higher rate of seepage in comparison to the average for common embankment fill and the native subsurface soils.

Drainage layer flow in some locations may include a portion of groundwater entering the layer from below, especially downslope of existing wetland areas that are buried beneath the fill. Provision will be made during construction to locally increase the thickness of the drain layer in such areas, as discussed in *Geotechnical Engineering Analyses and Recommendations* (Hart Crowser 2000g) and *Geotechnical Engineering Analvses and Recommendations, Phase 5* (Hart Crowser 2001c). This will ensure that existing seeps and shallow flows are maintained, and that flows issuing from the drainage layer can be managed in a way that will protect the wetlands adjacent to the new embankment.

There is no danger that groundwater contamination from the eastern side of the airport would be transported to the Third Runway project area or enter the drainage layer. Contamination present in perched groundwater on the eastern side of the site will not migrate to the west due to the absence of any plausible migration pathways. This is because the perched water-bearing zones in the glacial till on the eastern and western flanks of the airport are localized and discontinuous, and the glacial till is absent from the central area. Utility tunnels located within permeable outwash materials of the central area are well above the water table in the shallow aquifer and do not constitute a plausible pathway for contaminated water from the perched areas or in the Qva to be transported to the west side of the airport. See the cross section on Figure 6 of the *Analysis of Preferential Ground Water Flow Paths Relative to Proposed Third Runway* (AESI 2001).

On the scale of the airport, the drainage layer, which will begin over a half-mile away from the contaminated groundwater zone, will typically be placed on the existing ground surface mostly above the elevation of groundwater in the Qva aquifer, and will have only limited interaction with it. The drainage layer will collect water from existing small seeps and springs (where local perched groundwater currently discharges to the surface); the presence of the drainage layer will not change the overall movement of groundwater in the shallow aquifer beneath the airport. Furthermore, observations have shown that the maximum migration distance of impacted groundwater in the Qva beneath the perched zones on the eastern side of the airport is limited to less than 550 feet (AESI 2001).

Baseflow

Estimates of baseflow contribution from the area being filled by the Third Runway embankment generally show a slight increase in shallow groundwater flow that provides baseflow to the adjacent creeks. This was initially analyzed using a simple block-flow water balance model for two representative cross sections through the new embankment, as described in Appendix B of *Geotechnical Engineering Report - 404 Permit Support* (Hart Crowser, 1999a).

A subsequent analysis of baseflow effects developed using the HELP model, as described in Appendix C of *Geotechnical Engineering Analyses and Recommendations* (Hart Crowser 2000g), showed similar results. This work was independently verified by additional modeling prepared as part of the *Sea-Tac Runway Fill Hydrologic Studies Report* (PGG 2000), which gave similar results. Additional work by PGG with the same model for two additional embankment slices, as described in the *Sea-Tac Third Runway - Embankment Fill Modeling* report (PGG 2001), also gives similar results.

Output from the final work listed was incorporated in the HSPF models to estimate baseflow under low-flow conditions in the *Low-Flow Analysis (Flow Impact Offset Facility Proposal)* prepared by Parametrix (2001). This analysis shows a relatively small change in baseflow at the sub-basin level over the areas that include the Third Runway embankment (see page 2 of Parametrix (2001)).

Requirements for a temporary stormwater pond (Pond A) below the West MSE Wall raised concerns about temporary local effects on baseflow and wetland hydrology as a result of pond operations. The issues and a solution to avoid potential effects on groundwater flow and wetland hydrology are described in *Avoidance of Wetland Impacts, Temporary Stormwater Pond A* (Hart Crowser 2001a).

Groundwater Recharge

Rates of recharge to the deeper aquifers are controlled in part by water level elevations in the shallow regional aquifer. Since the water levels in the shallow aquifer will not be substantially affected by the Third Runway embankment construction, flowrates for water leaking through underlying aquitards to reach the deeper aquifers will not be affected.

Finally, rates of groundwater flow in the shallow regional aquifer and in the deeper aquifers will not be adversely affected by the additional weight imposed by the new embankment. In a letter to the Port entitled *Sea-Tac Third Runway - Aquifer Compaction*, Hart Crowser (1998) presented an analysis to demonstrate that the additional weight might result in, at the most, a loss of 4 percent of the thickness of the shallow regional aquifer. The corresponding reduction in aquifer transmissivity (3 percent) would not have a measurable effect on groundwater levels or flow rates beneath the embankment.

