Pacific Groundwater Group

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SEA-TAC RUNWAY FILL HYDROLOGIC STUDIES REPORT

June 19, 2000

Pacific Groundwater Group
Seattle, Washington

Sea-Tac Runway Fill Hydrologic Studies Report

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1.0 Executive Summary

This report summarizes investigations conducted to assess the hydrologic effects of constructing a fill embankment for a third runway at Seattle-Tacoma International Airport. In 1999, public concerns prompted the Washington State Legislature and Governor Locke to approve this study, which focuses on aquifers, wetlands, and Des Moines, Miller, and Walker Creeks, which drain the area. The study was conducted under the Washington State Department of Ecology's oversight by a team of consultants: Pacific Groundwater Group (PGG); Earth Tech, Inc.; and Ecology and Environment, Inc., (E & E).

The study area varies depending on the issue evaluated. The largest areas considered are the Miller Creek and Des Moines creek watersheds which comprise a total of about 15 square miles surrounding the airport and include the fill borrow sources. The smallest areas considered are local drainages in the middle reach of Miller Creek where extensive riparian wetlands will be affected.

The scope of work for this project contained the following tasks:

- Reviewing existing documents
- Interviewing Port staff, community organizations, individuals, and consultants
- Collecting additional field data
- Reviewing models used by Port consultants to assess hydrologic impacts
- Providing independent evaluation of certain hydrologic effects using new and existing data
- Reviewing Port mitigation proposals
- Informing stakeholders and the public on project progress
- Reporting

Existing data were compiled and analyzed to characterize land use, surface water flow, geologic conditions, groundwater flow, groundwater recharge, wetlands, and fish in the study area. These data were used to assess potential impacts associated with the proposed runway construction. Where existing data were insufficient or required independent confirmation, additional data were collected in the field, including borehole data, streamflow quantity and quality, wetland delineations and functions, and fish population and habitat information. This study also reviewed impact assessments previously completed by the Port.

Although the study considered many potentially important effects of the proposed runway embankment. and borrow-area excavations, it did not consider all Master Plan Improvements proposed by the Port. Furthermore, not all of the possible effects related to the embankment and borrow areas were evaluated. Therefore, this report does not address all hydrologic issues requiring satisfactory resolution for permitting. Consequently, it is not intended for use as a checklist by agencies during permit review.

1.1 Project Background

The Port of Seattle has purchased, or is in the process of purchasing, properties in a "buy-out area" west of Sea-Tac Airport. This area contained more than 400 homes, five farms, 17 domestic water rights or claims, neighborhood and arterial roads, 380 septic drain fields, and numerous water wells. The Port has demolished many structures and removed debris.

1.1.1 Proposed Construction

An embankment of fill soil is proposed to create a high, flat surface upon which the third runway would be built. The fill would be more than 150 feet thick in places. The west margin of the fill would be bounded by a slope or wall, depending on location. The east margin of the new fill would abut the existing fill, upon which the current runways are built. The volume of the fill required for the third runway embankment is reported to be 16.5 million cubic yards. It will consist of about 40 percent sand and gravel that is relatively silt-free and about 60 percent silty sand. These materials originate from glacial till and outwash soils. Additional fill is proposed for other Master Plan Improvements.

A bottom drain layer, in combination with coarse soils near the walls, has been included in the fill-embankment design. It is intended to prevent groundwater pressures near the west wall from building, a condition that could result in seepage through the wall. This drain layer is designed to direct groundwater seepage below the base of the wall to the remaining wetlands and Miller Creek.

1.1.2 Proposed Stormwater Controls

The Port proposes a strategy for controlling stormwater flows for existing and future facilities. This strategy is intended to lower peak flow rates in Miller, Des Moines, and Walker Creeks below pre-1994 rates. Within the fill area, the Port proposes to reduce flows by allowing some precipitation to infiltrate the fill and by storing runoff in local and regional detention ponds and vaults while restricting the rate stormwater is released from storage. This strategy relies on the expansion and construction of large regional ponds in Miller and Des Moines Creeks.

The third runway and connecting taxiways will be paved and cover about 32 percent of the new embankment surface. In the unpaved 68 percent, the embankment will likely grow grass. Water running off the paved surfaces is proposed to flow into "filter strips," which are water-quality treatment features. Water would flow into low areas at the bottom of the filter strips, then into catch basins. Water entering the catch basins would be conveyed through pipes under the runways to detention vaults or other detention facilities prior to discharge to Miller, Walker, or Des Moines Creek. The use of perforated conveyance pipes is being considered (which would enhance infiltration).

1.2 Physiographic Features Related to Habitat

Habitat conditions were evaluated by review of existing documents and collection of limited new field data. The team collected streamflow and water quality measurements on three occasions and at several locations. A stream habitat field survey was conducted on Walker Creek and fish presence and carcass surveys were conducted on all creeks. Team personnel also directly observed wetland conditions although a complete review of all previous delineations and function assessments was not conducted.

1.2.1 Land Use

Immediately west of the airport, land use is a mix of residential and agricultural, with development encroaching on the Miller Creek riparian corridor. This corridor features residential areas, agriculture, upland habitats, and slope and riparian wetlands, all of which lie adjacent to the creek. Outside this area west of the airport, the narrow riparian and ravine corridors associated with Miller and Walker Creeks are the primary areas that have not been extensively developed. Larger wetland complexes are associated with these drainages, including the Miller Creek Detention Facility and a large wetland complex that forms the headwaters of Walker Creek. About 40 acres of wetlands occur in the vicinity.

The area south of the airport contains a greater percentage of non-urban/residential land, including the Tyee Golf Course and acreage acquired by the Port as part of Noise Abatement Mitigation programs. In addition, Des Moines Creek has a significant forested riparian corridor that is undeveloped. Approximately 48.5 acres of wetlands lie near the Borrow Areas and Tyee Golf Course.

1.2.2 Surface Water

Miller and Walker Creeks drain the west side of the airport and the buy-out area. The watershed is approximately 9 square miles. Miller Creek originates from a number of sources; Arbor Lake, Lake Reba, Lora Lake, and Lake Burien; wetlands associated with the Miller Creek detention facility; and seeps along the west side of the airport. Streamflow increases downstream as groundwater discharges to the creeks, even during times of no rainfall. Miller Creek descends from an elevation of approximately 360 feet in its headwaters to Puget Sound at the Normandy Park Cove. The Miller Creek watershed contains significant residential and commercial development, resulting in approximately 23 percent impervious surfaces. Land use in the watershed is approximately 62 percent residential, 15 percent commercial, 3 percent airport, and 20 percent undeveloped.

Precipitation at SeaTac averages about 39 inches per year. An average of approximately 54 percent of the precipitation in the basin discharges through Walker and Miller Creeks at their mouths. The remainder of the precipitation in the Miller Creek basin evaporates or discharges as groundwater to Puget Sound.

Des Moines Creek drains the south part of the airport and the borrow areas. Its watershed covers 5.8 square miles. The creek drops from an elevation of approximately 350 feet to Puget Sound at Des Moines Creek Beach Park. The east fork of Des Moines Creek originates from Bow Lake where it flows through subsurface piping for approximately 1/2 mile. The west fork of Des Moines Creek originates in the Northwest Ponds in the northwest corner of the Tyee Valley Golf Course. The confluence of the two forks of Des Moines Creek lies in the central portion of the Tyee Valley Golf Course. As with Miller and Walker Creeks, streamflow increases downstream as groundwater discharges to the creek, even during times of no rainfall.

An average of approximately 41 percent of precipitation in the Des Moines Creek watershed discharges through Des Moines Creek at its mouth.

1.2.3 Fish Habitat

Despite the habitat degradation that has resulted from urbanization, anadromous and resident fish live in Miller and Walker Creeks. Adult Coho salmon use the Creeks from the mouth to the 1st Avenue South culvert and have been reported above 1st Avenue South. Juvenile Coho are distributed throughout, likely because of Trout Unlimited's releases from the Miller Creek Hatchery. A small population of resident cutthroat trout is distributed throughout much of the watershed. Water-quality data collected for this project during base flow periods indicate that low dissolved-oxygen levels may limit fish production. This project did not analyze or review stormwater quality data.

Despite habitat and water-quality degradation, anadromous and resident fish populations are also present in Des Moines Creek. Adult coho and chum salmon use the stream reach from the mouth to the Marine View Drive culvert. Juvenile coho salmon are distributed throughout Des Moines Creek, likely because of Trout Unlimited's releases from the Miller Creek Hatchery. Steelhead and pink salmon runs have also been reported on Des Moines Creek. A small population of resident cutthroat trout is distributed throughout much of the Des Moines Creek watershed. No water-quality concerns related to fish production were identified in the base-flow water-quality data collected for this project.

1.3 Hydrogeologic Characterization

Characterization of hydrogeology was limited to the embankment and borrow areas. Existing data were used to characterize deep geology and groundwater conditions. Shallow conditions were observed by team personnel during drilling of boreholes and collection of groundwater measurements.

1.3.1 Geologic Units

The following geologic units underlie the study area:

- Recent deposits
- Qvr (Vashon recessional outwash)
- Qvt (Vashon till)
- Qva (Vashon advance outwash)
- Transitional beds
- Deeper units

These deposits are discussed below, from youngest to oldest. The Qvr, Qvt, and Qva were deposited by the Vashon glacier, which covered the study area from about 10,000 to 14,000 years ago.

The youngest natural soil unit comprises recent deposits of peat and highly organic, fine-grained soils. These deposits cover the low elevations near Lora Lake and the area surrounding the central reach of Miller Creek. They probably also cover the upper reaches of Walker Creek. The recent deposits are typically 10 to 20 feet thick near Lora Lake but are thinner along Miller Creek, to the south. Brown silt and medium sand layers are mixed with the peat. These layers form the bulk of the recent deposits in the central Miller Creek reach.

The recent deposits are underlain by a layer of silty sand with some gravel that forms the Qvr, or Vashon recessional outwash, a regionally extensive deposit. The Qvr is the uppermost unit along the east flank of the central Miller Creek valley, near the proposed fill embankment. It may also underlie the recent deposits in the valley bottoms. The Qvr ranges in thickness from 0 to about 30 feet in the project area and is missing in places. The degree of saturation of this unit by groundwater varies widely.

The Qvr is usually underlain by Vashon till (Qvt), a dense layer of gravel and silt in a sandy matrix. This unit is often referred to as "hardpan" in driller's logs. The Qvt ranges in thickness from 0 to 20 feet in the study area. The degree of saturation of the unit by groundwater varies widely. This layer restricts the vertical migration of groundwater and promotes horizontal "interflow" on its upper surface.

The Qvt is commonly underlain by the Vashon advance outwash (Qva), another regionally extensive layer of sand with varying amounts of silt and gravel. The Qva was encountered in almost all borings that penetrated through glacial till in the area. It is the uppermost unit to be modeled by the Port's environmental consultants and comprises the "shallow regional aquifer" identified by previous investigators.

The transitional beds underlie the Qva, Qvt, Qvr, and recent deposits where they are present. These beds were deposited in quiet waters prior to advances of the Vashon glacier. They consist of silt and clay and restrict the movement of groundwater.

Several deeper geologic units are recorded in logs for deep wells in the area, including the "intermediate" and "deep aquifers" described in the South King County Ground Water Management Plan. Because of their depth and large extent, these units are not as sensitive to local changes in recharge as are shallow deposits and groundwater-fed streams that depend entirely on local recharge. Furthermore, changes in recharge to deep units depend on changes in recharge to shallow units. Consequently, for this project, local changes to shallow groundwater recharge and discharge were analyzed and changes to deeper groundwater recharge were inferred from them.

1.3.2 Current Groundwater Flow Conditions

The shallow aquifers in the region are recharged by local precipitation. In the buy-out area, they are also recharged by water that discharged from septic drain fields which was imported from outside the local area as a public water supply. In the study area, groundwater is recharged by up to an estimated 24 inches of precipitation per year depending largely on land use, soil type, and vegetation. In the residential area acquired by the Port of Seattle, an additional 3 inches of septic discharge per year contribute to groundwater recharge.

Two groundwater flow regimes were identified in the Miller Creek basin—a shallow one and a deep one. The shallow system involves the recent deposits, the Qvr, and, in some areas, the Qva. Groundwater in the recent deposits and Qvr discharges to the middle reach of Miller Creek and the upper reach of Walker Creek. The uppermost Qva groundwater may also discharge to the creeks, especially in the Walker Creek headwaters. Groundwater in the deeper system discharges year-round to deep wells, to the lower reaches of the creeks, and to Puget Sound. Near the headwaters of Walker Creek, groundwater in the Qva may discharge more easily to the creek than within the Miller Creek basin, creating an extensive wetland.

1.4 Impact Assessments

1.4.1 Fill Chemistry Effects

Gravel from a mine on Maury Island is being considered as fill for the proposed runway expansion. The top eighteen inches of gravel at Maury Island contain high levels of arsenic, cadmium, and lead originating from the former ASARCO smelter in Tacoma. The top 18 inches of soil at Maury Island are proposed to be contained at the island mine prior to aggregate extraction. Ecology must have assurance that the fill used for the airport project will not result in exceedances of state water quality criteria. The Port and Ecology are working to determine what screening methods and contingencies are necessary to ensure that water quality criteria are met.

This project analyzed the potential effects to ecological receptors, such as the benthic community and wildlife-consuming benthic organisms, if contaminants in the Maury Island fill were to migrate from soils to nearby sediments. Surface and subsurface soil data of the potential Maury Island fill were compared to ecological benchmarks to assess whether unacceptable ecological risks may occur. Based on the above analysis, use of subsurface soils as fill should not pose an unacceptable risk to ecological receptors.

1.4.2 Groundwater Recharge Effects

The Project team assessed groundwater recharge in the project area and found that recharge could change because of the following actions:

- Changing infiltration of precipitation by changing land cover, soil type, and slope
- Conveying runoff from impervious surfaces away from local recharge areas

- Eliminating the discharge of imported water through leaks and septic systems throughout the year
- Eliminating irrigation with local and imported water sources in summer

The net effect of the changes to irrigation and imported domestic water appears to be about zero in the irrigation season (summer). In winter, recharge will be reduced by eliminating the septic discharge and leaks.

The change to *precipitation-derived* recharge was evaluated in a cross section of the proposed fill. This calculation considered the conversion of wetlands and forest to grass on the embankment fill. It also considered the widths of the only two impervious surfaces on the cross section (12th Avenue South and the third runway). The calculation suggests about an 11 percent decrease in groundwater recharge along the cross section, largely as a result of the large increase in impervious area. However, this estimated magnitude of change is probably high because no secondary infiltration of runoff from the third runway was assumed, and modeled water use by grass on the new embankment was possibly higher than expected for the fill soils.

The quantity of water seeping downward through the glacial till was also simulated with the cross-section model. The *volume* of seepage would likely change only slightly under the built condition; however, because total recharge would be reduced, the *percentage* of recharge seeping through the till would increase substantially.

The 11 percent reduction in local recharge is large, but dependent flows to local wetlands and the creeks will be reduced only in winter when abundant water is typically present anyway. A similar reduction in recharge basin-wide would cause a major impact to baseflows. To assess basin-wide impacts, the Port's recharge calculations that considered all Master Plan Improvements were reviewed. The HSPF model parameters used in the Port's recharge analysis do not appear to correspond to those used in actual basin modeling also conducted by the Port. Therefore, a confident assessment of basin-wide recharge and baseflow impacts is currently lacking. A confident assessment of basin-wide recharge and baseflow effects should be possible by analyzing a properly implemented and documented HSPF model.

A small reduction in recharge to deeper aquifers of the Des Moines Creek upland may occur; however, the small reduction would not affect these aquifers' ability to supply water to wells. This conclusion is based on the relatively large recharge areas of these aquifers compared to the airport, the fact that the effects will be apportioned between shallow and deep aquifers, and the reported estimates of shallow recharge.

1.4.3 Fisheries Effects

No direct effects on fish habitat are expected in Walker or Des Moines Creek because of construction. Miller Creek would be relocated in the Vacca Farm area but this reach currently provides poor habitat for salmonids because it features sparse riparian vegetation, a substrate dominated by sand and silt, little complexity, and no instream structure. The proposed Miller Creek channel construction will provide a net gain in habitat since it will feature a mixture of pools and riffles, gravel and cobble substrate, riparian vegetation, and replacement of woody debris. Proper construction and long-term monitoring are vital to successful Miller Creek relocation including control of turbidity during initial wetting. Some sediment transport during initial wetting is likely, and has the potential to damage habitat downstream.

An uncontrolled release of stormwater is likely at some time during construction given the size of the project and human error; however, the size and quality of a release cannot be predicted, nor can its impacts on fish be quantified. If habitat quality is further degraded because of indirect construction effects such as an uncontrolled release of turbid water, resident populations of cutthroat trout and anadromous Coho salmon would likely decline.

The enhancements to the riparian buffer corridor and instream habitat of Miller Creek will undoubtedly benefit local stream habitat for resident cutthroat trout if they are implemented and maintained properly. However, the proposed mitigation is limited in that it will only affect localized Miller Creek habitat and resident cutthroat trout. Indirect construction and post-construction effects such as alterations to base flow, peak flow, and sediment input could affect the entire stream systems, not just the airport project area. The Port predicts reduction in summer base flow in Des Moines Creek as a result of reduced groundwater recharge and supports augmenting low summer stream flows by pumping from a Port-owned well and discharging the water into the creek.

The watershed trust funds for the Miller and Des Moines Creek watersheds can be beneficial. However, significant habitat restoration in Miller, Walker, and Des Moines Creeks will require substantially more funding than what is currently offered through the basin trust funds.

1.4.4 Effects on the Hydroperiod in Local Wetlands

A hydroperiod is the seasonal change in the timing of groundwater discharge to wetlands and streams. For this project, effects to the hydroperiod were evaluated using a cross section of the proposed embankment fill near Miller Creek. The following effects are predicted if the embankment is built:

- Recharge would be 11 percent less along the cross section, and would spread-out within the fill, causing a significant timing lag in discharge to the wetlands and creek west of the embankment compared to the current condition.

- Discharge to remaining wetlands and the creek under the built condition would vary less throughout the year and the period of minimum discharge would be shorter. Flows would be lower in winter than under the current condition, and greater in summer compared to the current condition. The total quantity of water flowing to the wetlands would decrease because total recharge would decrease.

The timing changes would generally benefit the local wetlands that remain after filling and would slightly moderate seasonal low base flows and temperatures in Miller Creek. However, all water quantities are reduced on an average annual basis because total recharge is smaller under the built condition. Also, since the embankment is a small part of the Miller Creek watershed, the overall effect on streamflow is small. If the constructed fill has a lower silt content than was assumed for this analysis, the lag may be overestimated and the recharge volume may be underestimated.

1.4.5 Effects on Wetland Area and Functions

The fill activities associated with the improvement projects would result in the permanent loss of 13.88 acres of wetland in the Miller Creek watershed. In addition to the permanent impacts, construction activities would also result in the temporary loss of 1.86 acres.

Of equal importance to the acreage loss are the functional impacts that would occur. The effectiveness and opportunity for wetlands to improve water quality, provide suitable habitat, and function as floodplains were considered. An additional 1.68 acres of secondary effects may occur if the functionality of the remaining wetlands cannot be maintained. This acreage is attributed to the Wetland 18/37 complex adjacent to Miller Creek.

Given the urban character of the area, the wildlife expected to inhabit the area is restricted to common, highly adaptive species that use both wetland and adjacent upland areas. Species integrally tied to the wetland areas are likely restricted to waterfowl, amphibians, and small mammals. The construction of the airport improvements would affect local wildlife populations simply due to the size of the fill area. As indicated previously, the extent of fragmentation due to urbanization currently limits the viability of existing habitat. Reducing habitat size and availability would further reduce the suitability for small mammals and amphibians. To prevent a significant decline in the local populations, mitigation would be required to provide supplemental/alternative habitat on-site. However, the extent to which habitat could be provided is limited by the nature of the proposed project. FAA requirements limit the development of avian habitat within 10,000 feet of existing facilities to minimize the hazard of potential air strike by birds.

1.4.6 Review of Wetland Mitigation Proposal

Mitigation for the proposed third runway fill and safety areas must account for the permanent loss of 13.88 acres, and temporary effects in 1.86 acres within the Miller Creek watershed.

The preferred regulatory hierarchy for wetland mitigation is:

- On-site, in-kind
- Off-site, within the watershed, in kind
- Off-site, out of the watershed, in kind
- Off-site, out of watershed, out of kind

Because of environmental and regulatory constraints, it is not feasible for the Port to mitigate on-site and in-kind (on-site mitigation is restricted by FAA safety regulations).

The Port proposes the following on-site wetland mitigation measures:

- Removing existing development
- Establishing a vegetated buffer along Miller Creek
- Enhancing wetlands within the Miller Creek buffer
- Enhancing or restoring wetlands within the Des Moines Creek watershed
- Excavating the floodplain to compensate for lost flood storage
- Developing stormwater management facilities
- Restoring and enhancing 11 acres of farmland and farmed wetlands

Off-site mitigation includes developing a 67-acre site for wildlife habitat. The Port also proposes to establish Trust Funds to promote restoration projects for the Miller and Des Moines Creek basins downstream of the project area.

The overall mitigation plan is reasonably designed to compensate for wetland impacts and has the potential for success. The plan provides for in-basin compensation for the impacts to water quality and water quantity, as well as some mitigation for wildlife compensation. However, not all habitat mitigation is proposed to occur in the basin. For those impacts that cannot be entirely mitigated for in-basin, an off-site, out-of-basin mitigation plan has been developed by the Port.

Ecology and the King County Department of Development and Environmental Services have studied wetland mitigation successes and failures. King County concluded that mitigation, in general, is not being implemented, and when it has, it has often failed due to poor design, installation failure, and maintenance. Consequently, the studies call for more regulatory control and guidance during the planning, installation, and monitoring phases. They indicate that mitigation projects do not guarantee success and that closer regulatory oversight is merited for longer periods.

1.4.7 Shallow Groundwater and Wetland Effects in Borrow Areas

Des Moines Creek receives substantial base flow contributions from the Qva aquifer. It also receives contributions from shallow interflow soon after precipitation events, although this contribution is less critical for maintenance of low flows. Recharge to the Qva (shallow regional) aquifer is expected to increase slightly because of excavation in the borrow areas. The change in timing of discharge to the creek was not analyzed and could conceivably be faster or slower than under current conditions, and vary by location. Although the change is small, the change in recharge conditions would likely help dampen streamflow fluctuations and be beneficial in that regard.

Several depressional and slope wetlands may be negatively affected by excavation in borrow areas 3 and 4. The wetlands depend on perched groundwater flow above the Qva aquifer. The excavation is likely to redirect some of the perched flow, reducing discharge to the wetlands and potentially impacting wetland biota.

1.5 Review of Surface Water Management Proposals

The Project Team reviewed hydrologic analyses performed by the Port's consultants, including:

- Their approach to establishing a target flow regime for creeks
- The calibration of their surface water model
- Their designs for flow-control facilities

The results of these reviews are discussed below. The review distinguishes between *approaches* to issues and the *models* used to implement the approaches.

1.5.1 Target Flow Regime Approach

The Port consultant's approach for establishing hydraulic conditions that will preserve stable stream channels is reasonable. They characterized the current and proposed movement of surface water in the study area largely by developing hydrologic models of the watersheds. The models simulate the movement of rainfall under various land-use conditions and predict how slowly stormwater runoff from the airport should be released from storage facilities to achieve the desired flow conditions, or "target flow regime," in the creeks. Defining the target flow regime entailed calculating streamflows that would occur if the tributary drainage basins contained only 10 percent effectively impervious area (EIA). The Port used the Hydrologic Simulation Program-FORTRAN

(HSPF) model and assumed only 10 percent EIA in the watershed.

1.5.2 Surface-Water Model (HSPF) Calibration

Earth Tech reviewed the HSPF watershed models to assess how well they were calibrated by comparing the total flow volumes the models predicted to observed values at two locations each in the Des Moines Creek and Miller Creek watersheds. The Miller Creek HSPF model was found to overestimate water compared to the observed flows, indicating that it is not well calibrated, despite the matching of simulated and observed peak flows for selected storm events. The Des Moines Creek model was found to be more reliable.

The poor calibration of the Miller Creek models is related to the parameters selected for model input. There are several inconsistencies in the input data between models that simulate different land-use scenarios. In addition, since the model was constructed to simulate groundwater contributions to streamflow without considering prior precipitation or groundwater storage, it ignores the rigor offered by HSPF. This project team did not find sufficient confidence in the Miller / Walker Creek model to allow detailed evaluation of the model's results. In our opinion, the model would require modification before a thorough evaluation of the performance of the model, and a corresponding evaluation of proposed surface water controls, could be completed.

1.5.3 Flow Control Designs

The general approach used by the Port to size flow control facilities is appropriate. That approach involved applying the target flow regime concept, using local flow-control facilities in conjunction with regional facilities, and running the HSPF model to simulate the target, existing, and proposed watershed conditions. However, as noted above, the model used to size the flow-control facilities needs to be corrected to use this approach with confidence.

1.5.4 Construction Period (temporary) Impacts

The Stormwater Management Plan states the Port applies temporary erosion and sedimentation control measures that exceed minimum requirements of Ecology's manual. These measures include: developing construction stormwater pollution prevention plans for each capital improvement project; implementing conventional best management practices; applying advanced stormwater treatment techniques where necessary; supervising and monitoring contractor compliance; and funding independent oversight of construction erosion control compliance. This project's review of the plans, and field observations of current operations, generally supports the Port's opinion. However, an embankment construction of the magnitude and duration of the third runway project is subject to a range of climatic events and human errors, and an uncontrolled release of runoff from the disturbed site is probable despite proper implementation of construction BMPs.

2.0 Introduction

The Port of Seattle (Port) has proposed to place a fill embankment in an area west of the existing Sea-Tac Airport complex to build a third runway. In 1999, public concerns prompted the Washington State Legislature and Governor Locke to approve independent studies to investigate the hydrologic impacts of the fill project on aquifers; wetlands; and Des Moines, Miller, and Walker Creeks. With Ecology's oversight, consultants Pacific Groundwater Group (PGG); Earth Tech Inc.; and Ecology and Environment, Inc., (E & E) evaluated selected hydrologic impacts of the proposed project. This is the final report from that project. The study area includes the fill area and adjoining wetlands, streams, and aquifers potentially impacted by the proposed runway project. Also included in the study area are the fill borrow sources south of the current airport.

The Port has produced extensive evaluations of hydrologic impacts in the Master Plan Updates Environmental Impact Statement (Federal Aviation Administration, 1996). Wetlands Functional Assessment and Impact Analysis (Parametrix, 1999), Preliminary Comprehensive Stormwater Management Plan (or SWMP, Parametrix, 1999) and other documents. Local communities also sponsored technical evaluations including Sea-Tac International Airport Impact Mitigation Study ("HOK report" - Hellmuth, Obata + Kassabaum Inc., 1997), stream fisheries investigations, and reviews of Port documents. Communication was maintained with the Port of Seattle, Regional Commission on Airport Affairs (RCAA), and the Airport Communities Coalition (ACC) and their consultants. These parties were requested to provide pertinent technical documents and were interviewed. Informal, usually technical, meetings occurred between representatives of this project and the other parties on several occasions. A formal public involvement process was also maintained, including small group (stakeholder) meetings, publication of three fact sheets, and two public workshops.

2.1 Scope, Authorization, and Limitations

The work was authorized by Dan Silver of the Department of Ecology on September 16, 1999 and an amendment was signed on March 28, 2000 that represented scope changes in response to improved knowledge of existing data and analyses. The scope generally consisted of the following tasks:

- review of existing documents
- interviews with Port staff, community organizations, individuals, and consultants
- collection of additional field data including:
    - two rounds of base flow measurements,
    - two rounds water quality sampling,
    - geologic logging of six boreholes,
    - collection of one round of groundwater level data,
    - a water-well inventory in the buy-out area,
    - survey to review wetland delineations and conditions,
    - stream habitat surveys,
    - fish carcass survey, and
    - juvenile fish counts
- independent evaluation of certain hydrologic impacts using new and existing data, including effects on local groundwater recharge, groundwater flow, support of stream base flows through discharge of groundwater, wetland impacts, and fisheries impacts
- review and comment on Port mitigation proposals including wetlands, fisheries,

and permanent and temporary stormwater management

- review and comment on HSPF models used for stormwater designs
- informing stakeholders and the public on project progress and directions;
- reporting

The scope of this project includes changes resulting from the proposed third runway, borrow areas, and related construction, but not all Master Plan Improvements proposed by the Port. The North Employee Parking Lot (NEPL), South Aviation Support Area (SASA), Industrial Wastewater System (IWS) and terminal modifications are built or proposed improvements that were not explicitly considered by this project. This is an important distinction for large-scale environmental elements such as streamflow and groundwater recharge, because Port projects outside the purview of this project will affect these elements. The NEPL, SASA, and terminal areas are almost completely paved and account for much of the increase in impervious surface area resulting from Master Plan Improvements. In contrast, the foci of this project (proposed third runway, borrow areas, and local wetland and stream systems) will remain predominantly unpaved. This project also did not address proposed State and local surface transportation proposals being considered near Sea-Tac airport.

This project was conducted during a time of intense data gathering, modeling, data evaluation, and reporting by Port consultants, as well as review of these developments by community groups. Most documents were available during the document review period scheduled for this project in fall 1999. However, the Preliminary Comprehensive Stormwater Master Plan, Natural Resources Mitigation report, two subsurface conditions data reports, and other documents were provided during the winter of 1999 and spring of 2000. Changes to the evolving database were anticipated and accommodated to an extent. However, accommodation of additional data or issues was largely curtailed in January 2000 to allow the project to focus on completion of its chosen tasks. Therefore, new data and issues may have arisen since then or may arise in the future.

This report identifies hydrologic issues that were addressed by this study and yet are not resolved to a level of confidence satisfactory to the authors. This report does not address or list all hydrologic issues requiring satisfactory resolution for permitting processes and therefore this report cannot be used as a checklist by agencies during permit review.

The work was performed, and this report prepared, in accordance with generally accepted practices, used at this time and in this vicinity, for sole application to the third runway and borrow projects, and for the sole use of State of Washington Department of Ecology. This is in lieu of other warrantees, express or implied.

2.2 Report Organization

The remainder of this report is organized into two major sections and several appendices. The two major sections of the main body cover the fill area and borrow areas, respectively, which are shown on **Figure 2-1**. Within each of those sections a description of the proposed construction is followed by a description of the character of the area, comparison to previous characterizations, analysis of effects and impacts, and a comparison to previous assessments. The exception is that fish survey results from Des Moines Creek are discussed along with the Miller and Walker Creek results. Appendices are provided to present technical detail that would interfere with communication of findings in the main text.

This report documents data and analyses generated for this project that are not available in other publications. This report does not completely document all existing data related to the project. For instance, geologic data is voluminous and generally not documented in this report. The sources of geologic and other referenced data are provided.

3.0 Proposed Fill Area and Miller and Walker Creeks

3.1 Proposed Construction and Environmental Precautions Related to the Third Runway

3.1.1 Acquisition of Homes and Farms

The Port of Seattle purchased, or is in the process of purchasing, land and homes in the "buy-out area" **(Figure 3-1)** on the west side of the existing Sea-Tac International Airport. The built environment in this area contained:

- more than 400 homes
- five irrigated commercial properties (farms)
- 17 domestic water rights or claims
- neighborhood and arterial roads
- 380 septic drain fields (Parametrix, 1999e)
- numerous water wells

The Port has demolished structures and removed debris. The Port added a process to identify and decommission water wells after an inventory of properties and disclosure of previously unknown wells by this project **(Appendix A)**.

3.1.2 Embankment Fill and Walls

An embankment of fill soil is proposed to create a high, flat surface upon which the third runway would be built. The top elevation of the fill would be about the same as the existing runways (390 to 410 feet elevation). The west margin of the fill would be bounded by a slope (2 horizontal to 1 vertical) or wall, depending on location. **Figure 3-1** shows the locations of the proposed walls.

The walls are proposed as mechanically stabilized earth (MSE) walls. For the purposes of this project important qualities of MSE walls are that they are composed of thin, vertical members on the outside of the wall, and a lattice of horizontal, flexible, porous reinforcing members layered with compacted soil and attached to the outside members. The reinforcing members typically extend into such embankments 80 percent of the wall height (Hart Crowser, 1999a).

The embankment is proposed to be built of fill soil derived from borrow sources on current Port property at Sea-Tac, and from an uncertain offsite source. The aggregate mine on Maury Island, Washington (about 8 miles southwest of the airport) has been identified as a possible offsite source. The volume of the fill required for the third runway embankment is reported to be 16.5 million cubic yards as follows (Hart Crowser, 1999a):

- Type 1 fill: About 40 percent (6.5 million cubic yards) relatively silt-free sand and gravel.
- Type 2 fill: About 60 percent (10 million cubic yards) more or less silty sand (glacial till and outwash soils).

Additional fill is required for other Master Plan improvements.

Type 1 fill would be used near the walls, under runways, and other selected areas. Type 2 fill would be used "to the maximum extent possible, balancing relatively high availability (low cost) with limitations of trying to compact such material in wet weather" (ibid.). **Appendix B** discusses native soil classifications, and **Appendix C** contains evaluation of the likely textures of the Type 1 and 2 fills based on specifications produced for the first phase of this fill (Phase 1 fill). Comparisons are shown to samples collected from the Phase 1 fill and Maury Island deposits.

The bottom of the fill would consist of a layer of relatively silt-free soil (Type 1) that would be designed to act as a drainage layer. The drainage layer, in combination with the Type 1 fill near the wall, is intended to prevent the build-up of groundwater pressures near the wall and seepage through the wall by directing groundwater seepage below the base of the wall to the remaining wetlands and Miller Creek (Hart Crowser, 1999a).

Soft and/or organic soils in the vicinity of the walls may be reinforced or excavated and replaced by compacted inorganic fill to enhance wall stability. Dewatering of these excavations may be required during construction. Removal of organic material (grass, trees, roots) is proposed below the bulk of the embankment, but extensive removal of native soils is not likely.

3.1.3 Surface Water Management on and Near the Proposed Embankment

In the Preliminary Comprehensive Stormwater Management Plan (SWMP - Parametrix, 1999e), the Port presents analyses of the current conditions under which surface water moves through the watersheds affected by the Sea-Tac Runway Fill and by other improvements planned at the airport. The Port proposes a stormwater flow control strategy for existing and planned facilities that is intended to reduce storm peak flows in Miller, Des Moines, and Walker Creeks to below flow rates that would be generated by similar storm events on land uses that existed in 1994.

Within the area of the runway fill, the Port proposes to accomplish the reduction in peak storm flow rates by storing runoff in local and regional detention ponds and vaults while restricting the rate of stormwater released from the storage facilities. This strategy further relies on expansion and construction of large regional ponds in Miller and Des Moines Creeks. Peak flow rates may also be moderated by promoting infiltration into the fill.

Although nearly flat, the surface of the embankment will be sloped to manage runoff of precipitation. The third runway and connecting taxiways will be paved and will comprise about 32 percent of the new embankment surface (Parametrix HSPF basins SDW-1, SDW-2 and SDS-7). Grass will be grown on the unpaved 68 percent. Water running off the paved surfaces is proposed to flow into "filter strips" which are water quality treatment features. The filter strips are proposed to be 75-foot-wide, unlined, uniformly-sloping grass areas adjacent to the pavement except in connecting taxiways where the strips are proposed to be 30-feet wide. Water would flow into low areas at the bottom of the filter strips, then laterally to catch basins spaced hundreds of feet apart in the low areas. Water entering the catch basins would be conveyed through pipes under the runways to detention vaults or other detention facilities prior to discharge to Miller, Walker, or Des Moines Creek. The use of perforated conveyance pipes is being considered (which would enhance infiltration).

3.1.4 Wetland and Creek Protections During Construction

The Stormwater Management Plan states the Port applies construction temporary erosion and sedimentation control (TESC) measures that exceed minimum requirements of the Ecology Manual. These measures include: storm water pollution prevention plans (SWPPPs) for each capital improvement project; conventional TESC best management practices (BMPs); more advanced stormwater treatment techniques where necessary; supervising and monitoring contractor compliance; and funding independent oversight of construction erosion control compliance.

3.2 Character of the Hydrologic Environment

3.2.1 Land Cover

Materials that cover the land surface affect water quantity and quality in important ways. Vegetation of various types, water bodies, and man-made structures including pavement are examples. Detailed cover maps exist for portions of the area; for instance, wetland classifications include vegetation types, and road distributions are mapped throughout. The Master Plan FEIS includes vegetative cover descriptions for some of the area. Also, the HSPF surface water models of Miller Creek and Des Moines Creek include land cover parameters, measured as total acreage of various pervious and impervious surfaces within each sub-basin. Parametrix Inc. (SWMP) generated sets of land cover parameters for modeling conditions in 1974, 1994, "current" and 2004 conditions. These sets include parameters for all proposed Master Plan Improvements including the third runway embankment, NEPL, and SASA.

This project assigned land cover types based on field observations and design plans where detailed evaluations were performed. The land cover types used in detailed assessments near the embankment are summarized below.

Near the proposed west wall of the embankment, the existing slope is forested and underlain by a thin mantle of outwash soils, or glacial till. Twelfth Avenue South is paved, and separates the slope on the east from grassy and forested wetlands to the west near Miller Creek. This condition is consistent in the embankment area, except that extensive areas of grass, forest, and landscape vegetation occur on outwash and till soils in addition to the wetlands west of 12th Avenue. The Vacca Farm has wetland-type soils and is fallow. Houses are sparse to moderately dense in this buy-out area and paved roads are sparse compared to most urban areas.

Under the proposed built condition, the forested slope and some low areas, including wetlands, would be covered with compacted fill which would grow grass. In addition, all houses, and presumably utilities, would be removed from the buy-out area.

3.2.2 Geology

The sequence of geologic units present in the fill area is described in this section. Surface materials have been characterized through geologic mapping (Booth and Waldron, in press). Subsurface conditions have been explored specifically for various construction and environmental projects at the existing airport by Port consultants. Subsurface data are also available from off-site wells that are recorded with the Washington State Department of Ecology. Associated Earth Sciences Inc. (AESI) was hired by the Port to compile a computer and hard-copy database of boring logs that includes onsite and offsite well data. Parts of the database were provided to this project along with AESI's interpretations of subsurface geologic structure.

Pacific Groundwater Group described soils from six borings in the project area and observed the activity of the Port's drillers and geotechnical consultant, Hart Crowser. The boring logs generated by Hart Crowser indicate generally the same densities, soil types, and contacts as logs generated by Pacific Groundwater Group. Boring logs are documented in numerous reports generated by Port consultants. The most recent work in the embankment and borrow areas is documented in several "conditions reports" by Hart Crowser (1999b, 1999d, 2000a, 2000b) listed in the references.

The geologic units are described below from youngest to oldest. In a classic sequence of units, all the units would be present, with the youngest on top. However, prehistoric erosion, landslides, reworking of units by water, and uneven original distributions commonly create conditions where not all units are present. Also, since each unit is not composed of a unique soil texture, density, or color, absolute identification of each unit is seldom certain.

This project focused on relatively shallow hydrologic processes. Specifically, our effort included understanding the soil units in the hydrologic regime that are responsible for base flow in the creeks. We found that groundwater below the Vashon Advance (Qva, shallow regional) aquifer does not discharge to the creeks. Therefore, geologic units deeper than the Qva received less scrutiny and are discussed together below.

3.2.2.1 Fill

The youngest unit of soil in the project area is fill used in construction of the existing airport runways. Its extensive distribution at the airport is indicated on the geologic map of **Figure 3-2**. However, the fill unit is also mapped in additional areas disturbed by cut and fill operations. The fill is generally described in boring logs as silty sand with gravel. Lower portions of the fill are saturated with groundwater at least seasonally. The characteristics of this fill were not considered in detail because it is east of the proposed third runway fill embankment.

3.2.2.2 Recent Deposits

The youngest natural soil unit consists of peat and highly organic fine-grained soils generated from recent and current geologic processes. This unit is not distinguished from the Vashon Recessional Outwash (Qvr) by Booth and Waldron (in press; **Figure 3-2**) but actually warrants a separate mapping unit. The recent deposits are present in the topographic low areas near Lora Lake, the central reach of Miller Creek, and probably the upper reaches of Walker Creek.

The deposit is typically 10 to 20 feet thick near Lora Lake and is somewhat thinner along Miller Creek south of there. The recent deposits appear to be only a few feet thick in the headwaters of Walker Creek. The peat is generally a dark-brown, soft, silty soil composed of decayed and compressed organic matter. Brown silt and medium sand layers are mixed with the peat, and constitute the bulk of the recent deposits in the central Miller Creek reach.

Hart Crowser reported estimates of horizontal hydraulic conductivity for soils that consist of mixed recent and Qvr deposits. The conductivities range ranging from $9x10^{-5}$ to $5x10^{-3}$ cm/sec. The recent deposits are generally finer than the Qvr, and likely account for the lower hydraulic conductivities in the range. Because of its low physiographic position, virtually the entire deposit is saturated with groundwater year-round. A hydrograph of groundwater levels measured by Hart Crowser, in a well screened in recent deposits, is shown as **Figure 3-3.** Pacific Groundwater Group accompanied Hart Crowser and participated in gathering one round of water level data from wells in the embankment area. The procedures used by Hart Crowser were observed by Pacific Groundwater Group and were found to be standard. However, the equilibration of water levels in the wells to atmospheric pressure (once the wells were opened) was not confirmed during the field work. The water levels could be erroneous if equilibration was not achieved.

3.2.2.3 Qvr

Older than the recent peat, silt, and sand is a unit of silty sand with some gravel that constitutes the regional Qvr deposit. This unit was presumably the basis for Booth and Waldron's mapping the Qvr unit (**Figure 3-2**). It is the shallowest geologic unit along the east flank of the central Miller Creek valley near the proposed fill embankment. It may also underlie the recent deposits in the valley bottoms, but it is commonly absent in that position based on boring logs.

Based on interpretations by AESI (undated) and Hart Crowser (1999b and 2000a), the Qvr ranges in thickness up to 30 feet in the project area, but is missing in places. Hart Crowser reported estimates of horizontal hydraulic conductivity for combined recent and Qvr deposits between $9x10^{-5}$ and $5x10^{-3}$ cm/sec. The Qvr deposits are generally coarser than the recent deposits, and likely account for the higher hydraulic conductivities in the range. Because of its widespread physiographic distribution, saturation of the unit by groundwater varies widely. The entire unit remains saturated year-round in the valley bottoms where it may occur below recent deposits. The lower several feet of the unit remain saturated in some intermediate and upland positions as documented with water level measurements collected by AESI and Hart Crowser. A representative hydrograph of groundwater levels measured by Hart Crowser, in a well screened in the Qvr, is presented in **Figure 3-3.** In other locations, the Qvr may be only seasonally saturated, or may remain unsaturated year round.

Whether or not a geologic unit is saturated is important because it aids in interpreting how groundwater may be moving within the unit. The absence of saturation indicates that groundwater is probably moving downward via unsaturated flow (except within the root zone where upward flow may occur). The presence of saturation is less diagnostic because horizontal, upward, or downward flow may be occurring.

3.2.2.4 Qvt

Glacial till (Qvt, hardpan) is recorded in most borings drilled in the project area. It is a dense unit of gravel and silt in a sandy matrix. It is usually massive and not stratified. In the project area it is similar in texture to the Qvr, although denser, and this likely explains the term "till-like soil" used by Hart Crowser (2000a). Till was compressed by direct contact with glacial ice. Booth and Waldron (in press) mapped glacial till at or near land surface immediately west of the existing runway fill as well as on other nearby uplands (**Figure 3-2**). In these mapped areas, a soil profile (commonly the Alderwood soil series) has developed on the till, but the geologic map reflects the glacial till underlying the soil. The till appears to be absent at borings HC00-B110 and HC00-B111 logged by Pacific Groundwater Group south of the cross section location.

Based on interpretations by AESI (undated) and Hart Crowser (1999b, 2000a), the Qvt ranges in thickness up to 20 feet in the project area, but is missing in places. Hart Crowser interpreted well tests indicating hydraulic conductivity values for Qvt-like deposits ranging from $1x10^{-4}$ to $5x10^{-4}$ cm/sec. This infers higher groundwater recharge potential than typically measured for glacial till aquitards (Booth, Massmann, and Horner, 1996; Bauer and Mastin, 1996). Reasons for the anomalously high results probably include the fact that lower hydraulic conductivity units such as till do not yield water to a well during drilling, and therefore are commonly not screened or tested. This results in a high bias in hydraulic conductivity based on well tests. Also, since groundwater generally moves vertically in aquitards, vertical hydraulic conductivity is of more interest than the horizontal values measured by Hart Crowser's slug tests. The term "till-like soils" used by Hart Crowser (2000a) to describe the soils in this category of testing results suggests that they included soils with texture, but not density, similar to till.

Because of its varied physiographic position, saturation of the till by groundwater varies widely. It is commonly thought to be unsaturated based on visual observations because water does not readily flow out of it when penetrated. Water percolating downward commonly accumulates on top of till because of its relatively low hydraulic conductivity relative to percolation rates and the hydraulic conductivity of overlying strata. The presence of water in overlying units is an indirect indicator of saturation within the till. The entire unit remains saturated year-round where it occurs below recent deposits and/or the Qvr in the valley bottoms. The unit remains saturated in some intermediate and upland positions as inferred by the occurrence of groundwater in the overlying Qvr. In other locations, the Qvt may be only seasonally saturated, or remain unsaturated year round.

3.2.2.5 Qva

The Vashon Advance Outwash (Qva) deposit is a widespread unit of sand with varying amounts of silt and gravel that commonly underlies glacial till. It was encountered in almost all borings that penetrated through glacial till in the area. However, many borings in the embankment area and buy-out area were terminated *within* the till and therefore data on the distribution and properties of the Qva are sparse. Booth and Waldron mapped the unit as comprising the land surface on a slope in the central buy-out area (**Figure 3-2**). The basis for this mapping is unknown. Borings logged by Pacific Groundwater Group in the vicinity (HC00-B111 and HC00-B110) encountered a thick silt, suggesting that the mapping may be erroneous, or that the Qva was interpreted by Booth and Waldron to be a silt at that location. Interpretations for this project assume the mapping to be erroneous and the slope to be comprised of transitional beds (Qtb) discussed below.

The Qva is the upper-most unit that will be explicitly modeled by Port consultants' (AESI and Papadopulos and Associates) regional groundwater (Modflow) model. AESI (undated) interprets the Qva to occur below the entire project area at a thickness of about 10 feet to more than 50 feet, with a top contact elevation as high as about 380 feet under the existing runways. The top of the Qva is interpreted at a depth of about 30 to 60 feet below the runways based on the AESI analysis. Near Miller Creek, the AESI analysis indicates the top of the Qva at an elevation between 220 and 240 feet based in part on the surface outcrop mapped by Booth and Waldron (in press), which is questioned as noted above. The presence of recent deposits and till extending to a depth of more than 26 feet near Miller Creek (HC00-B124) would indicate a maximum possible top elevation of 204 feet for the Qva at that location. If the Qva outcrop of Booth and Waldron discussed above is actually Qtb, then the AESI interpretation of complete continuity of the Qva must be incorrect. Since the Qva is the shallow regional aquifer, this difference could affect local groundwater flow.

The Qva observed by Pacific Groundwater Group during this project near Lora Lake, is a gray, slightly silty, fine sand. Gravels are occasionally present in the Qva and the unit is often stratified. It is usually distinguished from glacial till based on lower fines (silt and clay) content, stratification, and lack of cementation.

The Qva is the shallow regional aquifer of the South King County Groundwater Management Plan (South King County Ground Water Advisory Committee, 1989). Its regional extent, the perennial presence of groundwater in its lower portions, and its ability to yield water to wells in useful quantities, made this an important water supply source for residences prior to the availability of public water supplies in the area. Currently, potable supplies generally come from deeper aquifers. Below the uplands, groundwater in the Qva is unconfined (a water table exists), and the top of the unit is not saturated. Near the creeks, the Qva is completely saturated, and groundwater within it is confined below the overlying, less permeable Qvt and recent deposits.

The hydraulic conductivity of the Qva was not a matter of concern for this project, no tests were performed, and existing data were not reviewed.

3.2.2.6 Qtb

The transitional beds were deposited in quiet water environments prior to advances of the Vashon glacier and the bed therefore occur below the Qva, Qvt, Qvr, and recent deposits. The unit is composed of silt and clay. Based on texture, Pacific Groundwater Group interprets the thick silt encountered from 20 feet to 97 feet depth (elevation 264 to 187 feet) in boring HC00-B111 to be Qtb. However, as discussed above, Booth and Waldron (in press) appear to have mapped this unit as Qva.

Regardless of its name, the presence of silt from 20 feet to 97 feet in HC00-B111 indicates the lack of a "shallow aquifer" corresponding to the Qva at that location. Conditions at boring HC00-B110 to the southwest are similar.

3.2.2.7 Deeper Geologic Units

Several deeper geologic units are recorded in logs of deep water wells in the area. These include the "intermediate" and "deep aquifers" of the South King County Ground Water Management Plan. The top of the intermediate aquifer is commonly encountered 200 to 250 feet below ground in the airport area. The top of the deep aquifer is encountered at roughly 300 to 400 feet below ground in that area. Although the aquifers are not uniformly transmissive, groundwater flow to these deep aquifers occurs over virtually the entire Des Moines upland (used here as the glacial upland between Puget Sound and the lower Green River Valley). Because of their depth and large lateral extent, these units are less sensitive to local changes to recharge and discharge than are shallow groundwater resources and groundwater-fed streams that are entirely dependent on local recharge. Furthermore, changes in recharge to deep units is dependent on changes to recharge to shallow units. Therefore this project analyzed local changes to shallow groundwater recharge and discharge, and used those results to infer changes to deeper groundwater recharge. Detailed characterizations of the deeper geologic units is not necessary for that analysis and was not performed.

3.2.2.8 Comparison to Previous Geologic Interpretations

Two differences exist between the shallow stratigraphy described above, and that being used by Port consultants. The interpretation of 20 to 30 feet of moderate and low hydraulic conductivity sediments (recent and Qvt units) overlying the Qva aquifer in the middle Miller Creek reach is one difference. Booth and Waldron (in press) mapped Qvr as present throughout this area and did not differentiate the recent deposits documented in the borings by Hart Crowser (the borings may not have been available at the time of mapping).

The second difference is that Booth and Waldron (in press) map an extensive slope outcrop of Qva on the east flank of the middle Miller Creek reach near the proposed embankment. Logs of borings HC00-110 and HC00-111indicate the slope is probably composed of silt and clay, which is not typical for the Qva (the borings were not available at the time of mapping). A related issue is that AESI (undated) implies a continuous Qva aquifer below the creek, which is not indicated by the logs of the two noted boreholes.

A review of the deeper stratigraphic interpretations generated by Port consultant Associated Earth Sciences, Inc. (AESI) was also performed by Pacific Groundwater Group (**Appendix D**). AESI's work is part of the development of a regional groundwater flow model being commissioned by the Port. The general geologic layering presented by AESI in cross sections is consistent with Pacific Groundwater Group's interpretation. However, local inconsistencies were identified and in several cases the structural contouring of the units does not agree with the cross sections. See **Appendix D** for details.

3.2.3 Soil Water Balance Components

3.2.3.1 Water Sources

Precipitation and imported public water supplies are the two independent water sources to the area. Precipitation at SeaTac was used in calculations for this project. **Appendix B** provides details.

Drinking water to homes near the buy-out area is provided by local water districts that produce water from wells and buy water from the Seattle Water Department. The Seattle Water Department and the districts maintain wells in the intermediate and deep aquifers. Because the recharge area for these water sources extend far beyond the buy-out area, this water source is effectively "imported" from outside the area for the purposes of assessing changes to recharge resulting from the buy-out. Approximately 400 homes, each with a residential water supply will be removed. It is assumed that the pipes that supply water to the area will be decommissioned such that no leaks will occur.

3.2.3.2 Groundwater Recharge Estimates

Percolation of precipitation from the land surface was estimated with a proprietary spreadsheet model developed by Pacific Groundwater Group (Recharge model - **Appendix B**). Field observations of land covers were used to characterize the factors that significantly influence the recharge process. Soil types, land cover, and the presence/absence of shallow till were compiled from existing data and unique combinations thereof were assigned to individual "recharge classes." The recharge model was then used to estimate monthly and annual recharge for each recharge class. The model performs a daily water-balance calculation, but used average monthly values for precipitation and ambient temperature. Along with climatic data, information regarding plant water demand, soil hydraulic properties, and depth to till (where present) was used to perform the daily water balance. In the case of a perched upper aquifer, the model was calibrated to seasonal saturation of the soils above glacial till by adjusting till hydraulic conductivity.

Overland runoff from the recharge classes that were analyzed was assumed to be zero, and the effects of runoff were instead considered in interpretation of the output. Predicted runoff values are less than a tenth of an inch annually for various soils with forest cover, to about one inch annually for grass on till soils according to the HSPF water balance analysis presented in Appendix F of the SWMP. That model indicates 2 to 3 inches of runoff from the runway infields. Runoff from runways themselves is assumed to be 100 percent, and no secondary infiltration of runoff is assumed for this project or the Miller Creek HSPF models even though substantial secondary infiltration may occur.

Land-cover was divided into three categories (grass, forest, and barren). Water requirements for grass were used to represent the current and proposed runway infields and wetland meadows. Water requirements for coniferous and deciduous trees were averaged to represent the forested wetlands and forested uplands.

The spatial distribution of soils was based on surficial geology (Booth and Waldron, in press) and field observations. Soils were considered to be outwash, till, or wetland (saturated).

The recharge model was run for the unique combinations of land cover and soil occurrence discussed above. For Upland till areas, the model allowed shallow groundwater to accumulate above the till and slowly percolate downward based on a till permeability chosen to create seasonal saturation above the till (the assigned till permeabilities for this model do not affect other models). A detailed description of the method for estimating recharge is presented in **Appendix B**.

Figure 3-4 presents the average monthly estimates of recharge for the recharge classes near the proposed embankment. The estimates were calculated at the bottom of the root zone or the water table, which ever was shallower. Estimates range from 14.4 inches of recharge per year for wetland areas to 24.2 inches per year in mixed-forest areas on outwash soils. Barren outwash has a higher recharge (25.6 inches) than the vegetated classes, but was only considered in evaluation of borrow areas (Section 4). In general, the riparian wetland areas do not contribute to deep groundwater recharge; however, percolation does occur to the water table and that is plotted in **Figure 3-4.**

Wetland and till areas indicate negative recharge in summer. In those areas, water is extracted from the saturated zone by plant roots and thus a net loss of water occurs. Unlike HSPF analyses presented in the SWMP and elsewhere, interflow above glacial till is included as groundwater recharge in these analyses.

3.2.3.3 Comparisons to Previous Soil-Water Estimates

Applied Geotechnology Inc. (AGI), (Port of Seattle, 1996), Parametrix (1999e), and Hart Crowser (1999c), conducted water balance calculations for the proposed third runway. The AGI calculations related to Miller Creek watershed were not reviewed. The Parametrix and Hart Crowser calculations are complementary, with Hart Crowser calculating subsurface flow within the embankment using output from the Parametrix work.

The Parametrix water balance was based on the HSPF models of Miller and Des Moines Creeks. As discussed in Section 3.6.2, inconsistencies in model parameters between versions of the Miller Creek model, and poor calibration of the Miller Creek model, create a lack of confidence for use of that model in water-budget analyses.

The water budgets for the various land classifications used in the HSPF analysis in Appendix F to the SWMP are subject to some, but not all, of the Miller Creek model problems. Therefore, the results of that analysis were considered. Because these calculations compare current and proposed future conditions, they are discussed in Section 3.6.6 – Comparisons to Previous Groundwater Assessments.

3.2.4 Water Circulation

3.2.4.1 Shallow Groundwater Circulation and Discharge

Groundwater moves laterally and vertically from areas of higher potential energy (head) to areas of lower potential energy (influence of topography), and is influenced by the distribution of hydraulic conductivity (geology) because it tends to follow paths of high hydraulic conductivity. Head is measured by surveying the elevation of water levels. In the proposed fill area, higher head occurs where recharge enters the ground and lower head occurs in streams, in deep aquifers, and in the ultimate base level body, Puget Sound.

Two groundwater circulation patterns (regimes) were identified in the Miller Creek basin based on their scale and discharge locations. One regime is relatively shallow and discharges entirely to the local creeks. The other regime consists of groundwater that circulates deeper, and discharges year-round to deep wells, the lower reaches of the creeks, and Puget Sound. The deeper regime could probably be subdivided into subcategories, but that is not necessary for the purposes of this project. At the headwaters of Walker Creek, Hart Crowser (2000b) interprets Qvt to be discontinuous. In that case Qva groundwater may discharge more easily to the creek than within the Miller Creek basin, possibly explaining the extensive wetland in the Walker Creek head waters.

Evidence supporting the division of groundwater flow into two regimes is three fold: hydrostratigraphy, the vertical distribution of groundwater heads, and analysis of base flow in Miller Creek. This evidence is presented in the following paragraphs.

As described in Section 3.2.2, the recent and Qvr deposits have moderate hydraulic conductivity and are in direct contact with the middle reach of Miller Creek and the upper reach of Walker creek. Groundwater in these units is not impeded in its discharge to the creeks. The recent and Qvr deposits are typically underlain by Qvt, which has low hydraulic conductivity. Below the glacial till may lie a second aquifer, typically the Qva aquifer. The Qva aquifer is physically separated from the middle reach of Miller Creek by till and sometimes silt. As noted above, discontinuous till in the Walker Creek headwaters may create a more direct avenue of discharge between Qva groundwater and the creek there. Groundwater moving within the Qva aquifer is impeded from discharging to Miller Creek in most of the proposed embankment area by low hydraulic conductivity units. Some upward discharge through those units may nonetheless occur.