SUMMARY

- All relevant components of the watershed hydrology and hydrogeology have been studied.
- The embankment and wall design and construction methods include measures that will preserve, promote, or enhance the hydrology of remaining wetlands that are not filled by the embankment.
- On an annual basis, down-slope wetlands are predicted to receive slightly more water, spread over a longer period, with smaller peak flows, which should be beneficial to wetland hydrology.
- There will be no increase in peak flows through wetlands. Excessive water flows through the wetlands that are substantially greater than existing flows (especially highly erosive peak runoff events during storms) will not occur because storm flows will be diverted to stormwater ponds for detention and slow release directly to streams.
- If wetter conditions occur for longer periods, and post-construction monitoring reveals that there is an adverse effect on wetland flora, this will be rectified by adaptive management of flows.

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Attachments:
Figure 1 - Generalized Groundwater Conditions
Figure 2 - Water Balance Schematic
Figure 3 - Conceptual Site Flow Model, Third Runway Embankment

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Generalized Groundwater Conditions
Third Runway

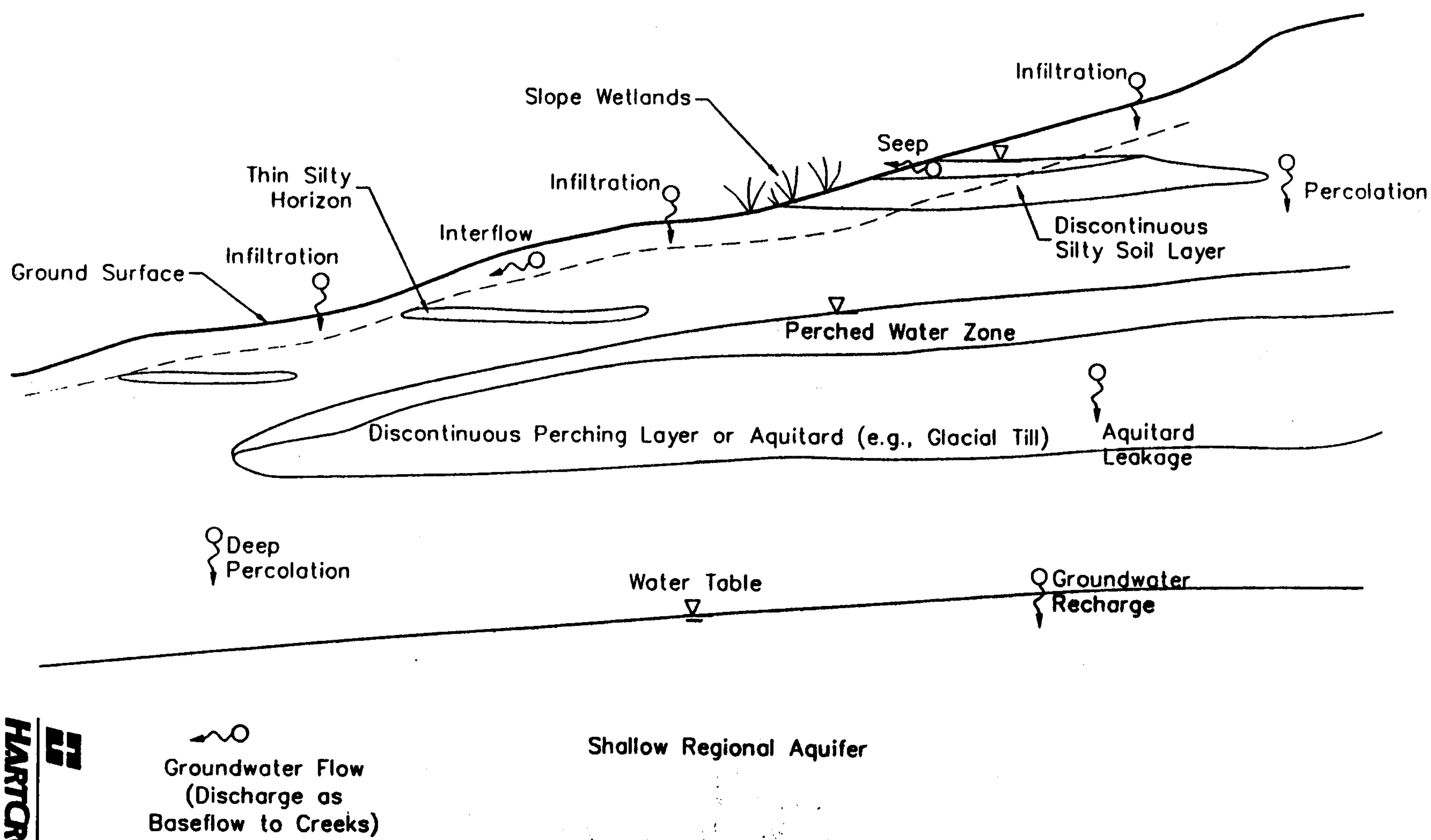

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Figure 1

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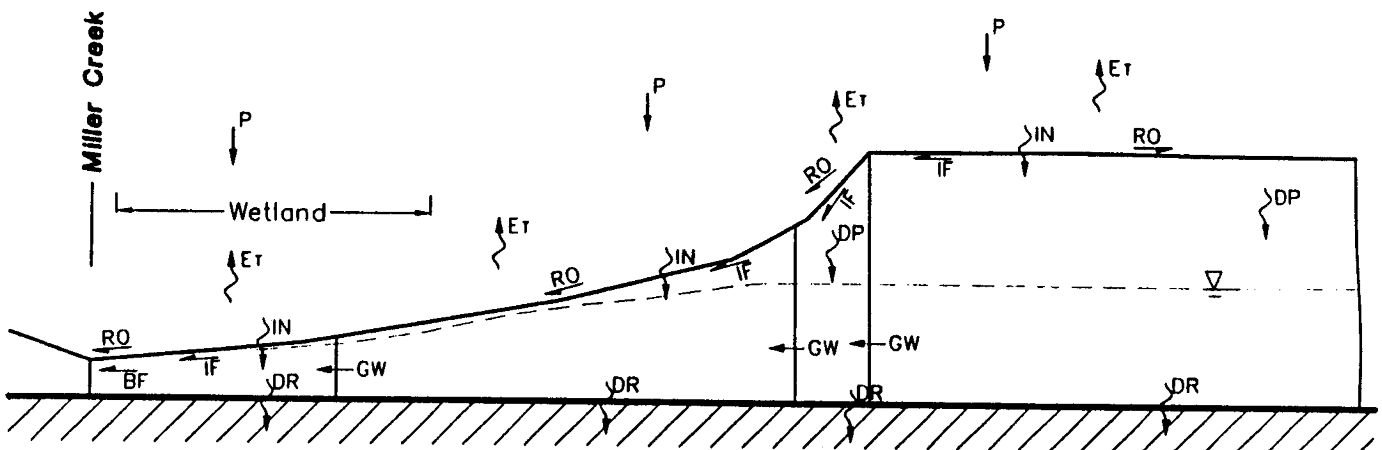
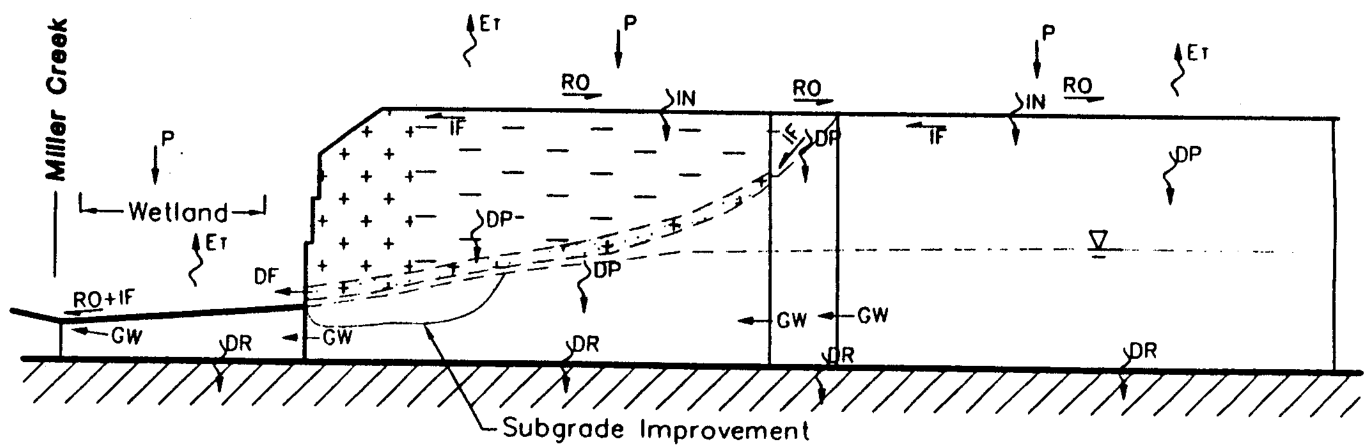
Water Balance Schematic
Third Runway Embankment