The second type of evidence used to identify the scale of the groundwater flow regime responsible for base flow to Miller Creek was the vertical distribution of groundwater heads near the creek. Hart Crowser has installed numerous monitoring wells in the proposed embankment area. Most of the wells monitor heads in the upper aquifer composed of recent and Qvr deposits within 25 feet of ground surface. A few wells monitor heads in a second aquifer. Where the second aquifer is separated from the upper aquifer by till, it can be formally considered the Qva aquifer. The more general term "second aquifer" may consist of the Qva in many cases but may also be a sandy unit near the bottom the Qvr. Since groundwater moves from zones of high to low head, groundwater in the second aquifer must have higher head than groundwater in the intervening recent/Qvr aquifer if it is going to discharge to a local creek. Water levels (heads) from nearby wells screened in the recent/Qvr and second aquifers were compared to assess the potential for this upward flow. Heads in the second aquifers were found to be lower or equal to heads in the recent/Qvr aquifer. Thus, upward discharge of deeper groundwater from the second aquifers to the streams was not indicated in those areas at those times.

Although the review described above indicates that inter-aquifer flow is predominantly downward, one example of upward inter-aquifer flow was noted, as was a case for upward flow from the probable Qva aquifer where it is not overlain by a shallower aquifer.

Upward inter-aquifer flow is inferred near the Miller Creek Detention Facility (MCDF) at well HC99-B43A which flows when uncapped, indicating sufficient head to flow into the Miller Creek detention facility (MCDF). A shallower Qvr aquifer exists there as well. This area is near the area proposed for expansion of the MCDF. That expansion would be created by excavation which could breach the aquitard that confines the high-head groundwater.

Breaching such an aquitard could cause uncontrolled groundwater discharge, erosion and discharge of sediment to the MCDF, and loss of stored groundwater. Further evaluation of the potential for that problem to occur is warranted.

Upward discharge of groundwater also occurs near the headwaters of Walker Creek at well HC00-B208. At that location water levels in the well stand above the adjacent ground surface. Also, the boring log for that well indicates the presence of only a thin mantle of recent deposits, underlain by a thick sandy unit that began to discharge groundwater at 34 feet depth. That sandy unit may be the Qva aquifer, in which case direct discharge of Qva groundwater to the creek is indicated.

The third type of evidence used to identify the scale of the groundwater flow regime responsible for base flow to middle Miller Creek was comparison of rates of gain in base flows in Miller creek to results from a local groundwater model. A simple finite difference slice model was developed to simulate shallow groundwater flow on the east flank of Miller Creek at cross section A-A' (**Figure 3-2**). **Appendix E** explains details of the model and Section 3.2.4.2 below explains the stream flow measurements used for comparisons to groundwater model predictions. **Figure 3-5a** shows the idealized geometry assumed for the Qvt aquitard and Qvr/recent aquifer for this model. Simulation included accounting for groundwater recharge only within the area of the proposed embankment fill (the section extends about 1250 feet east from Miller Creek at that location).

Figure 3-6 presents the results of the slice model for current conditions. The figure shows predicted water flow over a year. Water outflow is divided into surface flow, groundwater discharge, and seepage downward through the till. Overland ('surface") flow and groundwater flow contribute water to wetlands and the creek near the proposed west wall. The plotted values for surface and groundwater flow are flow to the west end of the cross section model. The plotted values of recharge and percolation through the till ("till seepage") are sums across the entire cross section. In a conceptual sense the till seepage reaches the Qva aquifer. This downward seepage is not accounted for further within the cross section. Units of measurement are cubic feet per day, per foot of width (cfd/f). The total volume of recharge, surface flow, till seepage, and groundwater flow are indicated in the legend. The plot shows how those volumes are distributed over the year.

Although the model was never intended to be calibrated to base flow gain rate, the sum of modeled groundwater flow, modeled surface flow, and septic discharge was in the range expected for base flow contributions from east of the creek for the current conditions. The analysis suggests that base flow consists mostly of local, shallow groundwater flow and that contributions from the Qva aquifer are small in this reach. Further explanation of base flow measurements follows in Section 3.2.4.2.

3.2.4.2 Streamflow

King County has maintained stream gaging stations at various locations over selected periods on Miller, Walker, and Des Moines creeks. This review focused on the data used in the calibration of HSPF models by Port consultants. Flow duration curves for two gages on Miller Creek, and one gage on Walker Creek, are presented as **Figure 3-7**. The gage locations are shown on **Figure 2-1**. The "observed" values on **Figure 3-7** are hourly data from the gages. The flow duration curves indicate that data from gages 42A (mouth of Miller Creek) and 42E (mouth of Walker Creek) include some inaccurate readings in the low flow range. The sharp drop off in observed flow data suggests problems with the gages recording lower flow rates. Simulations using the calibration-scenario HSPF models prepared by the Port's consultants produce durations for most flow rates in excess of observed values.

Pacific Groundwater Group measured base flows in Miller and Walker Creeks at numerous locations in October 1999 and January 2000 to assess gains in base flow. Measurements were made with a Swoffer current meter on a wading rod. **Table 3-1** and **Figure 3-8** present the data along with King County measurements for those dates. The October 1999 measurements preceded the onset of seasonal rains and represent low flow conditions for 1999 (which was a very wet year). The January 2000 measurements also occurred after a period of no rainfall and represent winter base flow conditions plus discharge of stormwater from MCDF.

The measurements indicate that flow increases downstream at both times of year and that the flow rate varies depending on the season. Flows in Miller Creek increased substantially from October to January. About half of the increase at the Kiwanis Club appears to result from the release of stored groundwater and stormwater from the Miller Creek Detention Facility. The other half comes from increased shallow groundwater flow to the stream in the project area.

To assess contributions to base flow from the embankment area, the rate-of-gain per foot of stream reach was estimated using the Miller Creek data from the Lora Lake and SR-509 stations. **Table 3-2** summarizes the calculations, which indicate that Miller Creek gained approximately 6 cubic feet of water per day per foot (cfd/f) of stream length in October, and 11 cfd/f in January. Examination of the flow records of the King County gages indicates that base flows in average rainfall years are on the order of 50 to 70 percent of the 1999 and 2000 measurements.

The slice groundwater model described in **Appendix E** used average recharge rates over the area of the proposed embankment and so must be compared to average streamflow contributions (not to the 1999 data) from the east flank of the valley. The slice model results plus estimated septic discharge contributions account for 2 cfd/f of base flow gain in middle Miller Creek in the fall, compared to the 1.5 to 3 cfd/f estimated from measurements. The slice model results plus estimated septic discharge contributions account for 8 to 9 cfd/f of base flow gain in middle Miller Creek in the winter, compared to the 4 to 8 cfd/f estimated from measurements. This is relatively good agreement.

3.2.4.3 Water Circulation in Wetlands

The hydrologic functions of various wetlands are described in Section 3.3.3. Slope, depression, and riparian wetlands occur in the project area.

3.2.4.4 Comparison to Previous Base-Flow Interpretations

The SWMP provides a description of Miller, Walker, and Des Moines Creeks in the context of stormwater management for the proposed master plan projects. The descriptions rely heavily on HSPF models of the basins. Because the analyses are largely comparative (pre- and post- development), model review is discussed in Section 3.6 – Analysis of Selected Impacts.

AESI (undated) used land surface in the Miller Creek and Walker Creek drainages as "control points" on Qva heads. Although numerically this approximation may be acceptable, base flow should not be solely linked to Qva aquifer discharge as implied by use of these "control points". The 20 to 30 feet of low hydraulic conductivity sediments commonly present between the Qva and the streams, and the presence of shallow groundwater flow within those sediments, should be considered.

Hart Crowser (1999b Figure 7) mapped horizontal groundwater circulation in the embankment area's "shallow regional aquifer". The shallow regional aquifer is elsewhere defined as the Qva (AESI undated). However, Hart Crowser uses data from wells clearly screened in recent deposits near the creek (above till). Given the preponderance of low hydraulic conductivity units in the near surface, heads in the various shallow aquifers should not be assumed equal, and data from wells screened in different stratigraphic positions should not be lumped without justification and acknowledgement.

3.2.5 New Water Quality Data

The water quality in Miller, Walker, and Des Moines Creeks was analyzed for a wide range of parameters that help define the environmental health of a creek. Surface water quality parameters, including oxygen, temperature, and turbidity, were measured during field visits. Other parameters were measured at Analytical Resources, Inc. **(Appendix F). Tables 3-3 and 3-4** present the results.

For both rounds of measurements, turbidity was highest just downstream of the Miller Creek Detention Facility and improved downstream. Groundwater and wetland discharges are typically very low in turbidity; therefore, Miller Creek turbidity improves as groundwater and wetland water flow into the creek downstream of the detention facility. In October, oxygen levels increased from 6 mg/L at Lora Lake to 9 mg/L at the Kiwanis Club. However, in January, oxygen levels ranged from 5 to 7 mg/L with no clear trend in water quality moving downstream. Water temperature ranged from 10 to 11, and 5 to 7 degrees C with no apparent trends, in October and January, respectively.

Discussion of water quality as it pertains to fish habitat is discussed in Sections 3.4 and 4.4.

3.3 Character of the Wetland Environment

The project area surrounding Sea-Tac Airport is primarily urban/residential. Immediately west of the airport, land use is a mix of residential and agricultural, with development encroaching on the Miller Creek riparian corridor. This corridor consists of a mosaic of land uses with residential areas, agriculture, upland habitats, and slope and riparian wetlands, all located adjacent to the creek. Outside the immediate vicinity, areas that have not undergone extensive urban development are restricted primarily to the narrow riparian and ravine corridors associated with Miller and Walker creeks. Larger wetland complexes are associated with these drainages, including the Miller Creek Detention Facility, and a large wetland complex which forms the headwaters of Walker Creek. In addition to these riparian, ravine and wetland systems, the only other major non-urban areas include the successional woodlots west of the airport acquired as part of previous Noise Abatement Mitigation projects (which had been residential but are now upland woodlots), Vacca Farm, and scattered lakes, ponds, and local recreational parks. No other significant parcels of undeveloped land were identified.

Approximately 11 acres of wetlands are present in the vicinity of in the Runway Safety Area Extension and 40.65 acres of wetlands occur in the vicinity of the Third Runway Impact Area (Parametrix 1999a). **Figure 3-9** identifies the wetlands within the project area based on mapping by Parametrix. This acreage does not include larger complexes (including the approximate 43-acre headwater wetland of Walker Creek), wetlands associated with Tub Lake, Arbor Lake, and Burien Lake, and smaller isolated wetlands that occur north of State Route 518, and west of State Route 509. Based on the field survey, extensive riparian wetland complexes also occur along both

Miller and Walker creeks within ravine areas west of SR 509. These all fall outside the bounds of the project area and are not discussed further.

3.3.1 Document Review and Field Analysis

Wetland field verification surveys were conducted during the week of December 4, 1999. Surveys were conducted throughout the Miller Creek drainage basin to assess the regional context of the project area.

Before conducting the field surveys, the following documents were reviewed:

- Available National Wetland Inventory Mapping (United States Fish and Wildlife Service);
- Available aerial photography of the project area;
- Wetland Delineation Report (Parametrix, Inc., Revised Draft, August 1999);
- Wetland Functional Assessment and Impact Analysis (Parametrix, Inc., Revised Draft, August 1999);
- Natural Resources Mitigation Plan (Parametrix, Inc., Revised Draft, August 1999); and
- Biological Assessment (Parametrix, Revised Draft, November 1999).

The field surveys focused on confirmation of the wetland delineations, evaluation of the wetland quality assessment, and analysis of the proposed mitigation.

3.3.2 Wetland Delineation

As a component of the EIS for the Port's Master Plan improvement projects, numerous consultants conducted wetland delineations within the proposed project area. Areas where access was denied were not delineated but rather best professional judgement was used in estimating the wetland boundaries. Following completion of delineation efforts, and in conjunction with the United States Army Corps of Engineers (USACE) Section 404 permitting effort required for the project, wetland scientists from the USACE conducted in-field verification surveys of delineated wetlands. E&E's field survey confirmed that boundaries as flagged in the field accurately depict the extent of wetlands, and are correctly depicted on available wetland maps. The field surveys also did not identify any wetlands that previously had not been delineated.

3.3.3 Wetland Characterization

To evaluate the potential effects on wetlands, it is necessary to characterize wetlands with respect to each other, their role in the watershed, and their functionality. The different methods of classifications used to categorize and assess the value of the wetlands in the project area are described below. The field survey and literature review were used to evaluate the previous classifications and assess their functionality in order to make an independent analysis.

3.3.3.1 Wetland Classifications

Parametrix classified wetlands in the project area by physiographic setting (e.g., slope, depressional, or riparian) and by regulatory class as defined by the *Washington State Wetlands Rating System* (Washington State Department of Ecology, 1993). During the field survey, both classifications were evaluated.

Table 3-5 lists the wetlands that E&E identified as potentially impacted by the fill activities, lists their classifications, and provides brief description of the wetlands' location and condition. Expanded discussions of the wetland areas are provided in the Wetland Delineation Report (Parametrix 1999a).

Most wetlands within the project area that are likely to be affected are slope wetlands. These wetlands are hydrologically driven by hillside groundwater seeps, with additional input from precipitation. The slope wetlands range in size from very small (the 0.05 acre Wetland 13) to the extensive Wetland 18/37 complex, located west of the existing airport. In addition to the slope wetlands, depressional and riparian wetlands are present. The depressional wetlands likely have resulted from segmentation of once larger wetland systems that have systematically been filled, or, have developed on low permeability fill soils. All riparian wetlands delineated in the vicinity are associated with Miller Creek.

E&E is in general agreement with the wetland classifications assigned by Parametrix (1999b) based on field surveys completed for the project. No wetlands in the project area are Class I, the highest quality and most significant wetlands in the state. Class I wetlands include those that contain documented occurrences of recognized species of concern, are recognized as regionally significant, or perform irreplaceable ecological function (i.e., bogs, mature forested wetlands, or estuarine wetlands). While Miller Creek is documented to contain protected fish species in its lower reaches, there is no documentation of these species occurring within the wetlands in the project area. Although there are forested wetlands in the project area, the evident local disturbance, and the estimated ages of the existing trees do not meet criteria established for Class I wetlands.

3.3.3.2 *Functional Assessment*

Wetlands are recognized for the value they provide on an ecosystem level. This value varies based on wetland size, location in the landscape, and on surrounding land use. To better estimate the value or quality a wetland provides within an ecosystem, it becomes necessary to assess specific functional attributes of a wetland.

Evaluation of wetland functions is an inexact science. Numerous models have been developed within the scientific community to specifically evaluate wetland functional capabilities, yet they all recognize that while certain functions can be directly measurable, oftentimes professional judgement is necessary to correctly apply the models. Furthermore, existing models have been developed to evaluate the functionality of wetland types (i.e., depressional or riparian) with the results between types not being comparable. Therefore, the use of models for large diverse projects usually does not provide useful data. Therefore, E & E assessed the quality of wetlands, using best professional judgement and scientifically established parameters. Our assessment is loosely based on the principles established in *Methods for Assessing Wetland Functions* (Hruby et al. 1999), which has been published for depressional and riparian wetlands within Western Washington.

Three basic categories of functional capability were assessed: water quality improvement, hydrology (or water quantity), and habitat suitability. Water quality function includes the ability of the wetland to effectively trap sediment, nutrients, and contaminants. Hydrologic function focuses on the ability of a wetland to provide flood storage, prevent downstream erosion, and potential for recharging aquifers. Habitat suitability is a broad-ranging category including both flora and fauna diversity, and the export of organic carbon, which can be beneficial to adjacent aquatic communities.

The qualitative assessment component of **Table 3-5** focuses on those wetland functions that E&E believes are likely to be affected by the airport improvement projects and on those functions that differentiate the wetlands within the project area. For example, most project area wetlands have little direct bearing on resident fish populations and are therefore all equally considered to be low quality. The exceptions to this (e.g., Wetlands 18 and 37) are specifically noted within the qualitative assessment column in the table. This assessment approach is conservative because wildlife was broadly grouped together rather than differentiating amphibians, and small mammals. The bird habitat functions of the wetlands are more related to the vegetative cover type and size. The larger and more diverse wetlands (particularly those with a forested component) provide moderate-to-high quality habitat for migratory bird species, while the smaller, typically emergent wetlands, offer low-to-moderate quality bird habitat.

In addition to evaluating the specific functions of a wetland, E & E assessed the effectiveness of a wetland to provide a specific function and also the opportunity to provide that function. The opportunity for a wetland to provide a particular function is driven by its size, the surrounding landscape (land use), and by the wetland's location within the watershed. Thus, while a depressional wetland is an ideal basin for storage of floodwaters and highly effective as a nutrient/sediment trap, a small headwater depressional wetland located in an undisturbed environment would have little opportunity to provide this function and thus would have a low functional assessment.

This qualitative discussion is based on a combination of the field survey conducted, and data provided as part of previous investigations in the project area. Prior to utilizing any data acquired previously, data comparisons were made for those wetlands where information was available from both previous field reports and the field survey. The validity of this previously acquired data was analyzed using professional judgement before incorporating the data into this assessment.

As indicated in the table, wetlands in the project area are important nutrient and sediment traps that filter-out anthropogenic inputs prior to discharge to Miller Creek. Refer to Section 3.4 for a more detailed discussion of the fish habitats available in local water resources. The riparian and larger depressional wetlands also provide flood retention capabilities in a highly urbanized watershed. Flooding is a recognized concern, and the Miller Creek detention facility, located immediately upstream from the project area is designed specifically to dampen flood flow through Miller Creek. From a wildlife population perspective, the wetlands within the project area provide necessary habitat/open space in an urban setting. Because of the urban development and fragmentation of the resource, the local wetland habitats benefit small amphibian and small mammal populations, as well as the more mobile avian species. Discussions of aquatic habitats are discussed in Section 3.4.

3.3.4 Comparison to Previous Wetland Characterizations

Project area wetlands were evaluated to verify the accuracy of the delineations and qualitative assessment completed as part the Wetland Delineation Report (Parametrix 1999a). Based on the field surveys completed, which represented a random sampling of wetlands within the project area, the wetland delineations presented in the delineation report provide an accurate representation of the extent of wetlands that occur in the project area.

Wetland delineation is an interpretive skill that requires professional judgement, particularly at wetland boundaries, where the available vegetative, hydrologic, and soil indicators can be marginal at best. Based on the wetland flagging present in the project area, the delineations completed within the project area are conservative in estimating the extent of wetlands, meaning that the marginal areas were more likely to be included as wetland area, rather than upland.

In reviewing the functional assessment completed for the project, the analysis also showed that the qualitative assessment provided a reasonable representation of functional ability of wetlands within the project area. The framework used for this analysis used *Methods for Assessing Wetland Functions* (Hruby et al. 1999) which was not available during the preparation of the previous studies completed at STIA.

Methodologies and references referred to in the Wetland Functional Assessment and Impact Analysis included *the Wetland Evaluation Technique* (WET) (Adumus et al.1987), *Hydrogeomorphic Classification of Wetlands* (Brinson 1993) and *Wetland Values: Concepts and Methods for Wetland Evaluation* (Reppert et al 1979). However, to some extent, professional judgement is the key to the analyses presented in the report. While neither previous wetland evaluations, nor the quality and functional assessment conducted as part of this analysis provide numerical quantification of wetland impacts, both approaches effectively identify those functions that would be impacted by the implementation of the Sea-Tac improvement projects. Numerical quantification of wetland impacts would not necessarily improve the overall qualitative assessment of impacts, particularly in light of the fact that a significant portion of the wetland impacts are to slope wetlands, for which there are no recognized/approved models.

3.4 Character of Fish Habitat and Populations

This discussion of fish habitat in Miller, Walker, and Des Moines Creeks focuses on the abilities of these creeks to support salmonid species. Different salmonid species and life history stages have different optimal habitat preferences that fall within a range of acceptable values. The optimal habitat preferences for juvenile and adult coho salmon (*Oncorhynchus kisutch*) are presented in **Tables 3-6, 3-7, and 3-8** for comparison purposes with existing habitat conditions. Only those habitat parameters that commonly limit salmonid survival and production are presented. Because optimal habitat preferences for coho salmon are generally more restrictive than cutthroat trout (*O. clarki*), decision making based on coho salmon habitat preferences should also be protective of cutthroat trout.

3.4.1 Miller Creek

3.4.1.1 General Watershed Description

The Miller Creek watershed is approximately 9 square miles and encompasses 5 governmental jurisdictions: the cities of Normandy Park, Burien, and SeaTac, Port of Seattle, and unincorporated portions of King County. Water flow for Miller Creek originates from Arbor Lake, Lake Reba, Lora Lake, Lake Burien, wetlands associated with the Miller Creek detention facility, and from seeps into the channel and riparian wetlands, especially located along the west side of the airport. Miller Creek falls from an elevation of approximately 360 feet in its headwaters to sea level at Puget Sound at the Normandy Park Cove. Significant residential and commercial development exists within the Miller Creek watershed, resulting in approximately 23 % impervious surfaces. Land use consists of approximately 62% residential, 15% commercial, 3% airport, and 20% undeveloped (Montgomery Water Group 1995).

Trout Unlimited (TU) operates the Miller Creek Hatchery located at the Southwest Suburban Sewer District in Normandy Park. The hatchery has been in operation for approximately 15 years. Annually, TU receives coho salmon eggs from the Washington Department of Fish and Wildlife (WDFW). Although the number of eggs received annually varies, the maximum number of eggs the Miller Creek Hatchery can raise is 300,000.. TU reports egg to juvenile survival that usually approaches 100%.. TU plants juvenile coho throughout Miller, Walker, and Des Moines Creeks. Fish plantings are conducted at various times throughout the spring and with different size fish in an attempt to maximize survival of planted fish. Coho salmon released by the Miller Creek Hatchery are not tagged or identified with any distinguishing marks.

3.4.1.2 Watershed Development

Urbanization has degraded salmonid habitat in Miller Creek. The stream habitat lacks complexity and variability and is dominated by fast water riffle/run habitat. Sedimentation is prevalent throughout the watershed. Optimal habitat parameters for salmonids such as presence of woody debris, undercut banks, and overhanging vegetation are absent throughout much of the stream system. Pool to riffle ratio is reported to be approximately 15:85, well below the optimal 50:50 ratio (Batcho 1999a). Development and impervious surfaces in the watershed have significantly affected the stream's hydrograph, causing less wetland and groundwater storage and resulting in high peak flows and lower base flows. These factors cumulatively result in limiting habitat factors for different salmonid life stages, particularly high-quality gravel for spawning adult salmonids and refuge habitat for age-0 juvenile salmonids (i.e., fish that emerged this year).

3.4.1.3 Water Quality Related to Fish

Miller Creek's water quality has also been degraded by urbanization in the watershed. MacCoy and Black (1998) reported toxic metals such as arsenic, lead, and mercury in Miller Creek sediment and sculpin (bottom-dwelling/feeding fish) tissue at concentrations exceeding the probable-effects level developed by the Canadian Council of Ministers of the Environment (CCME). Probable-effects levels identify a threshold above which adverse effects are predicted to occur frequently; concentrations exceeding these guidelines may or may not result in an adverse effect on aquatic organisms but are intended to indicate potential sediment quality problems that warrant further study. MacCoy and Black (1998) also reported polynuclear aromatic hydrocarbons at concentrations in Miller Creek sediments exceeding the CCME threshold effects level, which defines the concentration below which adverse effects to aquatic organisms are expected to be rare.

Voss et al. (1999) reported the presence of numerous pesticides in Miller Creek. The insecticides carbaryl and diazinon were present at concentrations exceeding the chronic aquatic life criteria recommended by the U.S. Environmental Protection Agency (1998). Voss et al. (1999) noted that the ecological effects to the stream are unknown because the duration of exposure to pesticide concentrations above the chronic aquatic life criteria is unknown.

Pacific Groundwater Group collected surface water samples during fall and winter base flow periods throughout the upper portion of the Miller Creek watershed and analyzed for in situ water quality parameters (pH, temperature, conductivity, turbidity, and dissolved oxygen (**Table 3-3**). These parameters appear to be within expected values for the region; however, dissolved oxygen levels as low as 4 mg/L likely limit salmonid utilization in the sampled area. Water samples also were analyzed for total metals, total suspended solids (TSS), ammonia, nitrate, nitrite, total phosphorus, ortho-phosphorus, biological oxygen demand, and total oil and grease (**Table 3-4**). Washington State Surface Water Quality Standards include maximum concentration levels (MCLs) for arsenic, cadmium, copper, lead, and zinc (WAC 173-201A 1997). Arsenic and cadmium were not detected in Miller Creek. Based on the calculated hardness in Miller Creek of 95 to 150 mg/L, detected concentrations of copper and zinc were well below the Washington State MCLs. One out of four lead concentrations was above the MCL based on the calculated hardness of 95 mg/L for that sample. The maximum TSS value was 17 parts per million (ppm), indicating minimal suspended particles (of which sediment is one component) in the water column during these base flow periods. Total oil and grease was below 2 ppm, indicating minor inputs of petroleum constituents at the time of sampling. Significant changes to water quality likely occur during stormwater runoff events.

Stormwater at the airport falls into one of two types of catchments: the Stormwater Drainage System (SDS) and the Industrial Wastewater System (IWS). This project did not independently review original SDS or IWS water quality data or discharge data. The following brief discussion is from the FEIS (FAA, 1996) and other sources.

In general, the IWS collects water close to the airline gates where fueling and plane de-icing operations occur while the SDS collects water from the taxiways and runways. The IWS drains are connected to one of three storage lagoons where the water is treated and discharged to Puget Sound. The IWS lagoons are not hydrologically connected to the Miller creek watershed. On the other hand, SDS drains are connected to drainage ditches and, hence, discharge to the Miller Creek and Des Moines creek watersheds. Chemicals specific to airport operations, that are potentially present in SDS runoff, include de-icing chemicals draining off planes during taxi and take-off and de-icing chemicals used on the runway. The FEIS (FAA, 1996) indeed reports occasional glycol and ammonia detections in SDS discharges from those sources, and also reports that copper and zinc occur at elevated concentrations in SDS discharges.

Other SDS water quality parameters were reported to be similar to other basin stormwater. Analyses of seven water quality parameters in SDS discharge (total suspend solids, biochemical oxygen demand, oil and grease, total phosphorus, total copper, total lead, and total zinc) were reported in the FEIS (FAA, 1996). Results were compared to the total basin loading for these parameters in Miller Creek. It was reported that discharge from the airport contributes between 0.5 and 4.3 % of the total basin loading for these parameters. These values are less than the 5% of the Miller Creek watershed that the airport encompasses.

3.4.1.4 Fish Populations

Despite habitat and water quality degradation as a result of urbanization, anadromous and resident fish populations are present in Miller Creek. Adult coho salmon are known to use the stream reach from the mouth to the 1st Avenue South culvert, however, adult coho have been reported in Miller Creek above 1st Avenue South (Batcho 1999a, personal communication). Juvenile coho salmon are distributed throughout Miller Creek, likely because of Trout Unlimited's Miller Creek Hatchery release efforts. Steelhead (*O. mykiss*) runs have been reported on Miller Creek, but this was not field verified. A small population of resident cutthroat trout is distributed throughout much of the Miller Creek watershed. Pumpkinseed sunfish (*Lepomis gibbosus*) reportedly have been introduced to Miller Creek; E&E observed one pumpkinseed in the lower portion of Miller Creek. Three-spined stickleback (*Gasterosteus aculeatus*) has been observed in the vicinity of Lake Reba, however E & E did not verify stickleback presence. E & E did not document the distribution of pumpkinseed or three-spined stickleback in Miller Creek.

3.4.2 Walker Creek

3.4.2.1 General Watershed Description

Walker Creek is a major tributary of Miller Creek; however, information about the creek is lacking because it is commonly not discussed as an exclusive watershed. Walker Creek originates in a series of wetlands located within a triangle formed by Des Moines Memorial Drive, Highway 509, and South 176th Street. The original confluence of Walker Creek and Miller Creek was downstream of First Avenue South, but decades ago Mr. Walker altered the stream (Gower, pers. comm. 1999). Walker Creek currently parallels Miller Creek downstream of First Avenue South and drains into Miller Creek approximately 0.25 mile from the mouth of Miller Creek at the Normandy Park Cove area.

3.4.2.2 Watershed Development

Urbanization has degraded salmonid habitat in Walker Creek. The stream habitat lacks complexity and variability and is dominated by fast water riffle/run habitat. Sedimentation, which is detrimental to salmonid production, is prevalent throughout the watershed. Habitat parameters such as presence of woody debris, boulder cover, and undercut banks are absent throughout much of the stream system. Overhanging vegetation is present throughout most of the system and is dominated by shrubs and trees; this provides cover for fish and shading to minimize water temperature increases above tolerable levels for salmonids. However, grass is common streamside vegetation in residential areas throughout the watershed. Grass possesses little value as riparian vegetation because it does not provide overhanging cover, substantial inputs of organic matter to the stream, or streambank stabilization below the top soil unit, all of which are important habitat parameters for salmonid production.

3.4.2.3 Water Quality

PGG measured temperature, pH, conductivity, turbidity, and dissolved oxygen during base flow periods in October and November 1999 and January 2000 at two locations in Walker Creek: near the First Avenue South retaining wall and near the mouth at the intersection with 12th Avenue South. These water quality parameters also were measured in November 1999 at two locations west of Highway 509 (**Table 3-3**). The results indicated low dissolved oxygen levels that may limit fish production. In November

1999, dissolved oxygen levels of 3 mg/L at both the First Avenue South retaining wall and the intersection at 12th Avenue South could substantially limit salmonid usage of the creek in the sample areas. In addition, the dissolved oxygen levels of 0.2 mg/L and 0.4 mg/L measured in Walker Creek west of Highway 509 likely prevent salmonids from using this area.

3.4.2.4 Fish Populations

Despite habitat degradation, anadromous and resident fish populations are present in Walker Creek. Adult coho salmon are known to use the stream reach from the mouth to the 1st Avenue South culvert; however, adult coho have been reported in Walker Creek above 1st Avenue South (Batcho 1999). Juvenile coho salmon are distributed throughout Walker Creek, likely because of Trout Unlimited's Miller Creek Hatchery releases. A small population of resident cutthroat trout is distributed throughout much of the Walker Creek watershed.

3.4.3 Carcass Surveys

Previous studies have investigated the composition of natural and hatchery fish in the anadromous salmonid returns in Miller, Walker, and Des Moines Creeks (WDFW 1996, BioAnalyists 1998, Batcho 1999). However, reported composition has varied; thus uncertainty exists in the composition of natural and hatchery fish in the anadromous salmonid runs in these creeks. All fish released from WDFW hatcheries receive an adipose fin clip to indicate their hatchery origin. However, not all privately permitted fish releases require fish to receive adipose fin clips. For example, the Miller Creek Hatchery does not clip coho salmon adipose fins because of the small size of fish at the time of release and the labor intensive nature of fin clipping (Batcho 1999). Hence, fin-clipped fish found in Miller, Walker, or Des Moines Creek are likely straying fish from another nearby hatchery or net pen operations (Batcho 1999). The two most likely sources of fin-clipped coho in the adult salmon return are the Des Moines Creek Net Pen operated by TU or the Soos Creek Hatchery operated by the WDFW. Non fin-clipped fish in Miller, Walker, or Des Moines Creeks could have four possible origins: first generation fish from the Miller Creek Hatchery, second (or greater) generation fish from the Miller Creek Hatchery, wild fish that have sustained a population, or wild fish that have strayed from nearby populations.

E & E conducted carcass surveys to establish the proportion of marked and unmarked fish in Miller, Walker, and Des Moines Creeks. **Figures 3-10 and 3-11** show survey locations. These data can serve as an indicator of the creeks' ability to support natural anadromous fish spawning populations and the success of the Miller Creek Hatchery in reestablishing these spawning populations. However, carcass survey data are limited because identifying the presence of returning adult salmon does not establish that successful spawning (i.e., a naturally reproducing population) is occurring on the creek. Juvenile fish surveys are more suited for this purpose as described in Section 3.4.4.

3.4.3.1 Methods

In December 1999, E&E performed carcass surveys by walking upstream (in the stream when possible) from the creek mouth to a predetermined upstream boundary. The Miller and Walker Creek upstream boundary was 1st Avenue South and the Des Moines Creek upstream boundary was Marine View Drive. E&E classified every carcass encountered by species, sex, presence of an adipose fin clip, and the estimated percent of egg voidance in females (egg voidance is the measure of eggs expended by the female during spawning). Because a substantial amount of time had elapsed since the salmon had expired, many carcasses were in an advanced state of decay and, as a result, one or more data parameters were unidentifiable.

3.4.3.2 *Results*

Data from the carcass surveys are presented in **Table 3-9**. The majority of fish were coho salmon; two chum salmon were observed in Des Moines Creek and one in Walker Creek. Most females appeared to void the majority their eggs, although the range of egg voidance was 0-100 percent. Egg voidance numbers should be interpreted with extreme caution because significant decay and subsequent washout of the carcasses had occurred since the fish expired. Therefore, the reported percentages are likely overestimates of the actual percent of egg voidance.

On Miller Creek, E&E observed eleven coho salmon in the sample reach (**Table 3-10**) Sex and adipose fin determination could not be made on two of the eleven coho observed. Of the nine identifiable coho, six were female and three were male. Eight fish were identified as WDFW hatchery fish (i.e., adipose fin clips) while one fish still possessed an adipose fin. Egg voidance in female coho on Miller Creek ranged from 0-100, but most females had voided >80% of their eggs.

On Walker Creek, 42 fish were observed in the sample reach; 41 fish had expired and one live fish was observed downstream of the 13th Avenue South culvert in Normandy Park (**Table 3-11**). Species determinations were made on 21 fish: 20 were coho salmon and one was a chum salmon. Sex determination was made on 24 fish: 12 female and 12 male salmon were observed. Adipose fin determination was possible on 18 fish: 12 fish were identified as WDFW hatchery fish and six had the adipose fin. Egg voidance in female coho on Walker Creek ranged from 70-95%.

On Des Moines Creek, nine fish were observed; six fish had expired and three live fish were observed in quiet water downstream of the Marine View Drive culvert in Des Moines (**Table 3-12**). Species determinations were made on nine fish: seven were coho salmon and two were chum salmon. Sex determination was made on six fish: two female and four male salmon were observed. Adipose fin determination was possible on six fish: one fish was identified as a WDFW hatchery fish and five still had an adipose fin. Egg voidance in female salmon on Des Moines Creek ranged from 0-90%.

3.4.3.3 *Conclusions*

WDFW hatchery fish comprise the majority of anadromous coho salmon runs on Miller and Walker Creeks. Because no WDFW hatchery is located within the Miller Creek basin, these hatchery fish are likely straying from the Soos Creek or Keta Creek Hatchery in the Green River watershed or from the Des Moines Creek net pen. Conversely, only one of six anadromous salmon on Des Moines Creek was identified as a WDFW hatchery fish. This result was unexpected because of the proximity of the Des Moines Creek net pen operated by TU. The non-WDFW hatchery fish in the anadromous salmon returns on Miller, Walker, and Des Moines Creeks could fall into one of four categories as described above. Because non-WDFW hatchery fish comprise only a small portion of the anadromous salmon returns on Miller and Walker Creeks, the Miller Creek Hatchery does not appear to be successfully contributing significant numbers of coho to the salmon run based on the data collected for this field survey.

3.4.4 Juvenile Fish Survey

E&E used the presence of juvenile salmon in Miller, Walker, and Des Moines Creeks as an indicator of the ability of each creek to support a naturally reproducing anadromous salmon run. Carcass surveys can establish various characteristics of the returning adult population such as proportion of fin-clipped fish or sex ratios. However, in addition to the presence of adult salmon, a multitude of other criteria need to be satisfied for adult salmon to successfully produce viable juveniles. These factors include, but are not limited to, water flow, water temperature, dissolved oxygen, and degree of gravel sedimentation. Therefore, the presence of age-0 salmon in Miller, Walker, or Des Moines Creeks prior to annual Miller Creek Hatchery releases indicates that adequate conditions currently exist for the survival of fertilized eggs to emergent fry.

3.4.4.1 Methods

E & E conducted juvenile fish surveys on March 24 and 25, 2000. No planned Miller Creek Hatchery releases had occurred on Miller or Walker Creeks prior to the juvenile fish surveys. However, accidental releases of approximately 100 fish occurred in early March (Yonkers 2000). TU released juvenile coho salmon in the upper portion of Des Moines Creek near the Tyee Valley Golf Course approximately 2 weeks before the Des Moines Creek juvenile fish survey. This hatchery release is expected to have insignificant effects on the results of the Des Moines Creek juvenile fish survey because hatchery fish were released approximately 3 miles from the juvenile fish study area, juvenile coho often establish territories and remain in the same location for extended periods of time (Hoar 1958), and recently emerged coho in the creek are distinguishable from Miller Creek Hatchery coho based on size.

The juvenile fish survey study area for Miller and Walker Creeks consisted of the reach from the mouth to the downstream intersection with First Avenue South. The Des Moines Creek juvenile fish survey study area consisted of the reach from the mouth to the downstream intersection with Marine View Drive. E&E conducted the surveys by walking from the mouth toward the upstream boundary. Sample locations were biased to habitat preferred by juvenile salmon, such as pools, backwaters, undercut banks, or areas with instream or overhanging cover. Biased sampling locations were limited because preferred slack water habitat was not abundant. Juvenile fish were captured with a 1/16" delta mesh fully hung beach seine measuring 6 feet deep and 20 feet long. Certain habitat was inaccessible with the beach seine because of substrate irregularities or debris. A small mesh dip net was used as an alternate capture method when juvenile fish were observed but could not be accessed with the beach seine. Sampling frequency was dependent upon juvenile fish capture success; the goal of sampling locations and sampling frequency was to identify juvenile fish distribution throughout the study area. If a significant number of fish were captured at any sampling location, the number of fish anesthetized and measured was limited to 20. The remaining fish were enumerated and released at the point of capture.

Corralled fish were led to the streambank where they could be netted and transferred to a 5-gallon holding tank. Captured age-0 fish were individually anesthetized in a separate 5-gallon tank containing a solution of tricaine methanesulfonate (MS-222; 50 mg/L) to reduce handling stress and allow for rapid fish identification and length measurements. Fish were handled immediately after signs of equilibrium loss. Fish greater than or equal to age-1 were large enough to identify and measure quickly without anesthetic. After data collection, fish were immediately transferred to a third 5-gallon fresh water recovery tank and remained until equilibrium was regained. All fish were released at the point of capture. General habitat characteristics of sampling locations and location in the stream system were described for all areas where fish were captured. Species and length data were used to document the presence or absence of different species and age classes of fish.

Capture success with the beach seine was approximately 50%. Numerous fish were observed during beach seine deployment but were not retained because of interference with submerged logs and other obstructions. Fish also may have escaped through gaps in the bottom of the net before the beach seine could be completely sealed.

3.4.4.2 Results

The Miller Creek juvenile fish survey results are presented in Table 3-13. E & E captured fish at 7 sampling locations throughout the sampling reach (i.e., mouth to First Avenue South). Two species were identified: coho salmon and cutthroat trout. E & E captured cutthroat trout (likely age 2-5) throughout the sampling reach; cutthroat were often associated with deep water, commonly at the upstream edge of a plunge pool. Coho salmon (age-0) were also distributed throughout the sampling reach. A total of 15 age-0 coho were captured in Miller Creek. Age-0 coho length ranged from 26-50 millimeters (mm) fork length (FL), with an average length of 37.5 mm. Age-0 coho were typically found at about 6 inch depth in slack water associated with side channels, edge habitat, or instream structure such as logs or boulders. Biased sampling locations were difficult to identify because slack water preferred by age-0 coho appeared to be limited. E & E observed numerous age-0 fish (presumably coho) in slack water habitat between sampling locations but beach seine or dip net capture methods were not employed because of sample gear inaccessibility or because of proximity to another sampling location.

The Walker Creek juvenile fish survey results are presented in Table 3-14. E & E captured fish at 8 sampling locations throughout the sampling reach (i.e., mouth to First Avenue South). Two species were identified: coho salmon and cutthroat trout. Cutthroat trout (likely age-2) were captured throughout the sampling reach; cutthroat were often associated with deep water, commonly at the upstream edge of a plunge pool. Coho salmon (age-0) were also distributed throughout the sampling reach. Sixty age-0 coho were captured in Walker Creek; however, only 32 were retained for length measurement. Age-0 coho length ranged from 26-45 mm FL with an average length of 38.25 mm. Age-0 coho were typically found at about 6 inch depth in slack water associated with edge habitat or instream structure such as logs or boulders. Side channel habitat is scarce throughout Walker Creek. Biased sampling locations were moderately difficult to identify because slack water preferred by age-0 coho appeared to be somewhat limited. Although, slack water habitat associated with edge habitat or instream structure was more prevalent on Walker Creek compared to Miller or Des Moines Creeks. E & E observed numerous age-0 fish (presumably coho) in slack water habitat between sampling locations but beach seine or dip net capture methods were not employed because of sample gear inaccessibility or because of proximity to another sampling location.

The Des Moines Creek juvenile fish survey results are presented in Table 3-15. E & E captured fish at 2 sampling locations in the upper portion the sampling reach (i.e., mouth to Marine View Drive). Two species were identified: coho salmon and cutthroat trout. One cutthroat trout (likely age-2) was captured at Station 1 in the upstream portion of a mid-channel pool. A total of 6 age-0 coho were captured in Des Moines Creek. Age-0 coho length ranged from 34-38 mm FL, with an average length of 35.8 mm. Age-0 coho captured at Station 2 were found at about 6 inch depth in slack water associated with edge habitat and instream boulders. Biased sampling locations were difficult to identify, particularly in the lower portion of the sampling reach, because slack water preferred by age-0 coho appeared to be limited.

3.4.4.3 Conclusions

Age-0 coho salmon were present throughout the sampling reach in each stream system. Despite degraded habitat on Miller, Walker, and Des Moines Creeks that likely limits coho salmon production, adequate habitat and water quality conditions currently exist to allow for some coho salmon egg to age-0 survival. No age-0 chum salmon, or steelhead were captured during the juvenile fish surveys. As a result, it is unlikely that viable spawning populations of these species exist on Miller, Walker, or Des Moines Creeks.

3.4.5 Habitat Survey

Many organizations have surveyed in-stream and riparian habitats of Miller and Des Moines Creeks with the goal of evaluating the habitat for current or potential use by salmonids, primarily coho salmon, cutthroat trout, steelhead, and chum salmon (Trout Unlimited 1993, Resource Planning Associates 1994, Shapiro and Associates 1994, Parametrix, Inc. 1999c, BioAnalysts, Inc.. 1998). Although it is difficult to compare specific results obtained by the different habitat assessment methods, the habitat surveys performed thus far have reached the same general conclusion: adequate salmonid habitat exists on Miller Creek in the stream reach from Puget Sound to the 1st Avenue South culvert while upstream of this culvert the habitat is marginal. In Des Moines Creek, adequate habitat exists from Puget Sound to South 200th Street, however, much of this reach is inaccessible because if the migration barrier at Marine View Drive. Local agencies agree with these general descriptions (Masters 1999, Schnieder 1999). In general, urbanization degraded the creeks, but the creeks do support small resident fish populations, including salmonids. Limiting factors for the ability of these creeks to support fish populations include degraded physical habitat, water quality, increased peak flows, and migration barriers. Despite the degraded stream habitat, anadromous salmon runs (primarily coho salmon) exist on Miller, Walker, and Des Moines Creeks.

In contrast to Miller and Des Moines Creeks, only one habitat survey has been completed on Walker Creek. Therefore, E&E performed a brief field survey of Walker Creek habitat in December 1999, to confirm the baseline habitat characteristics, using methods found in *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers, Second Edition* (EPA 1999).

3.4.5.1 Methods

E&E surveyed five, 100-foot habitat stations on Walker Creek.

1. Normandy Park Cove area.
2. Residential area upstream of 13th Avenue in Normandy Park.
3. Relatively undisturbed area in the Walker Preserve.
4. Upstream of 1st Avenue South.
5. Residential area upstream of Ambaum Avenue.

Habitat stations were randomly selected within separate geomorphic segments as defined by BioAnalysts (1999). Data from the habitat surveys are presented in **Table 3-16**. Specific habitat parameters were scored through a consensus of two biologists as described in *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers, Second Edition* (EPA 1999). Each habitat parameter score was then summed to obtain the total habitat score for the sample station. Station 3 received the highest habitat score, which was expected based on the relatively undisturbed habitat in the Walker Preserve. The other four stations fall into the marginal or the low end of the suboptimal habitat categories, indicating degraded habitat. Water quality data collected for Walker

Creek included temperature, ranging from 6.5-7.6 °C; dissolved oxygen, ranging from 12.14-13.32 mg/L; and pH, measuring 7.70-7.88. These water quality parameters are within acceptable ranges for salmonid species. Turbidity measurement at Station 2 was high compared to the other stations; the reason for this deviation is unknown. The major substrate components of most of the habitat stations were sand and gravel. These results are consistent with the results of the detailed Walker Creek habitat survey performed by BioAnalysts (1999).

3.4.5.2 Conclusions

The results of this field survey of Walker Creek are consistent with the results of the habitat survey performed by BioAnalysts (1999). The lack of channel complexity (i.e., optimal pool:riffle ratio of 50:50), the high degree of sedimentation, the lack of available cover, and the sparse riparian vegetation appear to be the habitat parameters that limit salmonid production in Walker Creek. Habitat quality is below optimal throughout most of the watershed, especially in residential areas.

3.4.6 Comparison to Previous Fish Habitat and Population Studies

3.4.6.1 Literature Review

Significant volumes of information and data have been collected regarding the proposed expansion of the airport and natural resources in the vicinity of the airport. Documents were prioritized and reviewed for pertinence to the project scope and the source of the document. Information obtained from objective sources, such as the King County Department of Natural Resources, the WDFW, or scientific literature, was weighted with greater significance. Information generated by sources directly or indirectly involved with the proposed airport expansion was reviewed with a critical eye. These sources include, but are not limited to, the Port of Seattle, public interest groups, or private citizens. Biota-related fieldwork performed during this project was designed to clarify contradictions in available information.

3.4.6.2 Proportion of Marked Fish in Anadromous Salmon Population

Uncertainties associated with anadromous fish returns in the Miller, Walker, and Des Moines Creeks remain after review of the existing data (TU 1993, Shapiro 1995, WDFW 1996, Parametrix 1999d, BioAnalysts 1998, Batcho 1999). The proportion of marked (adipose fin clip) and unmarked (no adipose fin clip) fish reported in annual fish returns is inconsistent. All fish released from WDFW hatcheries receive an adipose fin clip to indicate their hatchery origin. The Miller Creek Hatchery operated by TU does not clip coho salmon adipose fins because of the size of fish at the time of release. The anadromous fish return data collected during the carcass surveys generally agreed with data reported by TU (Batcho 1999) and BioAnalysts (1999). All surveys indicate that hatchery fish comprise the majority of anadromous salmon returns to Miller, Walker, and Des Moines Creeks. Although differences exist in carcass survey results and previously documented percentages of adipose fin clipped fish in the salmon return, these differences can be explained by natural annual variability in salmon returns and different sample sizes among the three studies.

3.4.6.3 *Spawning Activity*

Reports of the occurrence of spawning on Miller, Walker, and Des Moines Creeks are inconsistent. The WDFW (1996) reported no evidence of spawning activity, but TU (numerous years) and BioAnalysts, Inc. (1999) reported anadromous fish spawning in the creeks. E&E originally planned to do redd counts but these were not performed since a significant amount of time had elapsed since salmon had entered the creeks and completed any spawning behavior. Therefore, visual indicators such as observed spawning behavior or freshly overturned gravel were absent and conclusive determination of redd locations was not possible. However, at the time of the carcass surveys, E&E met with a resident living on Miller Creek upstream of the SWSSD who had filmed anadromous salmon returning and holding in Miller Creek throughout the month of November. Video footage conclusively shows a pair of salmon exhibiting spawning behavior such as nest building and quivering body movement (Fish 1999). Therefore, information gathered during this project supports observations by TU and BioAnalysts, Inc., that salmon spawning activity is occurring on Miller, Walker, and Des Moines Creeks.

3.4.6.4 *Juvenile Fish Presence*

No known organization or agency has performed age-0 juvenile fish surveys shortly after fry emergence from the gravel on Miller, Walker, or Des Moines Creeks. Therefore, juvenile fish surveys cannot be compared to previous characterizations and are considered baseline information. Juvenile fish survey results identify that adequate habitat and water quality exists for fish survival from the egg to fry stage.

3.4.6.5 *Aquatic Habitat*

Many organizations surveyed in-stream and riparian habitat of Miller and Des Moines Creeks in order to evaluate the habitat for current or potential use by salmonids, primarily coho salmon, cutthroat trout, steelhead, and chum salmon (TU 1993, Resource Planning Associates 1994, Shapiro 1995, Parametrix 1999c and 1999d, BioAnalysts 1999). The reports generally make the same conclusions, but with some exceptions. In general, urbanization has degraded the creeks, but the creeks still support small resident fish populations, including salmonids. Limiting factors for the ability of these creeks to support fish populations include physical habitat, water quality, hydrology, and migration barriers. Physical habitat limitations include a lack of habitat complexity, a low pool:riffle ratio, and limited in-stream structure, especially large woody debris. Water quality limitations include high summer water temperatures and low dissolved oxygen levels. Hydrology limitations include rapid fluctuations in water flow, extreme variation between peak winter flow and low summer flow. Local agencies (i.e., King County and WDFW) agree with the habitat descriptions reported for Miller and Des Moines Creeks. In addition, E&E biologists confirmed that the reported physical habitat characteristics on Miller and Des Moines Creeks reflect field conditions.

Only one habitat survey has been performed on Walker Creek (BioAnalysts 1999). This habitat survey was performed to verify previous study results and confirm the existing habitat characteristics. Although different methods were used to assess the habitat condition, the results of the surveys conducted on Walker Creek were consistent with the BioAnalysts (1999) habitat assessment. In general, the habitat assessments identified that the primary limiting characteristics for the maintenance of salmonid populations are fine-sediment in streambed pools, lack of woody debris and complex in-stream structure, and sparse riparian vegetation.

3.4.7 Regional Significance of Local Fishery

Puget Sound coastal watersheds in King County encompass 92 square miles. In southern King County, Miller and Des Moines Creek watersheds encompass 9 and 6 square miles, respectively, and are two of the largest Puget Sound coastal streams. Coastal Puget Sound streams are typically small stream systems that drain highly urbanized areas. In 1992, 67% of the land use in coastal Puget Sound watersheds in King County was urban/residential. King County estimates that urban residential land use will increase to 77% in these watersheds by the year 2012. Forest and park land use is not expected to change over this same time period, however, rural land use is expected to decrease from 23% to 14% to compensate for the increase in urbanization (King County 1995).

Historically, these watersheds have supported abundant anadromous and resident fish populations. Today, many of the coastal Puget Sound streams support small salmonid populations. Although coastal Puget Sound streams do not support regionally significant numbers of fish, they are important locally. Numerous community-based restoration efforts have begun in a number of the watersheds to enhance salmonid habitat and to plant salmon within the creeks. For example, in 1993, the Hylebos Creek/Lower Puget Sound Basin Plan was the first comprehensive basin plan developed for an urban stream in King County. The basin plan identifies that the costs of restoration are very high, and even if completely implemented, full restoration of the basin is not possible (King County 1995).

Two major river systems exist in the area: the Green River/Duwamish River watershed and the White River watershed. The lower watersheds of both of these river systems are highly urbanized, with similar urban/residential land use estimates compared to the percent of urban land use reported above for small coastal Puget Sound watersheds. Significant portions of the upper watersheds in both of these river systems remain undeveloped. However, projected increases in urbanization would modify the existing land use in the watersheds and likely result in habitat and water quality degradation.

Annual escapement estimates for the four-year period of 1988 through 1991 indicate that the Green River/Duwamish River Watershed supports a total of 44,928 anadromous salmonids: 14,048 are considered wild and 30,880 are cultured. Wild fish are defined as any fish that spawns naturally, which could include hatchery fish that are successfully reproducing. Two fish hatcheries in the watershed contribute to the cultured anadromous salmonid returns: the Soos Creek Hatchery operated by the WDFW and the Keta Creek Hatchery operated by the Muckleshoot Indian Tribe. The Green River/Duwamish River salmonid escapement comprises 50% coho salmon, 45% chinook salmon, 4% chum salmon, and 1% winter steelhead.

Salmonid escapement estimates for the same four year period on the White River indicate a total run of 20,967 anadromous salmon: 5,563 wild fish and 15,404 cultured fish. The White River Hatchery operated by the Muckleshoot Indian Tribe is a significant contributor to the total annual salmon production in the White River watershed. The White River salmonid escapement comprises 75% coho salmon, 15% chinook salmon, and 9% chum salmon. The White

River supports the White River spring chinook population which is a distinct stock not found in other basins (King County 1995).

Therefore, regional river systems support orders of magnitude greater numbers of anadromous salmonids than do Miller, Walker, and Des Moines Creeks. Thus, population effects to salmonids in Miller, Walker, and Des Moines Creeks would be local; no significant regional effects to salmonid populations would occur if population declines in these local creeks were to occur.

3.5 Threatened and Endangered Species

This section provides information on aquatic wildlife species (state and federal listed species), which may occur in the project vicinity. Two federal agencies, acting in accordance with the Endangered Species Act (ESA), manage threatened and endangered species populations: the United States Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS). Federal projects that could affect listed species under the ESA are subject to consultation with both agencies. Among the federally listed species that might occur within the area include threatened coastal/Puget Sound bull trout and threatened chinook salmon. The USFWS is responsible for the threatened coastal/Puget Sound bull trout. The threatened chinook salmon is managed by NMFS whom also manages other anadromous threatened and endangered aquatic species.

Management of other sensitive wildlife species varies, and usually is conducted in cooperation with State wildlife agencies. The federal action agency for this project is the FAA and they are directed to plan, implement and consult on projects, which might impact federal listed species. However, other laws and regulations effect wildlife control at airports.

Only one aquatic species, the threatened coastal/Puget Sound bull trout (*Salvelinus confluentus*) potentially occurs in the project area. The bull trout has very specific life history requirements such as cold water temperature and clean gravel and cobble substrate that is often associated with unaltered stream systems. Because of its specific habitat requirements, the bull trout has difficulty inhabiting or adapting to stream systems with anthropogenic or natural perturbations. Therefore, the bull trout is not expected to be present in Miller, Walker, or Des Moines Creeks. In addition, E&E could not find conclusive records indicating that the bull trout historically inhabited these creeks.

NMFS manages anadromous threatened and endangered aquatic species. In Puget Sound, no anadromous salmonids are listed as endangered, but chinook salmon is listed as threatened. Unconfirmed data indicate that chinook salmon have been observed in Miller Creek, however, no conclusive records could be found supporting this observation (Fish 1999). The Puget Sound/Strait of Georgia evolutionary significant unit (ESU) of coho salmon is currently a candidate species being considered for listing under the ESA. Small spawning populations of coho salmon exist on Miller, Walker, and Des Moines Creeks. Therefore, outcome of the NMFS ESA listing process for Puget Sound coho salmon will have significant impacts on the protection and habitat restoration efforts for the species and the allowable activities within watersheds with known coho salmon populations. Two additional anadromous salmonids documented to occur in Miller, Walker, or Des Moines Creeks include chum salmon and steelhead. Small numbers of chum salmon were observed in Walker and Des Moines Creek during the carcass surveys; steelhead presence in the creeks was not confirmed. NMFS has determined that the Puget Sound chum salmon ESU and the Puget Sound steelhead ESU are not warranted for protection under the ESA at this time.

The WDFW does not consider any fish species as threatened or endangered. The three fish species are listed as sensitive in the State of Washington: Olympic mudminnow (*Novumbra hubbsi*), margined sculpin (*Cottus marginatus*), and pygmy whitefish (*Prosopium coulteri*), have not been documented to occur in Miller, Walker, or Des Moines Creek. Thirty-eight fish species are identified as State Candidate Species. Only two freshwater or anadromous candidate species occur in the Puget Sound region: chinook salmon and river lamprey (*Lampetra ayresi*). Neither of these species are expected to be present in Miller, Walker, or Des Moines Creek.

The WDFW also maintains the Priority Habitats and Species (PHS) list, which serves as a catalog of species and habitat types identified as priorities for management and preservation. A priority species is defined as fish and wildlife species requiring protective measures and/or management guidelines to ensure their perpetuation. Species are included on the PHS list if they satisfy one of three criteria: 1.) State Listed and Candidate Species; 2.) aggregations that are vulnerable to significant population declines by virtue of their inclination to aggregate (such as fish spawning and rearing areas); and, 3.) species of recreational, commercial, and/or tribal importance that are vulnerable to habitat loss or degradation. The three fish species known to occur on Miller, Walker, and Des Moines Creek (i.e. coho salmon, cutthroat trout, and chum salmon) are included on the PHS list. Coho salmon are considered a priority species because they satisfy criteria 2 and 3, cutthroat trout are a priority species because they satisfy criteria 3 only, and chum salmon satisfy all three priority species criteria. However, the chum salmon state listing is for populations separate from this region of Puget Sound (WDFW 1999).

3.6 Analysis of Selected Impacts

This section describes independent analyses of possible third runway project impacts, and comments on impact analyses provided by the Port of Seattle.