P Precipitation
ET Evapotranspiration
RO Runoff
IF Interflow
IN Infiltration
DP Deep Percolation
GW Groundwater Flow
BF Base Flow
DF Drainage Flow
∇ Water Table
DR Deep Recharge
Drainage Layer
New Embankment
Free-draining Backfill



a) Pre-Construction



b) Post-Construction (with MSE Wall and Internal Drainage Layer)

Not to Scale

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Figure 2

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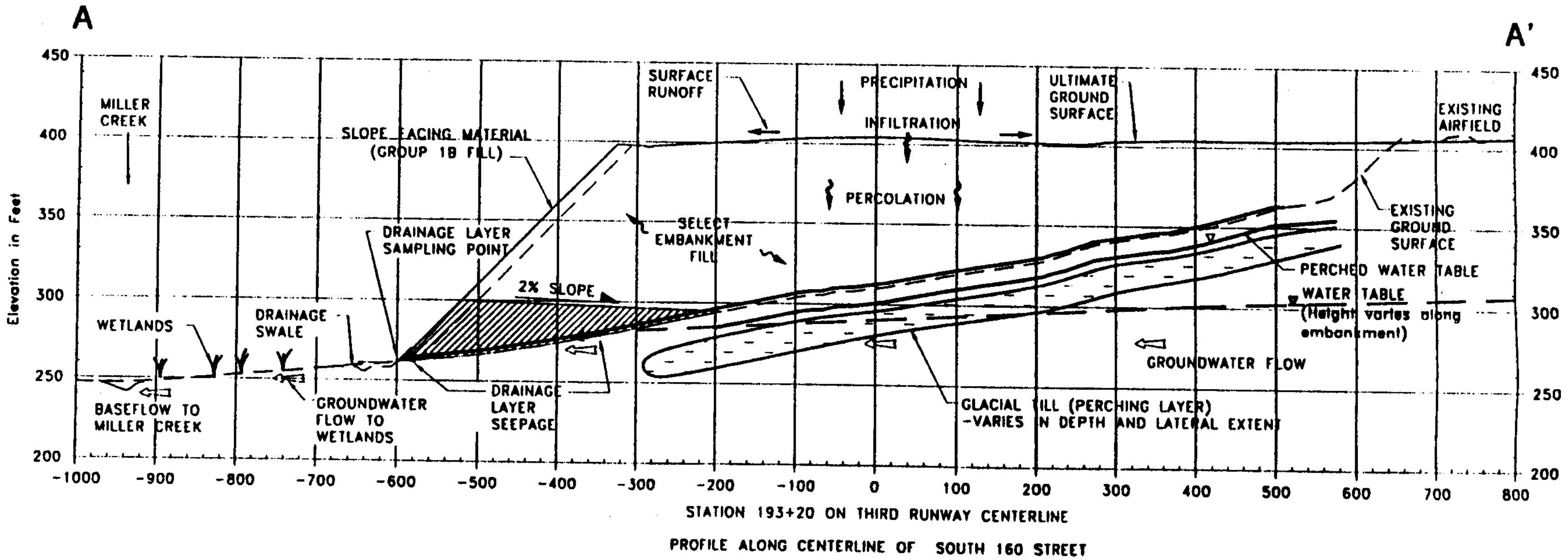
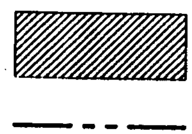
Conceptual Site Flow Model

Third Runway Embankment



Note: The conceptual model is a schematic representaation of flow paths at a typical cross section through the Third Runway embankment. Conditions, dimensions, elevations, and details vary along the length of the embankment.

LEGEND:



Drainage Layer Cover

Drainage Layer

Horizontal Scale in Feet
0 200 400
0 100 200
Vertical Scale in Feet
Vertical Exaggeration x 2

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Figure 3

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