3.6.1 Effects on Ecology from Possible use of Maury Island Fill

Gravel from a mine on Maury Island is being considered as fill for the proposed runway expansion. The top eighteen inches of gravel at Maury Island contain high levels of arsenic, cadmium, and lead originating from the former ASARCO smelter in Tacoma. The top 18 inches of soil at Maury Island are proposed to be contained at the island mine prior to aggregate extraction. Ecology must have assurance that the fill used for the airport project will not result in exceedances of state water quality criteria. The Port and Ecology are working to determine what screening methods and contingencies are necessary to ensure that water quality criteria are met.

This project analyzed the potential effects to ecological receptors, such as the benthic community, if arsenic, cadmium, and lead in the Maury Island fill were to migrate from soils to nearby sediments. Surface and subsurface soil data of the potential Maury Island fill were compared to ecological benchmarks to assess whether unacceptable ecological risks may occur. Based on this comparison, metals in the potential Maury Island fill soil should not pose an unacceptable risk to the environment. Appendix G contains further details and the Maury Island data.

3.6.2 Effects on Streamflow

The SWMP presents a strategy intended to mitigate the long-term effects on streamflow due to proposed improvements to the airport. The effects of concern include stormwater peak flow rates and durations, base-flow rates, and water quality. The stormwater plan was developed using HSPF computer model analyses described in the Section 3.6.2.1.

The Port proposes to control stormwater runoff from the airport using a combination of local and regional facilities to regulate the rate at which stormwater is released to Des Moines, Miller and Walker Creek watersheds. It is intended to control stormwater discharges so as to limit peak flow rates and durations of high flow rates to those that would occur under a hypothetical land-use scenario wherein the effective impervious surface area (EIA) is 10 percent in each watershed. Effective impervious areas are hardened ground surfaces that absorb a minimal amount of rainfall (pavements, rooftops) that are hydraulically connected to the receiving streams without flow attenuation. The flow conditions estimated to result under the hypothetical 10 percent EIA condition is termed the target flow regime. The target flow regime is identified in the plan as the proposed Level 2 discharge condition below the respective regional detention facilities in Miller Creek and Des Moines Creek.

3.6.2.1 Miller Creek HSPF Model Review

The HSPF watershed models were provided to Earth Tech for evaluation by this project. The modeled discharge volumes were examined to assess the models' calibration in accounting for the water budget. Total flow volumes predicted by the HSPF models were compared to observed values at two locations each in the Des Moines Creek and Miller Creek watersheds.

The period of flow rate calibration data used for the Miller/Walker Creek HSPF model is from October 1, 1992 to August 30, 1996. This four-year period of time is adequate to sufficiently calibrate the HSPF model.

In the Miller Creek basin, predicted volumes were compared to observed values for water years 1993 through 1996 at gages below Lake Reba and near the creek mouth. **Table 3-17** compares the total flow volumes, expressed as equivalent inches of precipitation across the area draining to each gage.

At both gages the HSPF model produces excessive volumes of water compared to the observed flows, indicating the model is not well calibrated, despite the matching of simulated and observed peak flows for selected storm events presented in Figure B-3 in the Appendix B to the SWMP. The poor calibration results from the parameters used in construction of the HSPF model for the Miller Creek/Walker Creek watershed.

There are several inconsistencies in the input data between models developed to simulate different land use scenarios in the watershed. In addition, the model simulates groundwater contributions to streamflow in a manner that is unconnected to prior precipitation and therefore does not take advantage of the rigor offered by HSPF. Miller Creek and Walker Creek share the same input files and parameter values. As a result they are discussed together in this report. Four Miller Creek/Walker Creek HSPF models, each representing a different land use scenario, were reviewed:

MILL-C	calibration land use conditions
MILL-PRE	pre-developed land use scenario (target flow conditions)
MILL94	1994 land use base scenario
MILL04	2004 land use scenario

Some model parameters describing how the watershed responds to rainfall are inconsistent with features in the Miller Creek/Walker Creek basin. The water imbalance described above may be attributed to how the model simulates the infiltration of rainfall into the shallow groundwater zone and the discharge of groundwater to the stream systems. The HSPF program is capable of tracking the portion of rainfall that infiltrates to the shallow and deep groundwater zones. This feature is important to the analysis of the base flows and flow durations of Miller and Walker Creeks, because the model can account for water in the groundwater zones available to resurface in the creek downslope. As rainfall patterns vary over time, the stored groundwater volume changes correspondingly, which influences the base flows in the streams. However, rainfall that percolates to groundwater is not tracked within the HSPF model constructed for the Miller and Walker Creek watersheds. Instead, the groundwater contribution to streamflow is simulated by a constant year-round flow rate introduced to a lower reach of Miller Creek. By constructing the model this way, the base flows modeled in the stream are disconnected from the amount of shallow groundwater that has been accumulated from prior rainfall. The simulated base flows are also not representative of the distributed and varied discharges from seeps observed in the watersheds.

The Miller/Walker Creek HSPF model incorporates time series inflows of groundwater. These inflows are equivalent to a constant 3.27 cfs total. If these time series represent springs, then the flows from these springs should be generated directly by the groundwater conditions computed by the model. The model would then simulate groundwater inflows to streams based on computed seasonal groundwater fluctuations.

PERLND parameters in the models were reviewed with respect to watershed conditions and consistency between models for the various scenarios.

Groundwater Deep Fraction (DEEPFR) is set in the models at a value of 0.3 for all land surface types except for outwash and fill types where DEEPFR has been set at 0.8. The DEEPFR parameter specifies how much of the infiltrated water continues downward into the deeper aquifer and how much travels laterally through an upper stratum. The DEEPFR should be set equal for all PERLND types unless there is a specific reason to alter this. No such reason is cited in the Preliminary Comprehensive Stormwater Management Plan.

Analyses with the slice groundwater models (Sections 3.2.4.1 and 3.6.4) suggest that the percent of recharge that percolates through the till would change from the current to the built conditions. In the current condition slice model, 46.5 percent of recharge flows down through the till and in the built condition slice model 53.5 percent of the (reduced) recharge flows down through the till. The DEEPFR parameter should be set accordingly and all airport fill parameters should be consistent for all HSPF model scenarios for both the Des Moines Creek and Miller Creek watersheds.

The two constant groundwater inflow series to the creek should be removed from the model, and the deep fraction should be adjusted to appropriately account for the variable inflow generated by groundwater storage. It is not appropriate to have the deep fraction active in the model while simultaneously introducing a constant groundwater inflow based on a time series. The combination of these two actions renders the model unusable for analyzing flow volumes and peaks. The model would require modification before a thorough evaluation of the performance of the model, and a corresponding evaluation of proposed surface-water controls, could be completed.

The MILL94 HSPF model parameter values (1994 land-use scenario) differ from the other three models in five instances. The specific parameters are KVARY, AGWRC, DEEPFR, INTFW and IRC. No explanation for the parameter differences between the models is provided in the Preliminary

Comprehensive Stormwater Management Plan. Adjustment of these parameters affects model calibration, base flow, storm flow peaks, storm recession rates and interflow.

It is possible that after changing the DEEPFR parameter and eliminating the groundwater inflow time series that several other parameters would need to be adjusted, specifically AGWRC, INTFW and IRC. These parameters can affect model estimates of peak and low flows.

Total watershed area is not consistent for the four model scenarios as shown in **Table 3-18.** Watershed area is greatest for the pre-developed scenario and smallest for the 2004 land use scenario, and the calibration scenario model contains 2.1 percent more gross watershed area than the 2004 scenario model. All PERLND types change between the four model scenarios. For example the pre-developed condition has 2345 acres of till soils, 2170 acres of outwash soils and 514 acres of impervious surface. This is changed under the 2004 land use scenario to 1377 acres of till, 2101 acres of outwash and 1206 acres of impervious surface. It is presumed that much of the difference is a result of historic and proposed fill placement at the airport, but a difference of more than 100 acres is not accounted for. A quantified description of the sources of land use changes, particularly within the airport site, would aid interpretation of model results.

With a larger percentage of the watershed assumed covered by till soils in the target flow scenario, the model will simulate more runoff volume and higher peak flows. With a larger percentage of outwash soils assumed in the 2004 land-use scenario, the model will simulate lower runoff volumes and rates. When attempting to size facilities that limit runoff from future land-use conditions to target flow rates, the effect of the shift from till to outwash soils between scenarios would be to undersize the facilities.

FTABLEs define the relationship between the volume and flow rate of water within a reach of the stream or within a facility. In reviewing the FTABLEs in the Miller and Walker Creek model, several were found to have values that are suspected to be inaccurate because in some of the FTABLEs the surface area of the reach decreases with increasing water depth. The suspect FTABLEs include those numbered: 66, 62, 54, 63, 1, 111, 11, 15, 16, 17, 34, 35, 38, 50, 53, 60.

The interception storage (CEPSC) parameter is set at 0.1 for all PERLND types. This includes both forest and grass. The value of this variable should vary depending on vegetation coverage.

In reviewing the Walker Creek portion of the HSPF model, it was found that although a portion of the runway fill embankment is to be situated in the headwaters of the Walker Creek drainage, this change in land use was not reflected in the land use within the 2004 scenario model.

Walker Creek shares the same PERLND parameters as Miller Creek within the HSPF model and therefor could have similar calibration and parameter problems.

3.6.2.2 Target Flow Regime

After analyzing the Port's target flow regime proposal, Earth Tech agrees that basing target flows for the stormwater management strategy on theoretical 10 percent EIA is a reasonable approach to establishing hydraulic conditions that would support stable stream channels.

The land uses inferred by the target flow regime represent a large reduction in impervious surface area from the 1994 existing condition baseline. EIA in the Miller/Walker Creek watershed exceeds 22 percent (refer to **Table 3-18)** under existing conditions. In the Des Moines Creek watershed, EIA exceeds 36 percent of the watershed when excluding areas tributary to the IWS. Therefore, if achieved, control of stormwater flows to a regime equivalent to that of 10 percent EIA would benefit the structural stability of the stream channels. Research conducted on local watersheds (Booth, 1989) indicates that increased EIA corresponds to dramatic increases in both flood flows and sediment transport in streams.

The representations of the target flow regime in the HSPF models for Des Moines Creek and Miller/Walker Creek watersheds were reviewed. Both models, termed "predevelopment", represent 10 percent of the gross watershed area as impervious surface. In the Miller/Walker Creek model, however, the amount of outwash soils in the remaining 90 percent of the watershed is inconsistent with the HSPF models representing other land use scenarios. Under predeveloped (target flow regime) conditions, the watershed is modeled as containing 2170.6 acres of outwash soils, whereas under the calibration and 1994 (existing) conditions models, the acreage of outwash soils assumed in the models increases to 2226.6 and 2225.7 acres, respectively. With increasing development, it would be expected that the amount of outwash soils would decrease as they are replaced with impervious surfaces and covered by fill. This change needs to be resolved in order to assess how well the model predicts the flow regime that would result under the assumed land use conditions.

The target flow regime HSPF models were not developed to represent hydraulic conditions that were present historically. Channel reaches and flood plains are not defined in their historic dimensions, and natural depression storage within the watershed is not included in the hydraulic routing in the models. The target flow regime models do not include existing natural storage or historic storage depressions that were eliminated in the course of urbanization. The result of the lack of storage in the models results in increases in estimated peak-discharge rates under the target flow regime scenario above what they would be if storage were included in the models. It is also expected that storage in the upper subbasins of the watersheds would increase the duration of low flows; therefore, the target flow regime model is suspected of underestimating low flow durations.

It is acknowledged that the target flow regime is intended, within the context of the plan, to be a hypothetical characterization of a low-development condition in the watersheds and not as an accurate recreation of a specific historic state. However, the plan does not qualify the results in this fashion, and the model results could be misinterpreted.

The target flow regime model results are affected by the inappropriate modeling of groundwater flow to the creeks perhaps to a greater degree than those of the various development scenarios. Under a less developed watershed condition, there is greater opportunity for precipitation to infiltrate the soils and maintain a supply of groundwater to the streams. Without a connection between the rainfall infiltration, groundwater storage, and the discharge of groundwater to the streams, a direct comparison of proposed conditions to the target flow regime cannot be adequately performed.

3.6.2.3 Proposed Flow Control Measures

The general approach to sizing flow control facilities, as presented in the SWMP, is appropriate. That approach included: applying the target flow regime concept, using Level 1 flow control facilities in conjunction with regional facilities to achieve Level 2 control, and using the HSPF model to simulate the target, existing and proposed watershed conditions. However, as noted above, confident technical execution of the approach requires corrections to the models used to size the flow control facilities.

Table 3-19 summarizes how the limitations in the modeling, if not corrected, would affect the sizing of flow control facilities. The effects are qualitatively assessed. Because of the fundamental concerns about the models' construction, the effect the model changes would have on facility size could not be reasonably quantified within the scope of this project.

The flow-control plan in Miller Creek relies on the expansion of the proposed regional Miller Creek Detention Facility (MCDF) at Lake Reba. Implementation of this project should be reviewed with regard to possible breaching of an aquitard near the excavation proposed for that project (Section 3.2.4.1). No alternatives are specified for provision of additional stormwater detention capacity in lieu of expanding the MCDF.

3.6.3 Effects on the Soil Water-Balance

Changes to total groundwater recharge in the project area could occur from the following actions:

- Changing infiltration of precipitation by changing land cover, soil type, and slope
- Conveying runoff from impervious surfaces away from local recharge areas
- Eliminating the discharge of imported water through leaks and septic systems throughout the year
- Eliminating irrigation with local and imported water sources in summer

3.6.3.1 Changes to Non-Precipitation Water Sources

Non-precipitation water sources would change in the buy-out area under the proposal. The net change in non-precipitation water sources to the buy-out area is summarized below. All the changes are likely to directly affect base flow of Miller Creek.

- -66,000 gallons per day (gpd), or -46 gallons per minute (gpm) year-round from cessation of septic discharge of imported water
- +84,000 gpd, or +58 gpm, in summer as a result of cessation of irrigation with local water sources
- -10,000 gpd, or -7 gpm, in summer as a result of cessation of excess lawn irrigation with imported water
- unknown changes resulting from leakage from water supply pipes
- net change: approximately zero in summer, and -66,000 gpd, or –46 gpm, in the non-irrigation season

The following three paragraphs explain these estimates.

An estimated 66,000 gpd of imported residential water supply is discharged through the 380 septic drainfields that would be abandoned in the buy-out area. **Table 3-20** summarizes the calculations. They are based on 80 gpd per person, 2.5 people per household, and 87 percent source-to-drainfield efficiency. This water is discharged to surface soils and is distributed throughout the buy-out area. This water contributes to recharge in the shallow groundwater regime that is closely tied to Miller and Walker Creeks. Calculations in **Table 3-2** suggest that the portion of this septic effluent in the middle Miller Creek reach may comprise 12 to 25 percent (1 of 4-to-8 cfd/f) of winter base flow *gains* in the middle reach of Miller Creek. The effect on total base flow would be smaller. These calculations assume that none of the effluent recharges deeper aquifers.

Cessation of irrigation with local water sources (the creek or shallow wells) would cause an increase in irrigation-season in-stream flow as a result of reduced evapotranspiration. Cessation of irrigation with imported water would cause a reduction in irrigation-season streamflows, assuming some excess irrigation occurs. SWMP Appendix G presents an analysis of commercial irrigation using local water sources in the buy-out area but does not consider excess irrigation with local or imported water sources. SWMP Appendix G estimates that 0.13 cfs (84,000 gpd) are pumped from local sources during the summer months and implies a corresponding increase in summer base flows. That estimate is probably high assuming some excess-irrigation water returns to the streams.

A rough calculation of lawn irrigation with imported water suggests that possibly 10,000 gpd over the summer recharges groundwater as a result of over-irrigation. That recharge source would terminate with the removal of public water supply to the area. The estimate is based on 400 homes, 0.25 acres of lawn per home, 1 foot of summer lawn irrigation, and 25 percent loss to deep percolation (excess irrigation).

The net effect of these changes appears to be about zero in the irrigation season (summer). In winter, the rate of base flow gain in middle Miller Creek may be reduced by the elimination of septic discharge. The change in winter base flow from these effects would be expected to be about -46 gpm, or -0.1 cfs. However, summer base flows are more critical than winter base flows for fish habitat.

3.6.3.2 Changes in Recharge from Precipitation

Change to *precipitation-derived* recharge in a cross section of the proposed fill was evaluated by this project. The calculation considered conversion of wetlands and forest to grass on the embankment fill, and the widths of the only two impervious surfaces on the cross section (12th Avenue South and the third runway). The calculation indicated about 11 percent decrease in groundwater recharge along the cross section, largely as a result of the increase in impervious area. This estimate is probably high because no secondary infiltration of runoff from the third runway was assumed, and a deeply-rooted healthy grass crop was assumed for the new fill. This calculation is applicable to a relatively small area proposed for change and is not representative of changes anticipated from the combined Master Plan Improvements.

The 11 percent reduction in local recharge is large, but dependent flows to local wetlands and the creeks will be reduced only in winter when abundant water is typically present anyway. A similar reduction in recharge basin-wide would cause a major impact to baseflows. To assess basin-wide impacts, the Port's recharge calculations that considered all Master Plan Improvements was reviewed. The HSPF model parameters used in the Port's recharge analysis do not appear to correspond to those used in actual basin modeling also conducted by the Port. Therefore, a confident assessment of basin-wide recharge and baseflow impacts is currently lacking. A confident assessment of basin-wide recharge and baseflow effects should be possible by analyzing a properly implemented and documented HSPF model.

3.6.4 Effects on Shallow Groundwater Circulation

Changes to the direction of groundwater flow would not be expected as a result of the embankment construction because the general locations of recharge and discharge remain the same. However, changes to the timing of groundwater discharge to wetlands along Miller Creek is likely. Analyses were performed to assess changes between the relative amounts of groundwater recharge to the shallowest two aquifers, and changes in timing of discharge from the shallowest aquifer to wetlands. These evaluations were made using the following three models:

- Recharge Model
- Hydrus-2D
- Finite-difference slice model (slice model)

The recharge model was used to estimate groundwater recharge for the current and proposed post-construction conditions at the third runway fill and borrow sources south of the runways (Section 3.2.3.2). Hydrus-2D was used to model circulation of water between the root zone and the water table assuming construction of the runway fill. The slice model was used to accumulate and move recharge downgradient under current and built conditions, to the Miller Creek riparian wetlands. The slice model also simulates groundwater circulation to the second (Qva) aquifer. **Appendices B, C, and E** discuss the structure and input to these models.

The recharge model and other soil-water balance models can calculate only quantity of water in the water budget. In order to assess the timing of discharge of groundwater to aquifers and wetlands, the Hydrus and slice models were necessary. These models use equations of groundwater flow, continuity, and mass balance to calculate groundwater movement. For the current condition, the slice model used recharge output from the recharge model directly because no embankment exists to retard movement of water to the saturated zone where predominantly horizontal flow occurs. For the built condition, recharge model results were input to Hydrus-2D, and then Hydrus-2D results were used as input to the slice model. The slice models used for the current and built conditions were similar except for the presence of the embankment and drainage layer (**Figure 3-5**).

The Hydrus-2D model simulated the spreading of recharge fronts as they are predicted to move downward through the proposed embankment fill. **Figure 3-12** shows model results for recharge to the top of the modeled embankment, and outflow to the drain layer at the bottom of the embankment for different fill thicknesses. Independent models were run for fill thicknesses of 150, 130, 110, 90, 70, 50 and 30 feet. The model suggests that substantial spreading of seasonal recharge is likely within the fill, with the amount of spreading increasing with increasing fill thickness as expected. Some discharge at the bottom of the fill is predicted to occur all year. **Appendix C** presents more information on the Hydrus-2D model.

The texture of the modeled fill was calculated based on specifications for Phase 1 fill (installed in 1998 and 1999) and proposed embankment composition described by Hart Crowser (1999e). The calculations were also compared to the texture of Phase 1 fill based on soil samples collected by Terra Associates (1998). Appendix C describes that the 55 percent gravel fraction and 16 percent fines fraction calculated for the general embankment by this method is near the middle of the range observed at the Phase 1 fill. However, most samples were observed to be coarser than the modeled fill. Also, the fraction of silt-plus-clay, as a percentage of the matrix, varied widely in the samples. The value calculated for the general embankment is near the middle of the range observed in Phase I soils. However, most field samples were measured to have a lower silt content than the modeled fill.

A simple finite difference slice model was developed to simulate horizontal and vertical groundwater flow within the drain layer and existing soils below the embankment. It is similar in structure to the slice model of the current condition presented in Section 3.2.4. Both slice models are described further in Appendix E. For the built condition slice model, outflow from the Hydrus-2D model was used as input to the simulated drain layer. **Figure 3-5** presents the geometry of the embankment slice model.

The slice model was used to simulate groundwater flow for both the current and built conditions. Two versions of the model were constructed to represent expected differences in flow system geometry and hydraulic properties. The slice model is based on a quasi-two-dimensional finite-difference formulation of the partial differential equation describing transient groundwater flow through a saturated medium. Model cells were only connected to laterally adjacent neighbors as opposed to overlying or underlying cells – thus the quasi-two-dimensional nature of the model. Each model cell can contain up to three different "soil layers", differing in thickness and hydraulic conductivity. The bottom elevation of each cell is defined by the top of the till layer, and downward flow through the till can be simulated. For each cell, the model also specifies storage coefficient and recharge per time-step. The model assumes unconfined flow (variable transmissivity) under horizontal gradients defined by head differences between adjacent cells. The model was implemented in a Microsoft Excel spreadsheet, using direct (explicit) methods to solve the finite-difference equation.

Figure 3-13 shows results of the embankment (built condition) slice model. It summarizes water outflow at the bottom of the proposed west wall in terms of drain outflow and groundwater flow (horizontal flow in soils below the drain layer). Recharge to the drain layer at the bottom of the fill (Hydrus-2D output) and seepage through the till to a second (Qva) aquifer are also shown but are summed over the entire cross section). Units of measurement on the plot are cubic feet per day, per foot of width (cfd/f). The water volumes summed over the year are listed in the legend. Changes between current and built conditions were interpreted by comparing **Figures 3-6 and 3-13** and indicate that:

- Recharge would be 11 percent less along the cross section, and would spread-out within the fill, causing a significant timing lag in discharge to the wetlands and creek west of the embankment compared to the current condition.
- Discharge to remaining wetlands and the creek under the built condition would vary less throughout the year and the period of minimum discharge would be shorter. Flows would be lower in winter than under the current condition, and greater in summer compared to the current condition. The total quantity of water flowing to the wetlands would decrease because total recharge would decrease. Based on the total volumes and the timing plots, the model suggests that 71 percent of surface flow predicted by the model under the current condition would discharge from the drain below the wall under the built condition. The surface flow occurs in winter and spring, whereas the modeled drain discharge is less seasonally variable (more detailed interpretation of the timing of modeled discharge is inappropriate, especially for the built condition, for which no confirmatory field observations are available).

- The *volume* of seepage downward through the till would likely change only slightly under the built condition; however, the *percentage* of recharge seeping through the till would increase substantially.

A formal model sensitivity analysis was not conducted. However, the distribution of water quantity between surface/drain flow and till seepage is known to be sensitive to assigned hydraulic conductivity for the till. Higher hydraulic conductivity for the till allows more water to seep downward, and less is left over to discharge horizontally. Appendix E presents the assumptions and basis for modeling the till with a hydraulic conductivity of 0.004 ft/day ($1.4x10^{-6}$ cm/sec) in both models. Although the *water quantities* are sensitive, the model results indicate that change in the *timing* of surface and drain flows between the current and built conditions is generally consistent over a range of till hydraulic conductivities.

The timing changes would generally benefit the local wetlands that remain after filling and would slightly moderate seasonal low base flows and temperatures in Miller Creek. However, all water quantities are reduced on an average annual basis because total recharge is smaller under the built condition. Also, since the embankment is a small part of the Miller Creek watershed, the overall effect on streamflow is small. If the constructed fill has a lower silt content than was assumed in the model, the lag may be overestimated and the recharge volume may be underestimated.

3.6.5 Effects on Deeper Aquifers

The intermediate and deep aquifers of the Des Moines upland supply water to the Seattle Water Department and Highline Water District. The aquifers are laterally extensive, underling virtually the entire Des Moines upland from Federal Way on the south, to nearly West Seattle on the north. They underlie the Qva aquifer which is the deepest geologic layer discussed in detail elsewhere in this report.

The precipitation that infiltrates below the root zone over the large aquifer area is apportioned between shallow, intermediate, and deeper groundwater flow regimes. The shallow regime includes all the groundwater discussed in this report. The deeper regimes include flow within the intermediate and deep aquifers. The regimes are somewhat interdependent, with reductions in recharge to the surface being equal to reductions to stream base flow plus reductions to recharge in lower aquifers. Conversely, pumping from deep aquifers can affect the quantity of water in the shallow regime and thus base flow in creeks. The proper tool for evaluation of these large scale effects is a multi-layer groundwater flow model. The Port is generating such a model at this time.

The small reduction in groundwater recharge to deep aquifers of the Des Moines upland would not materially affect the ability of these aquifers to supply water to wells. This conclusion is based on the relatively large recharge areas of these aquifers compared to the airport, the fact that the effects would be apportioned between shallow and deeper effects, and the shallow recharge estimates reported herein and in Port documents.

3.6.6 Comparisons to Previous Groundwater Assessments

Changes in shallow groundwater recharge resulting from cessation of septic discharges in the area have not previously been reported.

Appendix F to the SWMP presents analyses related to potential base flow impacts from the proposed airport improvements, including the runway embankment fill. Table F-2 of the appendix summarizes the proposed changes in land use upon which the Port derives conclusions regarding base flow effects. Comparisons between the land areas cited in Table F-2 and those used the HSPF modeling of various scenarios revealed inconsistencies between the modeled land uses. **Table 3-21** compares the Table F-2 values to the corresponding existing- and proposed- conditions HSPF model input data. The differences in gross basin acreage amount to several percent, and large discrepancies are found in the relative proportions of till and outwash soils in the Miller Creek and Walker Creek watershed. These differences could significantly influence the estimates of base flow effects.

The analysis presented in Appendix F to the SWMP uses the HSPF parameter input to generate a "recharge index". The index is independent of the groundwater accounting problem within the Miller Creek model; but, as implemented by Parametrix, the index *is* sensitive to the HSPF input parameters. Parametrix included interflow as a groundwater component from the HSPF "airport fill" land use type but excluded it from other land use types. The models of groundwater movement generated by Pacific Groundwater Group indicate that interflow would not occur within the airport fill. Therefore, although the HSPF model is inappropriate for generating interflow within airport fill, Parametrix correctly compensated for this problem by including interflow as "groundwater" in this analysis.

The exclusion of interflow in calculating the recharge index for other land use types is neither correct nor incorrect, but a judgement dependent on the definition of groundwater. The Parametrix index effectively excludes water that enters streams within about one to seven days of a precipitation event (i.e.: interflow). Using data in Appendix F to the SWMP, recharge reduction would total 2.8, 3.3, and 6.6 percent if interflow were included for all land types. These values are compared to 1.8, 2.0, and 6.8 percent calculated by Parametrix for all of Miller Creek, Miller Creek below SR518, and Des Moines Creek basins, respectively.

The anticipated major changes in land-use classes involve changes to impervious surfaces, and conversion of forest and grass to airport fill; therefore comparisons between water budget components for these land classifications are summarized. The HSPF results are from Appendix F to the SWMP. As noted above, the HSPF parameters of that appendix are apparently not the same as the parameters used for other Miller Creek HSPF model analyses.

- The HSPF model estimates that 59 to 62 percent of precipitation becomes interflow or groundwater recharge in forest areas. This value compares well to 64 percent for the PGG recharge model of the mixed forest.
- The HSPF model estimates that 71 to 74 percent of precipitation becomes interflow or groundwater recharge in grassy areas. This value is substantially higher than the 59 percent estimated by the PGG recharge model. The difference between these rates is caused primarily by different amounts of calculated evapotranspiration, but the reason for the differences in the evapotranspiration rates is not known. Evapotranspiration is calculated within the recharge model using the Blaney-Criddle method, published crop factors for grass (Dunne and Leopold, 1978), and an assumed 24-inch rooting depth as used within Bauer and Vacarro's deep percolation model. Although they are standard, the crop factors and rooting depth used by the PGG recharge model may be excessive for the grass that is likely to grow on the embankment. In that case, more recharge would be calculated by the PGG recharge model, and the numbers would be closer.
- The HSPF model estimates that 63.5 percent of precipitation becomes interflow or groundwater recharge in the new fill areas. That value compares reasonably well to the 59 percent estimated by the recharge model (modeled as grass on outwash). The

difference results from the aforementioned difference in evapotranspiration estimates, and the offsetting assumption wherein the HSPF model assumed 6.6 percent runoff while the recharge model assumed no runoff.

Hart Crowser's water balance calculations (Appendix B to Hart Crowser, 1999c) used both the total quantity of groundwater recharge, and the groundwater distribution (interflow, shallow, deep) from the Parametrix HSPF model of Miller Creek (which version is not clear). As noted above, the accounting of groundwater in the Miller Creek model is unreliable but the quantity not lost to runoff and evapotranspiration should be acceptable if the land class parameters are correct. The details of the Hart Crowser calculations were not provided and therefore no detailed review was possible.

Runoff from the runways is modeled in HSPF as 100 percent of precipitation. Although not quantified by independent analyses during this project, secondary infiltration of this runoff into the embankment fill may be substantial. The filter strips that would receive runoff are unlined grassy slopes with catch basins spaced hundreds of feet apart and would provide an opportunity for infiltration of pavement runoff. Also, the conveyance pipes that would transfer water from the catch basins to stormwater detention facilities may be perforated. The perforated pipes would serve to drain saturated ground if it develops below the runways, and to infiltrate runoff where the ground is not saturated. These features could cause secondary infiltration of runoff from the runways and taxiways on the embankment fill.

Two related estimates of changes to the timing of groundwater discharge have been attempted. First, the Miller Creek HSPF model was modified to address the changing soil layering, and, thus, partitioning of groundwater between shallow and deeper systems within the embankment area. Second, Hart Crowser's water-balance analysis (Appendix B to Hart Crowser, 1999c) included analysis of a slice similar to the west-wall slice model presented in this report. However, they used Miller Creek HSPF output, including partitioning of interflow, shallow groundwater flow, and deeper groundwater recharge. Details of Hart Crowser's calculations were not provided. Both analyses are questionable because of the inherent limitations on HSPF groundwater modeling, and the particular problems with HSPF groundwater accounting in the Miller Creek model. Therefore, we did not compare either estimate to those prepared for this study.

3.6.7 Impacts to Wetlands Including Mitigations

In order to evaluate potential impacts to wetland resources that would occur as a result of the proposed Seattle Tacoma International Airport (airport) third runway expansion, E&E conducted field surveys and reviewed literature. The purpose of the field surveys was to provide E&E wetland scientists with an understanding of the existing conditions, proposed changes, and the regional context. Using the gathered data, E&E assessed the existing wetland conditions, evaluated the functionality and value of the wetlands potentially impacted, estimated the effects of the potential impacts, and evaluated proposed mitigation measures.

For discussion purposes this analysis is broken into two discussions, the first regarding the size of the potential impact, and the second regarding the functional impacts that would result.

3.6.7.1 Acreage Impact

Based on previous reports coupled with the field verification of wetland boundaries, E&E calculated that the fill activities associated with the airport improvement projects would result in the permanent loss of 13.88 acres of impact in the Miller Creek watershed. In addition to the permanent impacts, construction activities would also result in the temporary loss of 1.86 acres in the Miller Creek watershed (**Table 3-22**). As shown in **Table 3-23**, 36 wetlands would be impacted. Of these 36 wetlands, 11 wetlands would have impacts greater than 1/3 acre. These 11 wetlands account for 11.26 acres (>60%) of the direct impacts from the entire project.

E&E also evaluated secondary (indirect) impacts, defined where a loss of about 50 percent or more of existing wetland acreage would occur. Additional secondary impacts are identified because loss of that much acreage within a wetland could have significant ramifications on the functional ability of the remnant wetland. Based on these assumptions, an additional 1.68 acres of secondary wetland impact could be associated with the project if the functionality of the remaining wetland cannot be maintained. This potential acreage loss is attributed to the Wetland 18/37 complex adjacent to Miller Creek.

Table 3-23 presents a summary of impacts compiled by E&E, associated with proposed construction activities. These impacts are presented by hydrogeomorphic classification, as well as by cover type.

3.6.7.2 Functional Impact

Of equal importance to the acreage loss is the functional impact that would occur. The effectiveness and opportunity of wetlands to provide functions associated with water quality improvement, water quantity, and habitat was discussed in Section 3.3.3.3.

The Miller Creek watershed is located within a highly urbanized area. The undeveloped areas (both upland and wetland) provide some filtering of runoff prior to discharge into the creek. As a result, the larger wetlands within the watershed have a moderate-to-high potential to provide nutrient and sediment trapping. The functionality of the slope wetlands within the project area is somewhat lower due to the rate of water flow through them. Even with this reduction, the wetlands are frequently cited as providing moderate-to-high capability because of the influx of urban runoff. The creation of over 50 acres of new impervious surface as proposed as part of the Master Plan Update could increase overland flow to Miller Creek, and carry with it an increased sediment load. As a result, the loss of 0.14 acres of wetlands in the Runway Safety Area, and 13.74 acres of wetlands in the embankment area could have significant consequences if not mitigated.

Most wetlands in the project area serve to provide base flow to Miller Creek rather than absorb and temporarily store floodwaters. Wetlands that contribute to the flood storage capability and that would be significantly impacted by the proposed airport expansion projects are restricted primarily to the riparian Wetland 18/37 complex, Wetland A1 located adjacent to Lora Lake, and 41a and b which is a farm pond and pasture. Construction of the airport improvement projects would result in a reduction of wetlands that seep to Miller Creek and floodwater retention capability of the watershed. Any proposed mitigation would need to account for these losses by providing equal or greater base flow to Miller Creek and sufficient flood detention to prevent any increase in downstream flooding.

Being located in an urban area, the wildlife expected to occur in the project area is restricted to common, highly-adaptive species that use both wetland and adjacent upland areas. Species integrally tied to the wetland areas are likely restricted to waterfowl, amphibians, and small mammals. The extensive fragmentation of the available habitat, in conjunction with the surrounding urban character limits the suitability of the project area to highly mobile species and smaller species requiring only minimal habitat sizes. The construction of the airport improvements would have an impact on local wildlife populations simply due to the size of the fill area. Reduction of habitat size and availability would further reduce the suitability for small mammals and amphibians. To prevent a significant decline in the local populations, mitigation would be required to provide supplemental/alternative habitat on-site. However, FAA requirements limit the development of avian habitat within 10,000 feet of existing facilities to minimize the potential bird air strike hazard.

3.6.7.3 Mitigation

Mitigation for the proposed third runway fill and safety areas must account for the permanent loss of 13.88 acres of wetland within the Miller Creek Watershed and 1.86 acres of temporary impacts. Based on E&E's analysis, mitigation should include development of a contingency plan that addresses the potential indirect impacts associated with significant reduction of wetland acreage in the remaining wetlands that are only partially impacted by fill activities and temporary construction activities.

The preferred regulatory hierarchy for wetland mitigation is:

- on-site, in-kind,
- off-site, within the watershed, in-kind,
- off site, out of the watershed, in-kind, and
- off site, out of watershed, out-of-kind.

Based on environmental and regulatory constraints, it is not feasible for the Port to offer mitigation on-site and in-kind. The difficulty and uncertainty of creating slope wetlands, and the lack of suitable sites within the basin restricts mitigation opportunities for creation of slope wetlands. Furthermore, the FAA policy of minimizing available wildlife habitat within 10,000 feet of the airport further restricts the opportunity for extensive in-basin mitigation. The Miller Creek and Des Moines Creek watersheds are quite small and are extensively developed, which restricts the mitigation opportunities.

Rather than replacement of a specific wetland type, E&E recommends that mitigation measures focus on the replacement of wetland functions. Therefore, in evaluating in-kind versus out-of-kind, the functions served by lost wetlands should drive the mitigation process.

As shown in **Tables 3-22 and 3-23**, a significant number of the wetlands impacted are slope wetlands. Impacts that need to be mitigated include water quality, water quantity, and habitat suitability as discussed in Section 3.3.3.2.

The Port has proposed the following wetland mitigation measures (Parametrix 1999a):

- On-site mitigation includes removing existing development, establishing a vegetated buffer along Miller Creek, enhancing wetlands within the Miller Creek buffer, enhancing/restoring wetlands within the Des Moines Creek watershed, excavating floodplain to compensate for lost flood storage, developing stormwater management facilities, and restoring and enhancing 11 acres of converted farmland and farmed wetland to shrub wetlands.

- Off-site mitigation includes developing a 67-acre site to mitigate for wildlife habitat. FAA safety regulations restrict on-site mitigation.

- Establishing a Trust Fund to promote in-basin restoration projects for Miller Creek and Des Moines Creeks downstream of the project area.

E&E believes that the overall mitigation plan is reasonably designed to compensate for wetland impacts discussed in Section 3.6.7 and has the potential for success. The plan provides for in-basin compensation for loss of water quality and water quantity functions, as well as some mitigation for wildlife compensation. For losses that cannot be entirely mitigated by in-basin remedies, an off-site, out-of-basin mitigation plan has been developed by the Port. The off-site mitigation site offers advantages over other in-basin sites including it's size, the ability to create a single large complex versus numerous smaller wetlands, and it's location adjacent to the Green River. Recognizing the concerns over the success of planned mitigation, additional safeguards would provide assurances that the mitigation plans would be implemented, and result in the successful replacement of lost functions. Additional recommendations for mitigation are presented in Section 3.6.7.5.

Loss of water quality functions can be mitigated through proper implementation of Best Management Practices (BMPs) during construction and the development/improvement of the buffering capacity of Miller Creek. Under current conditions, Miller Creek meanders through a residential neighborhood and an active muck farm. Elimination of anthropogenic nonpoint source pollution, including septic systems, fertilizers and pesticides, in combination with the stormwater management system proposed for the airport, development of a vegetated buffer along Miller Creek, and the restoration activities proposed at Vacca Farms should mitigate for the loss of water quality functions.

Loss of water quantity effects can be mitigated through implementation of a stormwater management program. Additionally, seepage from the embankment should provide the seepage necessary to maintain remaining local slope wetlands.

While significant loss of wildlife habitat would occur in conjunction with the fill activities, the proposed mitigation has the potential to increase the habitat suitability of the project area by creating a single contiguous open space along Miller Creek. Because of the FAA restrictions within the project area, off-site mitigation is required for the avian wildlife component. The development of this off-site mitigation would similarly provide a single large contiguous parcel that would attract all types of wildlife, not merely avian species.

3.6.7.4 Mitigation Ratios

No standardized mitigation ratios are currently in effect to establish the appropriate level of compensatory mitigation required. In a Mitigation Memorandum of Agreement between the USEPA and USACE (Mitigation MOA effective February 7, 1990), it was established that a permit applicant is required to replace the functional value of wetlands being impacted at a ratio consistent with the policy of "no net loss" and with an adequate margin of safety to reflect the expected degree of success of the mitigation plan. These requirements essentially require a case-by-case determination of appropriate mitigation ratios. To supplement this, Ecology has issued standardized ratio determinations to provide permit applicants with more guidance.

As part of the Washington State Wetlands Rating System (Ecology 1993), replacement ratios of 3:1 (3 acres of mitigation wetland to 1 acre of wetland lost) and 2:1 are proposed for Class II and Class III wetlands, respectively. A ratio of 1.25:1 is proposed for Class IV wetlands. These ratios are essentially doubled for enhancement of wetland areas. These ratios are only general guidelines, with the final ratios determined based on the likelihood of success of the proposed mitigation site. The stated goal of the policy is a 1:1 functional replacement of wetlands. Because of the historic trend of failed wetlands, the ratios have been increased.

However, a more recent publication presents mitigation ratios that are somewhat lower than presented in the 1993 report. The proposed ratios presented in the 1999 Washington State Department of Ecology draft Compensatory Wetland Mitigation Banks guidelines are:

- Wetland Restoration 1:1
- Wetland Enhancement 2:1
- Buffer Enhancement 5:1

These ratios recognize the value of wetlands, but also recognize the need for wetlands to be integrated into a much larger habitat that has upland components. While not receiving equal benefit, as it should not, the development of a large buffer area would be counted as part of the overall compensation package. Based on these guidelines, the proposed mitigation seems adequate and appropriate to compensate for the loss of wetlands.

3.6.7.5 Effectiveness of Wetland Mitigations

The King County Department of Development and Environmental Services published the *Results of Monitoring King County Mitigations* (Mockler et. al. 1998) which concluded that mitigation, in general, is not being implemented, and those that are have not been successful due to design failure, installation failure, and poor maintenance. The document itself does not call for an abandonment of wetland mitigation, but rather for more regulatory control and guidance provided during the planning, installation, and monitoring phases of the project. In response to this document, among others, Ecology also initiated a study to evaluate mitigation compliance on a statewide level.

Ecology is currently finalizing this report that presents a statewide perspective of the effectiveness of wetland mitigation in the recent past. The draft is expected to be issued in spring of this year. This is a two-phase project with only the first phase being completed (MacMillan, personnel communication 2000). Phase I focused on three issues: (1) if the site was constructed; (2) if the final design was constructed according to plan; and (3) if the wetland is operating up to performance standards. The project has shown that while over 90% of the projects were constructed, only ½ adhered to the final construction design, and only 1/3 of those that had performance standards are meeting all of their standards. This initial phase assessed compliance and did not account for any functional assessment of the wetlands to gauge if they were truly successful. Functional success of mitigation projects will be developed in Phase II. Without closer scrutiny of the data, it is impossible to assess the significance of the data, but two conclusions can be drawn:

- Constructed mitigation projects are not a guaranteed success, and
- Closer regulatory oversight is necessary for longer periods to monitor mitigation projects.

While the Port Mitigation Plan offers a reasonable opportunity for success, based on the cursory conclusions drawn, two additional mitigation elements should be considered. The first is financially driven, requiring the establishment of a bond by the project sponsor to insure that 1) the project is properly implemented, and 2) provide funding for contingency planning if the project did not meet performance standards, and additional action needs to be taken to rectify the deficiencies. The second mitigation element would be the establishment of a third-party environmental monitor, funded by the project sponsor, but under the directive of the regulatory agencies. This monitor would be able to verify the completion of the mitigation as per specification, and note/approve any modifications to the original design plans that were implemented based on site specific conditions. The Port has proposed a monitoring program for the current airport mitigation plan.

3.6.7.6 Comparison with Previous Permitted Projects

To provide a basis of comparison for the airport wetland mitigation plan, a previously permitted project, of similar size to the airport project, was evaluated.

Auburn Racing built a thoroughbred horse racing facility on a 165-acre site in Auburn, Washington. The project impacts included filling of approximately 17.4 acres of palustrine wetlands, including 0.3 acre of scrub-shrub wetlands, and 17.1 acres of emergent wetlands. Additional acreage of on-site wetland was converted to a regional stormwater detention facility for the City of Auburn. FAA wildlife hazards were not an issue for the racetrack, and development in the project area was not as expansive as that which occurs in the vicinity of airport. The mitigation project was sited within the same watershed as the racetrack. The functionality of this site in relationship to the airport mitigation site cannot be directly compared since a primary objective of the Auburn racetrack site was creation of waterfowl habitat.

The racetrack mitigation plan was designed to achieve a net gain in wetlands functions and to help achieve objectives of the Mill Creek Drainage Basin Special Area Management Plan. The mitigation site included an approximately one-quarter-mile reach of Mill Creek, which was restored, and a total of 56.5 acres of adjacent existing wetland and uplands used for wetland creation (1.5 aces), restoration (9.2 acres), and enhancement (45.8 acres). For permitting purposes, this application used compensation ratios of 1.5:1 or 2:1 for creation and restoration activities, and 3:1 and 4:1 for enhancement activities, resulting in a net functional gain of 4.6 acres.

3.6.8 Effects on Fish Habitat and Populations

Small populations of anadromous coho salmon and resident coastal cutthroat trout exist on Miller, Walker, and Des Moines Creeks. Despite the presence of salmonid populations in the creeks, the documented limitations of aquatic habitat likely limit the size of fish populations. Perturbations within the watershed that result in habitat loss or degradation would likely reduce the fish population because of the limited habitat and sensitivity of existing fisheries. Conversely, habitat restoration and supplementation of limiting habitat characteristics can allow for growth in the fish population.

3.6.8.1 Effects of Streamflow Changes on Fish

The streamflow regime is currently a limiting factor for water quality and aquatic habitat in Miller, Walker, and Des Moines Creeks. Proposed construction at the airport has the potential to significantly alter the streamflow regime in Des Moines Creek because the airport currently occupies approximately 1/3 of the Des Moines Creek watershed area. Conversely, the western and northern portions of the airport only occupy a small area within the Miller and Walker Creek watersheds. Proposed airport construction therefore has less potential to affect Miller and Walker Creek streamflow.

The slice model described in Section 3.6.4 predicts significant changes to surface and groundwater flow near the fill embankment. The fill embankment is predicted to serve as a water storage compartment that causes a time lag of water discharge to the wetlands and creek compared to existing conditions. Because of the lag time through the embankment, the model predicts that winter precipitation would express itself as surface water through the west wall drain in the summer months. This delayed surface water expression would have a generally positive effect on the local wetlands that remain, and a less-pronounced effect on low summer base flow in Miller Creek in general. Although model predictions are limited to the geologic cross section at the west wall, the model suggests that a similar effect on wetland and summer base flow would occur in Walker Creek.

The effects of contribution from the fill embankment to stream summer base flow in Miller and Walker Creeks should not be overstated. The embankment represents a small portion of the total Miller and Walker Creek watershed area.

3.6.8.2 *Habitat Parameters*

No direct construction impacts are expected for stream habitat in Walker or Des Moines Creek.

Direct construction impacts to Miller Creek stream habitat include the relocation of Miller Creek in the Vacca Farm area. This portion of Miller Creek provides poor habitat for salmonid fish populations because it has sparse riparian vegetation, substrate dominated by sand and silt, a lack of habitat complexity, and a lack of instream structure and large woody debris. Since the proposed Miller Creek channel construction includes a mixture of pools and riffles, gravel and cobble substrate placement, riparian vegetation planting, and large woody debris replacement, the proposed Miller Creek relocation has the potential of providing a net gain of salmonid habitat within the Miller Creek watershed. Proper construction and long-term monitoring are vital to successful Miller Creek relocation including control of turbidity during initial wetting. Some sediment transport during initial wetting is likely, and has the potential to damage habitat downstream.

Indirect effects to stream habitat in Miller, Walker, and Des Moines Creeks include alterations to base flow, peak flow, and sediment input to surface water. These habitat parameters currently limit salmonid populations. Low summer base flows affect habitat quality because exposed portions of the channel are no longer available for use which limits available slack water habitat for juvenile salmon refugia, riffles for macroinvertebrate production, and quality pools for resident salmonids. Lower flow also tends to increase water temperature in stream channels exposed to solar radiation. The Port predicts reduction in summer base flow in Des Moines Creek as a result of a six percent reduction in groundwater recharge in the Des Moines Creek basin. The Port supports augmenting low summer stream flows by pumping from a Port-owned well and discharging the water into the creek (Parametrix, 1999e).

Extreme peak flows degrade stream habitat by scouring stream banks and beds, and transporting coarse sediment too quickly through the stream system. High peak flows also washout streambank slack water areas used by juvenile salmonids and often displace smaller fish downstream because of their limited swimming ability. Substrate in Miller, Walker, and Des Moines Creeks have high fine-sediment content from urbanization throughout the watersheds which limits stream substrate available for salmonid spawning and age-0 fish refugia.

3.6.8.3 *Effects on Populations*

Direct construction impacts would likely have little effect on fish populations because direct impacts are limited to the Miller Creek reach at Vacca Farm. This reach of Miller Creek provides poor quality habitat for salmonids. Therefore, cutthroat trout, if present, are expected to be limited. Also, Miller Creek relocation can be conducted in such a way as to physically remove any fish from this reach of Miller Creek prior to being covered by fill material.

An uncontrolled release of stormwater is likely at some time during construction given the size of the project and human error; however, the size and quality of a release cannot be predicted, nor can its impacts on fish be quantified. Existing habitat in Miller, Walker, and Des Moines Creeks appear to limit salmonid population production; therefore, minor habitat degradation would likely have substantial effects on the local salmonid populations.

3.6.8.4 Comparisons to Previous Fish Impact Assessments

E & E's assessment of localized changes to Miller Creek habitat and resident cutthroat trout populations is consistent with information presented in the Biological Assessment (BA) for Master Plan Update Improvements at airport (Parametrix 1999). However, the BA does not address proposed construction impacts on a watershed level and does not provide sufficient detail to comprehensively evaluate how mitigation would be implemented and maintained to achieve the desired effects. More specifically, the BA evaluates construction effects primarily within the airport project area only. However, indirect construction effects from airport expansion such as alterations of water flow or changes to sediment input to the streams would have effects throughout the each watershed.

The Miller Creek riparian buffer corridor enhancement and the Miller Creek instream habitat enhancements, if implemented and maintained properly, would undoubtedly benefit local stream habitat for resident cutthroat trout in the airport project area. Actual design and implementation of the instream habitat enhancements could not be evaluated because these projects are still in a conceptual stage (Kleindl 1999). However, proposed mitigation is limited in that it would only affect localized Miller Creek habitat and resident cutthroat trout. Miller Creek riparian buffer and instream habitat enhancement would not mitigate for construction impacts to other portions of Miller Creek, other creeks such as Walker or Des Moines Creek, or other fish species such as coho salmon. For example, as described in Section 3.6.8.2, indirect construction and post-construction affects such as alterations to base flow, peak flow, and sediment input would occur throughout the stream systems and not just in the airport project area.

Conceptually, the watershed basin trust funds for the Miller and Des Moines Creek watersheds can beneficial. Without specific information regarding habitat restoration projects that would be acceptable for the basin funds and the accessibility of money through the trust fund, concerns of the actual implementation of habitat restoration through the basin trust funds exist. In addition, significant habitat restoration that is necessary in Miller, Walker, and Des Moines Creeks would require substantially more funding than what is currently offered through the basin trust funds. Although restoration of the entire watersheds is not the responsibility of the Port, a more proactive and comprehensive approach to aquatic habitat restoration would provide a greater benefit to the Miller, Walker, and Des Moines Creek watersheds.

3.6.9 Water Quality Impacts During Construction

The Stormwater Management Plan states the Port applies construction temporary erosion and sedimentation control (TESC) measures that exceed minimum requirements of the Ecology Manual. These measures include: developing construction stormwater pollution prevention plans (SWPPPs) for each capital improvement project; implementing conventional TESC best management practices (BMPs); applying more advanced stormwater treatment techniques where necessary; supervising and monitoring contractor compliance; and funding independent oversight of construction erosion control compliance.

3.6.9.1 *TESC Measures*

The Port has had TESC monitoring plans prepared for four projects related to the Third Runway program:

- North Employee Parking Lot (Herrera, 1998)
- Property Acquisition and Demolition (Herrera, 1998)
- Taxiway Construction (Herrera, 1998)
- Embankment Construction, Phase I (Herrera, 1998)

Of these four plans, the Embankment Construction, Phase I TESC Monitoring Plan is most relevant to this review effort as it describes the Port's approach to controlling impacts from construction of a large embankment. In addition, the Port has had prepared construction drawings and specifications detailing TESC measures for the Third Runway Embankment Construction - Phase I (Project No. airport-9763-T-1, March 9, 1998).

The monitoring plan document contains preliminary grading and drainage plan and site erosion and sedimentation control plans for the first phase of the Third Runway embankment construction. The project site is situated immediately south of S. 156th Way and between 12th Avenue S. and the Perimeter Road. The elements of the work are similar to those anticipated for subsequent planned phases of the embankment construction except that Phase I does not include a retaining wall. The work elements include:

- clearing and grubbing of vegetation and unsuitable materials
- excavation and embankment fill placement and compaction
- temporary erosion and sedimentation controls
- placing and spreading of topsoil
- seeding, fertilizing and mulching disturbed areas

The construction plans and specifications include more detailed descriptions of the TESC measures and procedures to be implemented in completing the embankment construction. The methods and details presented in the plans appear to generally conform to those of the Stormwater Management Manual for the Puget Sound Basin (Department of Ecology, 1992). Engineering calculations for sizing the facilities were not provided or reviewed. Provisions of the construction plans and specifications that are notable from a TESC perspective are itemized below:

- Placement of fill materials with higher fines content is restricted to the period from June 16 to September 16.
- A Sedimentation and Erosion Control Representative is to be provided by the Contractor with responsibility for TESC installation, inspection, maintenance and emergency response.
- Contractor's inspection and maintenance procedures and schedule are to be documented and submitted to Port for approval. The minimum frequency for inspection is specified to be weekly and following any storm event greater than 0.5 inches precipitation over a 24-hour period. A conflicting drawing note (Sheet C-120) requires daily inspection of TESC facilities.
- BMPs are to be installed prior to land disturbing activities commencing.
- The contractor is instructed to protect downstream properties from erosion damage due to increases in stormwater runoff volume, velocities and peak flow rates discharged from the site. However, the construction documents do not specify that increases in runoff volume, velocity or peak flow rate are to be prevented on site. Again, detailed engineering calculations that may

demonstrate the ability of the sedimentation pond system to control discharge rates were not provided for review. However, it would appear that smaller storm discharges would be controlled to a degree by the 2-inch diameter orifice specified in the outlet structure.

- The direction and maximum slope of the top of the embankment fill is specified to be controlled at the end of each workday.
- Although a temporary ditch is specified to be maintained along the east (up slope) edge of the fill placement, it would be advisable to construct the interception ditch on the far east boundary of the project area at the first stage of the project so as to minimize the flow of offsite water into the work area. The plans call for the interception ditch to be constructed at a later phase of the work.
- Reference is made to seeding final graded slopes prior to completion of other fill placement, but the contractor is not explicitly required to restrict or minimize the total disturbed area throughout the project duration.

During reconnaissance of the construction site in October 1999, it was observed that the sedimentation pond was in place and functional with grass lined swales draining to the pond from the north and south sides of the construction site. In addition, a batch treatment facility was on-site as a contingency measure to provide treatment beyond the sedimentation that occurs within the pond.

3.6.9.2 Critical Construction Planning and Execution Factors

Beyond the design of technical provisions to control erosion and sediment on the project site, the successful prevention of erosion and sedimentation problems from a large embankment project are dependent on critical planning and execution of the TESC installation and maintenance. Without rigorous implementation, monitoring and maintenance, the Port increases the risk of releasing a massive load of sediment into area streams as occurred during construction of the North Employee Parking Lot on Miller Creek. Following are critical planning and execution factors identified for the runway embankment fill that should be addressed:

- A contingency area was set aside at the base of the Phase 1 embankment project area in the event additional treatment capacity was needed or desirable. Similar provisions for supplemental treatment of flow control capacity need to be made available for subsequent phases of embankment construction in the event the project encounters exceptional climatic effects or construction problems.
- The subgrade for the embankment fill is till soils that are structurally vulnerable to moisture when disturbed. Construction operations should minimize the extent of subgrade exposed to rainfall and the movement of equipment on exposed subgrade.
- The top of the fill must be continuously graded during fill placement to direct runoff away from the tops of the embankment slopes and toward controlled drainage paths.
- The side slopes of the embankment should be fully stabilized with vegetation prior to crowning of the fill. Once the crown is completed, runoff that passes from the crown and over the face of the embankment would erode slopes that are not fully stabilized.

The Port's NPDES permit requires a Department of Ecology-approved Stormwater Pollution Prevention Plan for each construction project on the airport. Also, under the governor's certificate for the project, the Port is required to hire a third party to review and ensure all TESC plans are followed during construction. Vigorous and *independent* review of TESC practices by qualified personnel throughout construction is critical to minimize the chance of an oversight and to maximize control of runoff from the site.

All construction personnel should be trained in proper erosion control practices and informed of the manner in which the project's TESC systems are designed to operate. Personnel should be informed of the consequences of TESC failure to the receiving streams and the potential for a failure to cause a shut down of construction activities. Because of the potential damage that can be caused to a receiving water body by a single error on a project of this magnitude, training of all staff is critical to minimizing the potential for mistakes.

An embankment construction of the magnitude and duration of the third runway project is subject to a range of climatic events and human errors, and an uncontrolled release of runoff from the disturbed site is probable despite proper implementation of construction BMPs. The role of the TESC efforts is to minimize the probability and extent of such a release.

3.6.10 Long-term Temperature Effects

The changes in land coverages within the embankment fill area were reviewed for their potential effects on receiving water temperatures during warm weather low flow periods in the streams. Conditions both during dry periods and during rainfall events were considered.

During periods of extended low flow in Miller, Walker and Des Moines creeks, the discharge is supplied predominantly by groundwater. Absent rainfall, elevated temperatures in the streams can be caused by direct sunlight and surface contact with warm air. The majority of the precipitation falling on the proposed runway embankment would infiltrate through the fill, remain cool within the fill's mass, and discharge through the subdrainage layer at the base of the fill as cool groundwater to the stream systems. This condition is expected to have a beneficial effect on the receiving streams.

The potential for warm runoff from runway and taxiway pavement areas to enter streams and elevate temperatures was also considered. Such temperature effects are limited by frequency because intense rainfall typically occurs during periods of obscured sunlight and only infrequently during warm-weather periods. The majority of the precipitation falling during warmer weather would infiltrate the fill, even during intense rainfall events, because of low antecedent soil moisture during this period. Pavement runoff would flow to the shoulders of the taxiways and runway, with some runoff infiltrating to the fill or through the perforated storm drainage system (if constructed). The discharge of runoff subject to pavement warming would be a small fraction of the precipitation falling on the embankment fill. Temperature buffering within the fill would likely be high as discussed further below and inferred in the Section 3.6.4 discussion of time-lags within the embankment.

The potential for the proposed retaining wall to elevate stream temperatures was also reviewed. The retaining wall's planimetric footprint is very small, and its westerly exposure is subject to solar gain during a portion of the daylight hours in the warmer weather months of concern. The coincidence of high solar gain with rainfall is limited climatically, and the temperature within the wall is regulated by the mass of cool earth behind it. The small footprint of the wall also limits the amount of rainfall that comes in contact with the wall's surface. The small volume of stormwater directly contacting the wall and the limited opportunity for the wall to significantly elevate the temperature of the runoff suggest that the wall would not contribute to elevated temperatures in receiving streams.

The discharge of runoff subject to warming on pavement within the embankment area is small, most warm weather precipitation would be infiltrated into and cooled by the fill mass, and the year-round infiltration of precipitation through the fill would enhance warm weather low flows in streams with cool groundwater. Based on this combination of effects, the runway embankment is not expected to create adverse temperature effects during the critical low flow periods in the streams.

4.0 Proposed On-Site Borrow Areas and Des Moines Creek

4.1 Proposed Excavation

The Port of Seattle proposes to excavate soils from three areas south of the airport to supply a portion of the fill necessary for the third runway. **Figures 2-1 and 4-1** show the areas. These areas were acquired by the Port previously, and all structures and foundations were removed at the time of acquisition. Minimal pavement on some roads remains currently. Otherwise, area 1 is covered by grass and sparse forest, and areas 3 and 4 are largely forested. All areas are within the Des Moines Creek drainage. The excavations are proposed to include glacial till soils and underlying glacial advance outwash as generally indicated by the cross sections of **Figures 4-2 and 4-3.**

4.2 Character of the Hydrologic Environment

4.2.1 Soils and Geology

Figures 4-2 and 4-3 present geologic cross sections generated for this project based on previous soil borings. All the geologic units also occur in the Miller Creek drainage and were described in Section 3. In borrow area 1 the general geologic sequence within the depth of interest is: glacial recessional outwash, over glacial till, over glacial advance outwash. However, glacial till is at land surface on the south two-thirds of the site. A till-like aquitard occurs above the water table in the glacial advance deposits. Saturated conditions were not reported in the recessional outwash nor on the till-like aquitard in the glacial advance deposits. The glacial advance aquifer is unconfined except near Des Moines Creek where it is confined below the till. Wetlands are mapped within area 1, some of which are proposed to be excavated.

In borrow areas 3 and 4 the general geologic sequence is the same; however, advance outwash is at land surface on the north end where the till and recessional deposits are missing and recessional deposits lie directly on advance deposits on the southeast. Also, groundwater is perched above the aquitard (till-like soil) above the water table of the glacial advance aquifer. Hart Crowser has referred to the resulting saturated zone as the "perched water-bearing zone". A portion of the aquitard and perched water bearing zone are proposed to be excavated in borrow area 3.

Depression and slope wetlands occur within area 3. The proposed excavation does not include the wetlands, and includes only areas downslope from the wetlands. No wetlands occur in area 4.

4.2.2 Soil Water-Balance Components

Section 3 and **Appendix B** describe the soil-water balance calculations for conditions that include the land cover and soil types present in the borrow areas. **Figure 3-4** shows the seasonal trend of groundwater recharge for the land classifications. The analyses indicate about 23 inches of annual recharge to local groundwater under mixed-forest-on-till conditions, 22.5 inches in areas of grass growing on outwash, and 25.6 inches on barren outwash.

4.2.3 Character of Water Circulation

4.2.3.1 Groundwater Circulation

Conceptually, groundwater circulation in the borrow areas is very similar to that in the proposed embankment area. A shallow groundwater regime occurs in most areas within the Qvr and the "shallow regional aquifer" occurs below the till in the Qva aquifer. Both aquifers appear to discharge primarily to Des Moines Creek. Unlike the embankment area, little potential for Qva groundwater to flow under the creek is suggested.

4.2.3.2 Streamflow in Des Moines Creek

King County currently maintains three stream gaging stations on Des Moines Creek and additional sites have been used over the past 10 years. Flow duration curves for two gages are presented in **Figure 4-4**. The gage locations are shown on **Figure 2-1**. The sharp drop in the curve for observed data at the mouth of the creek suggests a problem with accurate recording of low flows.

Pacific Groundwater Group measured base flows in Des Moines Creeks at two locations in October 1999 and January 2000 to assess gains in base flow. **Table 3-1 and Figure 4-5** presents the data along with King County measurements for those dates. The October 1999 measurements preceded the onset of seasonal rains and represent low flow conditions for 1999 (which was a very wet year). The January 2000 measurements also occurred after a period of no rainfall and represent winter base flow conditions.

The measurements indicate that flow increases downstream over most of the creek at both times of year and that the flow rate varies depending on the season. However, some uncertainty in the interpretation exists because of moderate disagreement between King County and Pacific Groundwater Group measurements near the Tyee ponds. Flow in Des Moines Creek increased substantially from October to January. The downstream gains result from groundwater discharge to the creek. The gains vary substantially for different reaches. These data suggest large groundwater contributions upstream of South 18th Street, and little contributions downstream of that location. Comparison between the area of gain and the geologic map of Booth and Waldron (in print) suggests that most of the groundwater contributions come from groundwater within the Vashon glacial aquifers, and not deeper aquifers which outcrop near the creek downstream. The borrow areas are upstream of the South 18th Street measurement station.

4.2.4 New Water Quality Data for Des Moines Creek

This project collected samples of water from Des Moines Creeks and analyzed them for a wide range of parameters that help define the environmental health of a creek. Surface water quality parameters, including oxygen, temperature, and turbidity, were measured at every streamflow station in the field. Other parameters were measured at Analytical Resources, Inc. (**Appendix F**). **Tables 3-3 and 3-4** summarize the measurements.

Section 4.4.3 discusses the water quality in relation to fish health.

4.3 Character of Wetlands Environment

The methodology used in the development of this section is similar to that previously discussed for the Fill Area. Refer to Section 3.3 for a more complete discussion of the methodology.

4.3.1. Project Area Description

The area surrounding the airport is primarily urban/residential in nature. The area south of the airport contains a greater percentage of non-urban/residential land; however, due to the existence of the Tyee Golf Course and significant acreage of successional land that was historically residential but which was acquired by the Port as part of Noise Abatement Mitigation programs. In addition to these areas, Des Moines Creek has a significant forested riparian corridor that is undeveloped. Wetland areas within the Des

Moines Creek watershed but outside the project area include Bow Lake, and numerous riparian wetlands associated with Des Moines Creek that fall south of the project area.

Approximately 48.5 acres of wetlands are present within the Borrow Areas, and Tyee Golf Course (Parametrix 1999a). Based on existing aerial photography, extensive riparian wetland complexes occur along Des Moines Creek on its course to Puget Sound. Obviously, these all fall outside the bounds of the Port project area, and thus were not included in the Parametrix report.

4.3.1 Field and Literature Analysis

As discussed in Section 3.3, field surveys and a literature review were conducted to evaluate wetlands in the project area.

4.3.1.1 Wetland Delineation

As discussed in Section 3.3.2, E & E's field survey verified that wetland boundaries as flagged in the field reasonably depict the extent of local wetlands, and that the representation of these areas in existing reports is also reasonable. The field surveys did not identify any wetlands that previously had not been delineated. **Figure 4-6** shows the delineated wetlands and borrow areas.

4.3.1.2 Wetland Characterization

Table 4-1 identifies wetlands that could be directly impacted by excavation of on-site borrow areas as compiled by E&E. Expanded discussions of the wetlands are provided in the Wetland Delineation Report (Parametrix 1999a). Impacts to wetlands larger than 1/3 acre are shaded in the table. Discussion regarding the Ecology Class determination is provided in Section 3.3.3.1. In addition, wetlands in borrow area 3 may be indirectly affected by reduced water flows as discussed in Section 4.5.4.

4.3.1.3 Functional Assessment

Refer to Section 3.3.3.2 for a discussion of the functional assessment presented as part of **Table 4-1.**

4.3.2 Comparison to Previous Characterizations

Biologists evaluated project area wetlands to evaluate consistency with the wetland delineations and qualitative assessment completed as part of prior studies and presented in the Wetland Delineation Report (Parametrix 1999a). Based on the field surveys completed for this project, which represented a random sampling of wetlands within the project area, the wetland delineations presented in the delineation report provide an accurate representation of the extent of wetlands that occur in the project area. The USACE confirmed this assessment.

Refer to Section 3.6.7.2 for a comparison relating to functional assessment evaluations.

4.4 Character of Fish Habitat and Populations

4.4.1 General Watershed Description

The Des Moines Creek watershed covers 5.8 square miles and measures 3.5 miles long. The creek drops from an elevation of approximately 350 feet to Puget Sound at Des Moines Creek Beach Park. The East Fork of Des Moines Creek originates from Bow Lake where it flows through subsurface piping for approximately 1/2 mile. The West Fork of Des Moines Creek originates in the Northwest Ponds in the northwest corner of the Tyee Valley Golf Course. The confluence of the two forks of Des Moines

Creek is in the central portion of the Tyee Valley Golf Course.

In addition to the Miller Creek Hatchery that releases age-0 coho throughout Des Moines Creek, Trout Unlimited (TU) manages a net pen operation in the Des Moines Marina. Annually, TU obtains 30,000 coho and 30,000 chinook salmon (*O. tshawytscha*) smolts from the WDFW. All WDFW fish have received an adipose fin clip. TU feeds the fish for approximately 6 months and then releases them. These fish are believed to remain within Puget Sound during their ocean migration (Batcho 1999). Because of the proximity to Des Moines Creek, net pen fish could use Des Moines Creek for spawning.

4.4.2 Watershed Development

Most of the watershed is heavily urbanized with residential and commercial land uses throughout the cities of SeaTac and Des Moines. Surface water runoff in the watershed directly below Bow Lake has been greatly altered and is almost exclusively confined to culverts, roadside ditches, and storm drain piping. The Des Moines Creek forks are not heavily utilized by salmonid species, especially in the summer months when water quality parameters such as low dissolved oxygen and high temperature limit salmonid usage. When water quality has been good, cutthroat trout have been found in the upper watershed (DMCBC 1997). Downstream of the confluence of the two forks, the creek gradient increases, additional water enters the creek, and riparian vegetation density increases; as a result, dissolved oxygen increases and temperature decreases making the creek more hospitable to salmonids. Downstream of South 200th Street, the creek flows through a large wetland complex with well developed riparian vegetation. After the wetland complex, Des Moines Creek enters a natural ravine that has substantially eroded because of increased peak flows caused by urbanization in the upper watershed (DMCBC 1997, Masters 1999). Salmonid usage through the ravine reach is limited because of a lack of gravel for spawning and food production and a lack of slow water refuge from peak flow events (Masters 1999). Most of the streambed gravels have been scoured from this area, leaving a substrate of hardpan clay. Downstream of the ravine, the creek is channelized through the Midway Treatment Plant. Below the treatment plant, the topography widens and the creek flows through a floodplain with a meandering channel and well developed riparian vegetation. The creek flows through a 225-foot long box concrete culvert under Marine View Drive that is impassable to salmonids under most water conditions because the combination of high water velocity and shallow water depth is beyond adult coho swimming ability. The remaining 1/2 mile of creek flows through Des Moines Beach Park. This lower reach of Des Moines Creek is utilized by anadromous salmonids: coho and chum salmon were observed in this reach during December, 1999. Steelhead are also reported to use this creek reach, but their presence was not verified during this study. Adequate salmonid habitat reportedly exists between Marine View Drive and the Midway Treatment Plant, however, usage is limited because of the Marine View Drive culvert (DMCBC 1997).

4.4.3 Water Quality Related to Fish

PGG measured in-situ water-quality parameters (pH, temperature, conductivity, turbidity, and dissolved oxygen) during base flow periods in October 1999 and January 2000 at two locations in Des Moines Creek: upstream of South 200th Street at the Tyee Valley Golf Course and near the intersection with 18th Avenue South (Tables 3-3 and 3-4). No water quality concerns related to fish production were identified. Water samples also analyzed for total metals, TSS, ammonia, nitrate, nitrite, total phosphorus, ortho-phosphorus, biological oxygen demand, and total oil and grease. Based on the calculated hardness in Des Moines Creek of 83 to 100 mg/L, the detected concentrations of copper and zinc are below the Washington State standards (other heavy metals were undetected). The maximum TSS value was 3.8 parts per million (ppm), indicating minimal suspended particles (of which sediment is one component) in the water column. The total oil and grease results were below 2 ppm, indicating minor inputs of petroleum constituents at the time of sampling.

Voss et al. (1999) reported the presence of numerous pesticides in Des Moines Creek. Diazinon was present at concentrations equal to the chronic aquatic life criteria recommended by the EPA(1998). Voss et al. (1999) noted that the ecological effects to the stream is unknown because the duration of exposure to pesticide concentrations at the aquatic life criteria is unknown.

Stormwater at the airport falls into one of two types of catchments: the Stormwater Drainage System (SDS) and the Industrial Wastewater System (IWS). This project did not independently review original SDS or IWS water quality data or discharge data. The following brief discussion is from the FEIS (FAA, 1996) and other sources. Refer to Section 3.4.1.3 for more discussion.

The Des Moines Creek watershed receives discharge from the SDS that drains the taxiways and runways. Samples of SDS discharge were analyzed by the Port for seven water quality parameters (total suspend solids, biochemical oxygen demand, oil and grease, total phosphorus, total copper, total lead, and total zinc) and the results were compared to the total basin loading for these parameters in Des Moines Creek (FAA, 1996). According to that analysis, discharge from the airport contributes between 3.5 percent and 39 percent of the total basin loading for these water quality parameters. The total copper contribution of 39 percent exceeds the approximate 30 percent of the Des Moines Creek watershed area that is comprised by the airport. All other loading by the airport to the Des Moines Creek watershed was reported to be less than 25 percent.

4.4.4 Fish Populations

Despite habitat and water quality degradation, anadromous and resident fish populations are present in Des Moines Creek. Adult coho and chum salmon are known to utilize the stream reach from the mouth to the Marine View Drive culvert. Juvenile coho salmon are distributed throughout Des Moines Creek, likely because of TU Miller Creek Hatchery release efforts. Steelhead (*O. mykiss*) and pink salmon (*O. gorbuscha*) runs have been reported on Des Moines Creek, but this was not field verified. A small population of resident cutthroat trout is distributed throughout much of the Des Moines Creek watershed. Pumpkinseed sunfish and largemouth bass (*Micropterus salmoides*) reportedly have been introduced to lakes in the Des Moines Creek basin; however, the presence or distribution of pumpkinseed or largemouth bass in Des Moines Creek were not documented during this study.

4.5 Analysis of Selected Impacts

4.5.1 Des Moines Creek HSPF Model Review

In the Des Moines Creek basin, flow volumes predicted by the HSPF model were compared to observed values for the water years 1994, 1995 and 1996 at gages upstream of the Tyee pond and near the mouth of the creek. Table 4-2 compares the total flow volumes, expressed as equivalent inches of precipitation across the drainage area tributary to each gage.

The period of flow rate calibration data used for the Des Moines Creek HSPF model is from October 1, 1995 to March 30, 1996. This six-month period of time is not adequate to sufficiently calibrate the HSPF model. Normally a minimum of two years is required to adequately calibrate a watershed.

The calibration at each stream flow gage is reasonable but may be improved. There are two rain gages established in the Des Moines Creek watershed: the Sea-Tac gage located at the airport and the Tyee Pond gage located lower in the basin. Total precipitation recorded at the Tyee Pond gage is approximately 94 percent of the rainfall recorded at the Sea-Tac gage and seasonal variations are similar. The HSPF model utilizes only the Sea-Tac rain gage record for precipitation input. The model's calibration could be strengthened by utilizing rainfall input from both gages, applying the Sea-Tac gage record for the upper reaches of the watershed and the Tyee Pond data to the lower subbasins. This would allow better calibration at the upper gage site without overestimating volumes at the lower gage site.

A review of the Des Moines Creek HSPF model did not reveal serious limitations, and the calibration of the model appears to be reasonable for characterizing current surface water flow conditions in the watershed. However, several changes were disclosed in the input data between models developed to simulate different land use scenarios. Because the purpose of these models is to make relative comparisons of flow volumes and rates under proposed and target flow conditions, the inconsistencies present a significant limitation in the modeling. Four Des Moines Creek HSPF models, each representing a different land use scenario, were reviewed:

DM-C - calibration land use conditions
DM-PRE - pre-developed scenario (target flow conditions)
DM94- 1994 land use base scenario
DM04 - 2004 land use scenario

Groundwater Deep Fraction (DEEPFR) parameter defines how infiltrated groundwater behaves when it reaches a soil horizon. The DEEPFR parameter specifies how much of the infiltrated water continues downward into the deeper aquifer and how much travels laterally through an upper stratum. The DEEPFR parameter is set at 0.7 for the pre-developed (target flow) and calibration scenarios but is set to 0.6 for the 1994 and 2004 land use scenarios. Within the runway embankment fill area, the DEEPFR parameter in the calibration scenario model was set to 0.9, and it was changed to a value of 0.8 in models of the 1994 and 2004 land use scenarios. No explanation is provided in the project documentation for these apparent discrepancies.

The significance of the DEEPFR parameter in the Des Moines Creek model is that it applies to the amount of groundwater that is transmitted to a deeper aquifer and becomes unavailable to feed base flows in the stream. For outwash soils, all precipitation that infiltrates through the soil is subject to this parameter. This is over 99 percent of all runoff generated by outwash soils. For till soils, all precipitation that infiltrates through the soils and eventually through the hard till unit is subject to this parameter. This is usually less than half of the total runoff from till soils. The documentation does not explain why different DEEPFR values were used for a single land type.

Analyses with the slice groundwater models (Sections 3.2.4.1 and 3.6.4) suggest that the percent of recharge that percolates through the till would change from the current to the built conditions. The current condition slice model suggests 46.5 percent of recharge flows down through the till and the built condition slice model suggests 53.5 percent of the (reduced) recharge flows down through the till. The DEEPFR parameter should be set accordingly and all airport fill parameters should be consistent for all HSPF model scenarios for both the Des Moines Creek and Miller Creek watersheds.

Total watershed area is not consistent between the four model scenarios as shown in Table 4-3. There are also several changes between the models in defining the proportion of various soil types present within the watershed. Watershed area is greatest for the calibration scenario and smallest for the 2004 land use scenario. When diversions to the IWS are accounted for, the total watershed areas for the calibration and 2004 scenarios still differ by 7.6 percent.

All land types show changes between the four models. For example, the pre-developed condition has 2079 acres of till soils, 1223 acres of outwash soils, and 375 acres of impervious surface. This is changed under the 2004 land use scenario to 1002 acres of till, 851 acres of outwash and 1219 acres of impervious surface. Much of the shift is presumed attributable to the placement of fill for the airport and diversion to the IWS; however, there is no clear explanation provided for the changes, nor for the net change in gross watershed area between the models.

With a larger percentage of the watershed assumed covered by till soils in the target flow scenario, the model will simulate more runoff volume and higher peak flows. With a larger percentage of outwash soils assumed in the 2004 land-use scenario, the model will simulate lower runoff volumes and rates to be generated. When attempting to size facilities that control runoff from future land use conditions to target flow rates, the impact of the shift from till to outwash soils between scenarios would be to undersize the facilities.

Another set of HSPF model values are termed FTABLEs. FTABLEs define the relationship between the volume and flow rate of water within a reach of the stream or within a facility. In reviewing the FTABLEs in the Des Moines Creek model, several were found to have values that are suspected to be inaccurate because in some of the FTABLEs the surface area of the reach decreases with increasing water depth. The suspect FTABLEs include those numbered: 1, 2, 25, 44,64, 100, 105, 110, 115, 135, 140, 150, 190, 193, 198, 200, 203, 204, 205, 206, 207, 222, 360, 390.

4.5.2 Proposed Flow Control Measures

Discussion of the target flow regime is presented in Section 3.6.2.2. The general approach to sizing flow control facilities for the airport within the Des Moines Creek watershed, as presented in the Preliminary Comprehensive Stormwater Management Plan, is appropriate. The proposed approach includes applying the target flow regime concept, using Level 1 flow control facilities in conjunction with regional facilities to achieve Level 2 control, and utilizing the HSPF model to simulate the target, existing, and proposed watershed conditions. However, as noted above and in prior sections of this report, the technical execution of the approach requires several corrections if the modeling is to be used to size flow control facilities that would confidently achieve the desired conditions in the stream systems.

Table 3-19 summarizes how the limitations in the modeling, if not corrected, would affect the sizing of flow control facilities. Because of the fundamental questions raised in the models' use of parameters and differences in basin areas, the impact that the changes would have on facility size could not be made without actually revising the model.

The flow control plan relies on the construction of the proposed regional detention facility (RDF) below the airport on Des Moines Creek. Implementation of this project as part of the Des Moines Creek Basin Plan is to be a joint effort between the Port of Seattle, King County and the cities of SeaTac and Des Moines. In the event the RDF is not constructed, it is proposed that additional on-site detention vaults would be constructed at the airport to provide Level 2 control of airport runoff. No contingency locations were specified for provision of additional stormwater detention capacity in lieu of the Des Moines Creek RDF.

4.5.3 Accounting for the Industrial Waste System in HSPF Models

Portions of the airport most susceptible to contamination by de-icing and other service chemicals are drained to the Industrial Wastewater System (IWS). The IWS flows are conveyed to treatment lagoons which, in turn, discharge directly to Puget Sound. The IWS is, therefore, unconnected to the hydrology of the Des Moines Creek watershed except for the fact that the IWS consumes potential runoff and groundwater recharge area. There have been occasions where the IWS lagoons have overflowed to the Des Moines Creek system during extreme storm events.

The assumptions regarding diversion of stormwater to the IWS under each model scenario are difficult to track through the SWMP. Table 4-3 presents the reviewers' understandings of the acreage assumed tributary to the industrial waste system in the Des Moines Creek HSPF models. The areas for the IWS increase from 292 acres to 315 acres from the 1994 land use scenario to the calibration land use scenario. The areas for the IWS increase from 315 acres in the 1994 land use scenario to 424 acres in the 2004 scenario. The increases mean a corresponding decrease in area for either the Des Moines Creek watershed areas or the Miller Creek watershed areas. However, confirmation that the IWS area is accurately accounted for is complicated by the fact that the total watershed areas for Des Moines Creek and Miller Creek do not remain constant for all four model scenarios. Inconsistent accounting for areas to be diverted to the IWS may be a source of modeled changes to total basin areas.

4.5.4 Effects on Water Balance and Groundwater Flow

Analyses using recharge model results were performed to evaluate potential changes to recharge resulting from excavation of the borrow areas. The primary change in land type would be conversion of forested outwash and till soils to barren or grassy outwash. The reviewed Port documents did not indicate plans for post-mining reclamation or the promotion of vegetation.

In borrow area 1, the excavated area covers about 95 acres, and over 25 acres the glacial till would be removed to expose outwash. Based on these areas and recharge rates for forested and barren conditions, a small amount of additional groundwater recharge (annual average of not more than 2800 cfd (0.03 cfs)) to the Qva aquifer would be expected after excavation as compared to the current condition. The timing of discharge to Des Moines Creek may change over these limited areas but was not analyzed. The removal of the vadose zone, including perching layers, could cause faster or slower discharge to the creek as compared to the current condition.

In borrow area 3, the excavated area covers about 20 acres. Based on this area and recharge rates for pre- and post-construction conditions, not more than 500 cfd (0.006 cfs) of additional annual average groundwater recharge to the Qva aquifer would be expected after excavation as compared to the current condition. The timing of discharge to Des Moines Creek was not analyzed.

The excavation at area 3 is designed to narrowly avoid seven slope and depressional wetlands (**Figure 4-6**) which are dependent on water in the perched water-bearing zone (**Figure 4-3**). Independent interpretation of water levels in the perched aquifer indicate that water moves to the wetlands from generally the northwest, with considerable uncertainty about the precise direction. The perching horizon and perched water-bearing zone are proposed to be removed to the north and east of the wetlands, but not to the west (Figure 4-6). This arrangement was designed by Hart Crowser to avoid draining water away from the wetlands. However, a seepage face would likely develop on the west wall of the northern excavated area, and perched groundwater would seep into the excavation. The change in discharge location for some of the perched groundwater would cause groundwater elevations to decrease in the perched water-bearing zone west of the seepage face. The proposed design and existing analyses by Hart Crowser do not provide high confidence that water flow to the wetlands would be maintained at their current rate. Groundwater flow direction mapping has relied in part on moisture content interpretations from soil borings as opposed to surveyed static water level elevations, and the methods of the impact analyses indicating "a decline in groundwater level of 1.5 to 2 feet" of have not been provided (Hart Crowser, 1999c). This magnitude of water level change would likely have substantial impacts to wetland water flow, and possibly biota.

The seepage into the excavation is likely to infiltrate through the bottom of the excavation and recharge the Qva aquifer. New wetland area may be created in the bottom of the excavation in this process. Timing of discharge to the creek was not analyzed.

In borrow area 4, the excavated area covers about 35 acres and would remain within outwash soils. Based on the area of the footprint and removal of vegetation, an additional 900 cfd (0.01 cfs) of groundwater recharge to the Qva aquifer would be expected after excavation as compared to the current condition. Although the perching horizon identified in area 3 extends into area 4, the proposed depth of excavation in area 4 would not result in excavation of the perching horizon. The timing of discharge to Des Moines Creek was not analyzed.

4.5.5 Comparison to Previous Hydrogeologic Impact Assessments

Applied Geotechnology Inc. (1995) identified potential changes to groundwater recharge resulting from borrow activities but did not quantify the changes. In an appendix to the Master Plan FEIS, AGI (1996) estimated 0.32 cfs additional recharge from borrow areas which is substantially above this project's estimated maximum of less than 0.05 cfs. The basis for the difference is an unjustified assumption by AGI that recharge does not occur in till-mantled areas.

The modeling of borrow areas in the HSPF model of Des Moines Creek developed by Parametrix was not evaluated in detail; however, cursory review of the data presented in the SWMP suggests the cover type changes resulting from borrow activities were not modeled.

4.5.6 Impacts to Wetlands

This analysis evaluates the size of the potential wetland impact, and the resulting functional impacts.

4.5.6.1 Acreage Impact

Excavation of the borrow areas would result in the permanent loss of 1.45 acres of wetland in the Des Moines Creek watershed, and an additional temporary loss of 0.20 acres of wetland that would be disturbed during the construction phase of the project but restored to wetland conditions during operations. These totals are based on the information provided in previous reports coupled with the field verification of wetland boundaries. Of the 6 wetlands impacted, only one loss is greater than 1/3 acre.

Tables 4-4 and 4-5 present summaries of direct impacts expected from borrow excavation. These impacts are presented by hydrogeomorphic classification, as well as by cover type.

4.5.6.2 Functional Impact

Wetland 52, which is associated with Des Moines Creek is recognized as offering numerous functions in terms of water quality, quantity and wildlife populations. As proposed, the airport projects would only minimally impact this wetland complex. Similarly the Northwest Ponds (Wetland 28) also would not be significantly impacted. The wetlands on the golf course offer little functional value except for nutrient/sediment trapping. The wetlands to be removed at Borrow Area 1 provide a wider range of functions since they are part of a larger habitat system. However, these wetlands are located in an area that historically was residential, but was acquired as part of a noise mitigation program. The functions of the wetlands that will likely receive reduced water flows in borrow area 3 were not reported by Parametrix (1999b) nor evaluated for this project.

The large wetland complexes associated with Des Moines Creek would remain relatively unaltered, minimizing the impacts within the watershed. The primary impacts that would need to be compensated for are nutrient/sediment trapping, and wildlife populations.

4.5.6.3 Mitigation

The overall mitigation plan for the airport impacts are discussed in Section 3.6.7.

4.5.6.4 Comparison to Previous Wetland Impact Assessments

As discussed above in Section 4.5.4, Hart Crowser estimates 1.5 to 2 feet of perched water table depression near wetlands in borrow area 3. Any water table reduction would cause reduced flow to existing wetlands and possible impacts to biota. This effect was not identified by Hart Crowser, although the excavation was designed to minimize wetland impacts. This project concurs that perched water table depression and reduced flow to wetlands is likely to occur, but has not quantified the effect. Hart Crowser did not present the methods used in its prediction and they were therefore not reviewed. This project's findings disagree with the findings in the wetland functional assessment (Parametrix, 1999b) that states that no wetland hydrologic impacts will occur.

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Tables

Table 3-1
Creek Base Flow Measurement Results

Station	Total Discharge Rates (cfs) 10/22&23/99	11/7/99	1/27&28/00
Des Moines Creek	0.5	NM	1.7
KC-11C + KC-11G	1.0	NM	2.0
KC-11F	0.8	NM	1.8
Des Moines Creek at Tyee	1.4	NM	3.4
Des Moines Creek at South 18th	1.3	NM	3.4
KC-11D			
Miller Creek	0.4	NM	2.0
KC 42B	0.4	NM	1.8
Miller Creek at Lora Lake	0.9	NM	2.6
Miller Creek at S 156th St	0.9	NM	2.8
Miller Creek at 509 & Des Moines Memorial Drive	1.5	NM	3.8
Miller Creek at Kiwanis	2.7	NM	6.0
KC-42A			
Walker Creek	NM	1.0	0.8
Walker Creek near head	1.8	2.1	1.4
Walker Creek at 1st Ave Retaining Wall	NI	2	2.9
KC-42E	1.9	2.4	2.4
Walker Creek near mouth			

NM = Not measured
NI = Station not instrumented

AR 021972

Table 3-2
Comparison of Modeled and Measured Base Flow Gains in Miller Creek

	Flow in Middle Miller Creek October-99	Flow in Middle Miller Creek January-00	Flow at Lower Miller Creek
Flow in middle Miller Creek at MCDF (Lora Lake) (cfs)	0.4	1.8	
Flow in middle Miller Creek at SR 509 (cfs)	0.9	2.8	
Difference in flow (cfs)	0.5	1	
Gain in baseflow per foot of reach (cfs/f)	6.59E-05	1.32E-04	
Gain in baseflow per foot of reach (cfd/f)	6	11	
Gain reduced to average condition based on 1999 wet year (divide by 1.9) (cfd/f)	3		
Gain reduced to average condition based on 1999 wet year (divide by 1.5) (cfd/f)		8	
Expected range from east bank (50 percent to 100 percent) (cfd/f)	1.5 to 3	4 to 8	
Slice Model (average year) surface flow plus groundwater flow (cfd/f)	1	7 to 8	
Estimated potential contribution from septic discharge (cfd/f)	1	1	
Long term dry year "low flow" (Parametrix, 1999x) (cfs)			1.4
Long term dry winter baseflow (Parametrix, 1999x) (cfs)			4
Long term dry year average baseflow (Parametrix, 1999x) (cfs)			2.4
King County Gage October 99			2.7 (1.9 times typical "low flow")
King County Gage January 00			6 (1.5 times winter baseflow)

AR 021973

Table 3-3
Field Water Quality Analyses

Station	Date	pH	Temperature (°F)	Ec (uS/cm)	Turbidity (NTU)	DO (mg/L)
Des Moines Creek at Tyee (north of 200th St.)	10/23/99	7.23	51	212	0.7	5
Des Moines Creek at South 18th	10/22/99	6.2	50.1	288*	0.9	9
[redacted]						
Miller Creek North of Hwy 518 (Upstream of Tub Lake Trib.)	10/23/99	7.66	52	209	2.6	6
Miller Creek North of Hwy 518 (Downstream of Tub Lake Trib.)	10/23/99	7.36	52	209	2.5	4
Miller Creek at Lora Lake	10/22/99	6.2	51	315	15	6
Miller Creek at S 156th St	10/22/99	8.25 - 7.51	52	301	4	6
Miller Creek at 509 & Des Moines Memorial Drive	10/22/99	7.9	50	510	4	8
Miller Creek at Kiwanis (Upstream of Lake Burien Trib.)	10/22/99	7.59	52	253	2	9
[redacted]						
Walker Creek at 1st Ave Retaining Wall (South of 168th St.)	10/22/99	7.44	52	258	4	5
Walker Creek near mouth (at 12th Ave)	10/23/99	7.77	51	252	2.5	6
[redacted]						
Walker Creek near head in 18-inch pipe (West of Hwy 509)	1/28/00	7.06/7.17**	51	3.75	1.1	7
Walker Creek near head in 6-inch pipe (West of Hwy 509)	1/28/00	7.51/7.57**	44	179	7.3	6
Walker Creek at 1st Ave Retaining Wall (South of 168th St.)	1/28/00	7.84	44	364	5.4	5
Walker Creek near mouth (at 12th Ave)	1/28/00	8.15	42	210	4.3	8

**Conductivity meter not calibrated to 1413 us/cm standard*

***7.06/7.17 = Reading taken in pipe/Reading taken in sample collected in pipe*

Table 3-4
Laboratory Water Quality Analyses

Constituent	Method	WAC 173-201A Freshwater Chronic Criteria	Units	Samples collected October 25 and 26, 1999				Samples collected January 28, 2000			
				Miller Creek at S 156th	Miller Creek at Kiwanis	Des Moines at Tyee	Des Moines at S 18th	Miller Creek at S 156th	Miller Creek at Kiwanis	Des Moines at Tyee	Des Moines at S 18th
Total Metals											
Arsenic	6010	0.19	mg/L	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
Cadmium	200.8	*Calculated below	mg/L	0.0002 U	0.0002 U	0.0002 U	0.0002U	0.0002 U	0.0002 U	0.0002 U	0.0002 U
Calcium	6010	—	mg/L	27.8	24.8	21.8	20.7	21.0	21.0	19.3	19.1
Copper	6010	*Calculated below	mg/L	0.002 U	0.002 U	0.004	0.003	0.005	0.004	0.007	0.005
Lead	200.8	*Calculated below	mg/L	0.001	0.001 U	0.001 U	0.001 U	0.004	0.001	0.001 U	0.001 U
Magnesium	6010	---	mg/L	18.6	15.8	12.2	11.7	10.2	10.4	8.54	8.75
Zinc	6010	*Calculated below	mg/L	0.01	0.007	0.010	0.010	0.022	0.014	0.014	0.012
Hardness	Calculated	---	mg-$CaCO_3$/L	150	130	100	100	95	95	83	84
Conventionals											
Total Suspended Solids	160.2	---	mg/L	5	1.8 U	1.1 U	1.2	17	4.1	3.8	1.7
N-Ammonia	350.1	---	mg-N/L	0.06	0.013	0.017	0.010 U	0.066	0.013	0.010 U	0.010 U
Nitrate+nitrite	353.2	---	mg-N/L	1.3	1.3	0.86	0.69	1.3	1.3	0.56	0.54
total phosphorous	365 2	---	mg-P/L	0.080	0.071	0.040	0.043	0.098	0.060	0.06	0.051
ortho phosphorous	365.2	---	mg-P/L	0.03	0.038	0.017	0.025	0.026	0.029	0.005	0.013
biological oxygen demand	405.1	---	mg/L	2	3 U	2	2 U	2	2 U	2	2
total oil and grease	413.1	---	mg/L	1 U	1.2	1 U	1 U	1.6	1.8	1.4	1.5

U =undetected. Instrument detection limit reported.
Bold text exceeds WAC 173-201A Freshwater Chronic Criteria

**WAC 173-201A Freshwater Chronic Criteria for a sample is calculated from the hardness value for that sample*

Hardness (mg-$CaCO_3$/L)	150	130	100	95	83	84
Cadmium (mg/L)	0.001	0.001	0.001	0.001	0.0009	0.0009
Copper (mg/L)	0.016	0.014	0.011	0.011	0.010	0.010
Lead (mg/L)	0.004	0.003	0.003	0.002	0.002	0.002
Zinc (mg/L)	0.15	0.13	0.10	0.10	0.09	0.09

Table 3-5
Wetlands Potentially Affected by Fill Areas Associated with Proposed Third Runway

Wetland	Classification	Total Wetland Size	Brief Wetland Description	Ecology Class	Qualitative Functional Assessment
Runway Safety Area					
5	Slope PSS	4.63	Part of a larger forested complex associated with Miller Creek Detention Facility	III	M-H Wildlife M – Nutrient/Sediment trapping
New Third Runway					
9	Slope PFO/PEM	2.83	Part of extensive wetland complex part of the Miller Creek Detention Facility.	III	M-H Wildlife H – Flood Storage M – Export of Organic Carbon and Nutrient/Sediment trapping
11	Slope PFO/PEM	0.50	Elevated Forested/Emergent wetland; drains downslope toward the Miller Creek Detention facility	III	M- Wildlife M- Nutrient/Sediment Trapping
12	Sl[illegible] PFO/PEM	0	[illegible] side seep in north borrow area in AOA	III	
13	Slop[illegible]	[illegible]05	Forested Hillside seep in north borrow area in AOA	III	
14	Slope F[illegible]	0.19	Forested Depression located in north borrow area in AOA, adjacent to 12th Ave.	III	
15	Slope PEM	0.28	Small emergent wetland within AOA associated with stormwater drainage	III	M- Nutrient/ Sediment trapping
16	Depression PEM	0.05	Small emergent wetland within AOA associated with stormwater drainage	III	L-M – Nutrient/Sediment trapping
17	Depression PEM	0.02	Small emergent wetland within AOA associated with stormwater drainage	III	L-M – Nutrient/Sediment trapping
18	Slope Riparian Mixed	3.56	Component of largest wetland complex in the project area. Significant disturbance from adjacent urban/residential development. Fill encroachment evident. Downslope edge is riparian to Miller Creek. Dense Himalayan blackberry evident. Connected to wetland 37.	II	M-H – resident fish populations M-H – Wildlife Populations M- Flood Storage M-H – Export of Organic Carbon and Nutrient/Sediment Trapping
19	Slope PFO	0.56	Ravine PFO in former noise abatement area	III	M- Wildlife Populations M- Export of Organic Carbon and Nutrient/Sediment Trapping
20	Slope PSS/PEM	0.57	Drainage slope PSS/PEM in AOA	II	M-H Wildlife Populations M- Export of Organic Carbon
21	Slope PFO	0.22	Drainage channel in AOA	III	L-M – Wildlife Populations
22	Slope PSS/PEM	0.06	PSS/PEM slope in AOA	III	
23	Depression PEM	0.77	Grassy maintained PEM slope in AOA	IV	H – Sediment trapping L-M – Flood storage
24	Depression PEM	0.14	Maintained PEM in AOA	III	M- Nutrient/Sediment trapping
25	Depression PFO	0.06	PFO depression in AOA	III	
26	Depression PEM	0.02	PEM depression in AOA	IV	
W1	Depression PFO/PEM	0.10	PEM at the base of slope adjacent to temp. treatment ponds in AOA	III	M - flood storage L-M – Nutrient/Sediment Trapping

PFO –Palustrine Forested
PSS – Palustrine Scrub Shrub
PEM – Palustrine Emergent
FW – Farmed Wetland
AOA – Airport Operational Area
- Shading represents wetlands with a potentially large effect (>0.33 acres) from airport fill activities.

L – Low
M – Moderate
H – High

AR 021976

Table 3-5
Wetlands Potentially Affected by Fill Areas Associated with Proposed Third Runway

Wetland	Classification	Total Wetland Size	Brief Wetland Description	Ecology Class	Qualitative Functional Assessment
W2	Depression PFO/PEM	0.22	Closed depression in AOA	III	L-M wildlife Populations M- Flood Storage M-H – Nutrient/Sediment Trapping
35a-d	Slope PFO/PEM	0.67	Drainage swale adjacent to 160th Street, bisected by driveway fill	III	M- Wildlife Populations L-M – Export of Organic Carbon M-H – Nutrient/Sediment Trapping
37a-f	Slope - Riparian PFO/PEM	5.76	Component of largest wetland complex in the project area. Significant disturbance from adjacent urban/residential development. Fill encroachment evident. Downslope edge is riparian to Miller Creek. Dense Himalayan blackberry evident. Connected to wetland 18	II	M-H – resident fish populations M-H – Wildlife Populations M- Flood Storage M-H – Export of Organic Carbon and Nutrient/Sediment Trapping
40	Depression PFO	0.03	Isolated woodlot at corner of Wilson Road and 12th Ave.	III	
41a and b	Depression PEM	0.44	Farm pond and adjacent pasture	III	M – Flood Storage H – Nutrient/Sediment Trapping
44a and b	Slope PFO	3.04	Ravine leading to large offsite wetland (wetland 43) that forms headwaters for Walker Creek	II	M-H – Wildlife Populations M-H – Export of Organic Carbon M-H – Nutrient/Sediment Trapping
A1	Depression/ Riparian Mixed	4.51	Disturbed PFO/PSS/PEM adjacent to Lake Lora. Significant Himalayan blackberry in the understory	II	M - Resident Fish Populations M-H - Wildlife Populations H – Flood Storage H- Export of Organic Carbon and Nutrient/Sediment Trapping
A5	Depression PEM	0.03	Maintained/mowed grassy wetland	IV	
A6	Slope PFO	0.16	Woodlot with considerable Himalayan blackberry	III	L-M Wildlife Populations L-M Nutrient/Sediment Trapping
A7	Slope PFO	0.30	Successional woodlot with significant Himalayan blackberry component	III	L-M Wildlife Populations L-M Nutrient/Sediment Trapping
A8	Slope PFO/PSS	0.38	Disturbed community with extensive Himalayan blackberry	III	L-M Wildlife Populations L-M Nutrient/Sediment Trapping
A12	Slope PSS	0.11	Slope shrub wetland drainage	III	L-M Wildlife Populations
A18	Depression PSS	0.01	Small shrub pocket	III	
FW5 and 6	Depression/ Riparian FW	0.15	PEM wetlands in Vacca Farm still meeting jurisdictional criteria	IV	M- Flood Storage H- Nutrient/Sediment Trapping
R1	Riparian PEM	0.17	Riparian emergent adjacent to Miller Creek	III	M- Wildlife Populations H – Flood Storage M-H Export of Organic Carbon and Nutrient/Sediment trapping

PFO –Palustrine Forested
PSS – Palustrine Scrub Shrub
PEM – Palustrine Emergent
FW – Farmed Wetland
AOA – Airport Operational Area
- Shading represents wetlands with a potentially large effect (>0.33 acres) from airport fill activities.

L – Low
M – Moderate
H – High

AR 021977

Table 3-6
Optimal Habitat Preferences for Coho Salmon Survival

Habitat Parameter	Optimal Range	Benefit
Substrate Sedimentation	<30%	Sedimentation reduces water flow to deposited eggs and reduces available dissolved oxygen levels. Higher levels of sedimentation can be tolerated, but typically results in lower survival rates and smaller size at emergence.
Dissolved Oxygen Level	8-14.6 mg/L	Oxygen is necessary for egg survival and growth. Higher dissolved oxygen levels generally result in faster egg development and growth.
Water Temperature	4-11°C	Water temperature affects incubation time. Warmer water temperatures (up to a maximum tolerable level) generally result in shorter incubation times.

Adapted from Groot and Margolis (1991)

AR 021978

Table 3-7
Optimal Habitat Preferences for Juvenile Coho Salmon Survival

Habitat Parameter	Optimal Range	Benefit
Slack Water (Velocity)	<1 foot/second	Newly emerged salmon have limited swimming ability and require low water velocity to remain stasis. As fish grow, swimming ability increases and higher water velocities can be tolerated. Off-channel pools and stream edge slack water also possess good macroinvertebrate food sources for growth.
Instream Structure/Cover	30-70%	Boulders, undercut banks, overhanging vegetation, and large woody debris provide instream structure, cover from predators, and low water velocities. Large woody debris also traps organic matter and provides habitat for macroinvertebrate production.
Food Source	NA	Adequate macroinvertebrate food sources are necessary for growth and survival.

Adapted from Groot and Margolis (1991)

Table 3-8
Optimal Habitat Preferences for Adult Coho Salmon Spawning

Habitat Parameter	Optimal Range	Benefit
Gravel Size	5-15 cm	Gravel size provides interstitial pore space and allows for adequate water flow through the gravel. Gravel size is largely dependent on stream size and location within the stream system. Proper gravel size is needed to substantial depth because coho salmon have been documented to bury eggs up 40 cm into the substrate.
Water Velocity	0.5-1 m/s	Adequate water velocity is needed to keep the gravel free of sediment and provide sufficient water flow, and hence dissolved oxygen, through the gravel.
Water Depth	15-30cm	Female coho choose redd locations with adequate depth to insure sufficient water flow to eggs throughout incubation period. In areas where freezing is a factor, adequate depth insures water flow below the upper winter ice layer.

Adapted from Groot and Margolis (1991)

Table 3-9
Carcass Survey Results

Creek	Species	Sex (M/F)	Adipose Fin Clip (Y/N)	Percent Egg Voidance
Miller Creek	Coho	F	Y	80
	Coho	F	Y	80
	Coho	F	Y	100
	Coho	F	Y	20
	Coho	M	N	-
	Coho	F	Y	0
	Coho	M	Y	-
	Coho	M	Y	-
	Coho	F	U	95
	Coho	U	U	U
	Coho	U	Y	-
Walker Creek	U	U	U	U
	Coho	M	Y	-
	U	U	U	U
	U	U	U	U
	Coho	F	N	80
	U	U	U	U
	Coho	F	Y	80
	Coho	M	U	-
	U*	U	U	U
	U	U	U	U
	U	U	U	U
	U	U	U	U
	Coho	M	U	-
	U	F	U	90
	Coho	M	Y	-
	U	U	U	U
	Coho	F	Y	0
	Coho	M	Y	-
	U	U	U	U
	Coho	M	Y	-

Creek	Species	Sex (M/F)	Adipose Fin Clip (Y/N)	Percent Egg Voidance
Walker Creek cont.	Coho	F	Y	90
	Coho	F	Y	90
	U	U	U	U
	Coho	U	U	U
	Coho	M	N	-
	U	U	U	U
	U	U	U	U
	U	F	U	90
	U	F	U	70
	U	F	U	80
	Coho	M	N	-
	U	U	U	U
	Coho	M	N	-
	Coho	M	Y	-
	Chum	M	N	-
	Coho	F	Y	95
	Coho	F	N	95
	U	U	U	U
	Coho	M	Y	-
	U	U	U	U
	U	U	U	U
	Coho	F	Y	95
Des Moines Creek	Coho	M	N	-
	Coho	M	N	-
	Coho	F	Y	90
	Coho	M	N	-
	Coho	M	N	-
	Chum	F	N	80
	Coho*	U	U	U
	Coho*	U	U	U
	Chum*	U	U	U

** Denotes live fish.*
U = Undetermined. Because of the fish condition, the parameter could not be conclusively determined.

Table 3-10
Miller Creek Carcass Survey

Date	Fish No.	Species	Sex (M/F)	Adipose Fin Clip (Y/N)	Eggs Present (Y/N)	Location/Comments
12/2/99	1	Coho	F	Y	Y	Upstream of Normandy Park Cove Building
	2	Coho	F	Y	Y	Upstream of Normandy Park Cove Building
	3	Coho	F	Y	N	Adjacent to first residence upstream of Normandy Park Cove property
	4	Coho	F	Y	Y (80%)	50 feet downstream of 13th Ave. bridge
	5	Coho	M	N	-	Between 13th Ave. bridge and downstream edge of Southwest Suburban Sewer District (SWSSD)
	6	Coho	F	Y	Y (100%)	75 feet downstream of upstream SWSSD bridge
	7	Coho	M	Y	-	Adjacent to Mr. Brett Fish's residence; fish small (13 in.)
	8	Coho	M	Y	-	Adjacent to Mr. Brett Fish's residence
	9	Coho	F	U	Y (5%)	Adjacent to Mr. Brett Fish's residence
	10	Coho	U	U	U	Upstream of Mr. Brett Fish's residence
	11	Coho	U	Y	-	Upstream of Mr. Brett Fish's residence

Miller Creek surveyed between mouth and 1st Ave. S. culvert
Note: Two unidentifiable carcasses were found approximately 50 feet downstream of the downstream SWSSD fence.

Table 3-11
Walker Creek Carcass Survey

Date	Fish No.	Species	Sex (M/F)	Adipose Fin Clip (Y/N)	Eggs Present (Y/N)	Location/Comments
12/3/99	1	U	U	U	U	50 feet upstream of Miller Creek confluence
	2	Coho	M	Y	-	20 feet upstream of 2nd wood foot bridge at Normandy Park Cove
	3	U	U	U	U	Adjacent to Normandy Park Cove parking area
	4	U	U	U	U	Adjacent to Normandy Park Cove parking area
	5	Coho	F	N	Y	Adjacent to Normandy Park Cove tennis courts
	6	U	U	U	U	Adjacent to Normandy Park Cove tennis courts
	7	Coho	F	Y	Y	Upstream edge of Normandy Park Cove tennis courts
	8	Coho	M	U	-	Upstream edge of Normandy Park Cove tennis courts
	9	U*	U	U	U	Downstream of 13th Ave. bridge; live fish
12/4/99	10	U	U	U	U	Upstream of 13th Ave. bridge, residential area
	11	U	U	U	U	Upstream of 13th Ave. bridge, in braided log jam area
	12	U	U	U	U	Upstream of 13th Ave. bridge, in braided log jam area
	13	Coho	M	U	-	GPS point N47 26 47.2, W122 20 58.7; residential area upstream of 13th Ave. bridge
	14	U	F	U	Y	100 feet upstream of fish #12; residential area upstream of 13th Ave. bridge
	15	Coho	M	Y	-	110 feet upstream of fish #12; residential area upstream of 13th Ave. bridge
	16	U	U	U	U	Residential area upstream of 13th Ave. bridge
	17	Coho	F	Y	Y (100%)	Residential area upstream of 13th Ave. bridge/adipose missing
	18	Coho	M	Y	-	Adjacent to driveway parallel to creek in residential area upstream of 13th Ave. bridge
	19	U	U	U	U	Location where creek turns NE away from driveway that parallels creek
	20	Coho	M	Y	-	Location where creek turns NE away from driveway that parallels creek
	21	Coho	F	Y	Y (10%)	Location where creek turns NE away from driveway that parallels creek
	22	Coho	F	Y	Y (10%)	Location where creek turns NE away from driveway that parallels creek
	23	U	U	U	U	GPS point N47 26 44.2, W122 20 53.6
	24	Coho	U	U	U	GPS point N47 26 44.2, W122 20 53.6; LIVE FISH
	25	Coho	M	N	-	Walker Preserve
	26	U	U	U	U	Walker Preserve
	27	U	U	U	U	Walker Preserve
	28	U	F	U	Y	Walker Preserve
	29	U	F	U	Y	Walker Preserve
	30	U	F	U	Y	Walker Preserve
	31	Coho	M	N	-	Walker Preserve
	32	U	U	U	U	Walker Preserve
	33	Coho	M	N	-	Walker Preserve
	34	Coho	M	Y	-	Walker Preserve
	35	Chum	M	N	-	Adjacent to first house in residential area upstream of Walker Preserve
	36	Coho	F	Y	Y (5%)	Residential area upstream of Walker Preserve
	37	Coho	F	N	Y (5%)	Residential area upstream of Walker Preserve
	38	U	U	U	U	Upstream of large concrete retaining wall in residential area
	39	Coho	M	Y	-	Residential area adjacent to creek/adipose clipped
	40	U	U	U	U	100 feet upstream of 1st Ave. S retaining wall
	41	U	U	U	U	Location where creek heads west away from 1st Ave. S
12/5/99	42	Coho	F	Y	Y (5%)	100 feet upstream of SW 171st St.

Walker Creek surveyed between confluence with Miller Creek and 1st Ave. S. culvert.
Note: One live fish observed in shallow sandy pool downstream of 13th Ave. Bridge at tributary inflow; fish unidentifiable.*

Table 3-12
Des Moines Creek Carcass Survey

Date	Fish No.	Species	Sex (M/F)	Adipose Fin Clip (Y/N)	Eggs Present (Y/N)	Location/Comments
12/3/99	1	Coho	M	N	-	150 feet upstream of footbridge at creek mouth, Des Moines Beach park
	2	Coho	M	N	-	160 feet upstream of footbridge at creek mouth, Des Moines Beach park
	3	Coho	F	Y	Y	50 feet upstream of Red Building over creek, 50 feet downstream of parking lot bridge/adipose missing
	4	Coho	M	N	-	100 feet upstream of parking lot bridge, adjacent to Sun Home Lodge
	5	Coho	M	N	-	100 feet upstream of parking lot bridge, adjacent to Sun Home Lodge
	6	Chum	F	N	Y (20%)	25 feet downstream of Marine View Drive culvert, east channel
	7	Coho*	U	U	U	50 feet downstream of Marine View Drive culvert
	8	Coho*	U	U	U	50 feet downstream of Marine View Drive culvert
	9	Chum*	U	U	U	50 feet downstream of Marine View Drive culvert

Des Moines Creek surveyed between mouth and Marine View Drive concrete culvert.

Note: *Observed 3 live fish* in small pool approximately 50 feet downstream of Marine View Drive culvert.*
2 appear to be coho salmon and 1 may be chum salmon.

Table 3-13
Miller Creek Juvenile Fish Survey

Station	Fish	Species	Fork Length (mm)	Station Description
1	1-1	Cutthroat	220*	Approximately 150 feet downstream of confluence with Walker Creek adjacent to Normandy Park Cove lawn area; plunge pool below deadfall log; sample area is 28 by 14 feet; thalweg depth is 24 inches; substrate is 50% gravel and cobble (plunge pool and thalweg) and 50% sand (left bank back eddy)
	1-2	Cutthroat	186	*Estimated
	1-3	Coho	40	
	1-4	Coho	41	
2	2-1	Coho	37	Approximately 100 yards downstream of 13th Avenue, downstream of private lawn area; sample area is 22 by 12 feet; thalweg is 22 inches deep; substrate is primarily sand and silt with small amount of gravel
	2-2	Coho	50	
	2-3	Coho	46	
	2-4	Coho	41	
	2-5	Coho	37	
	2-6	Coho	48	
	2-7	Coho	39	
	2-8	Coho	37	
3	3-1	Cutthroat	108	Upstream of Mr. Fish's property near large fallen cedar; sample area 15 by 10 feet; thalweg is 24 inches deep; substrate is primarily gravel and cobble with 20% sedimentation
4	4-1	Coho	32	Downstream portion of Walker Preserve ; sample area is backwater area, 4 by 3 feet; thalweg is 6 inches deep; substrate is cobble and boulder with approximately 15% sedimentation (fish captured with dipnet)
5	5-1	Cutthroat	91	Residential area upstream of Walker Preserve; sample location is slackwater pool below deadfall log; area is 20 by 10 feet; thalweg is 24 inches deep; substrate is 100% silt and sand
	5-2	Cutthroat	96	
	5-3	Cutthroat	95	
	5-4	Cutthroat	94	
	5-5	Cutthroat	90	
	5-6	Cutthroat	92	
	5-7	Cutthroat	94	
	5-8	Cutthroat	103	
	5-9	Cutthroat	94	
	5-10	Cutthroat	104	
	5-11	Cutthroat	101	
	5-12	Cutthroat	90	
	5-13	Cutthroat	101	
	5-14	Cutthroat	95	
	5-15	Cutthroat	103	
6	6-1	Cutthroat	102	Residential area upstream of Walker Preserve; sample location is plunge pool upstream of large hardpan clay slackwater area; area is 15 by 10 feet; thalweg is 20 inches deep; substrate is 50% gravel, 20% cobble, 5% boulder, and 25% silt and sand
	6-2	Cutthroat	129	
	6-3	Cutthroat	131	
7	7-1	Coho	28	Confluence with small tributary (0.5 cfs) approximately 1/4 mile downstream of the First Avenue South retaining wall; sample location is small slackwater pool; area is 1 by 1 foot; thalweg is 4 inches deep; substrate is mostly cobble with 20% sedimentation
	7-2	Coho	34	
	7-3	Coho	26	
	7-4	Coho	27	

Table 3-14
Walker Creek Juvenile Fish Survey

Station	Fish	Species	Fork Length (mm)	Station Description
1	1-1	Coho	35	Downstream of 13th Avenue culvert; sample area 15 by 20 feet; thalweg is 12 inches deep; substrate is gravel and cobble with approximately 25% sand
	1-2	Coho	35	
	1-3	Coho	26	
2	2-1	Coho	40	Upstream of 13th Avenue, adjacent to dead end road/driveway; sample area 15 by 5 feet; thalweg is 9 inches deep; substrate is primarily sand and silt with small amount of gravel
	2-2	Coho	36	
	2-3	Coho	40	
	2-4	Coho	32	
	2-5	Coho	35	
	2-6	Coho	37	
	2-7	Coho	39	
3	3-1	Cutthroat	82	Downstream of Walker Preserve near houses at end of dead end road/driveway; sample area is plunge pool (12 by 6 feet) created by down tree; thalweg is 24 inches deep; substrate is primarily cobble at depth in plunge pool and sand and silt in pool tailout
4	4-1	Coho	42	Downstream portion of Walker Preserve ; sample area is 11 by 6 feet; thalweg is 11 inches deep; substrate is primarily cobble and gravel with approximately 25% sand
5	5-1	Cutthroat	97	Residential area upstream of Walker Preserve; sample location is upstream of private foot bridge; area is 14 by 5 feet; thalweg is 11 inches deep; substrate is 2-5 inch cobbles with approximately 30% sedimentation; right bank is hard pan clay, left bank is rip rap
6	6-1	Coho	38	Small plunge pool created by deadfall log with center notch for water flow in residential area upstream of Walker Preserve; sample area 8 by 5 feet; thalweg is 12 inches deep; substrate primarily sand and silt with 10% gravel and 10% cobble
7	7-1	Coho	42	Residential area approximately 200 yards downstream of the First Avenue South retaining wall; sample location is adjacent to lawn; area is 9 by 6 feet; thalweg is 22 inches deep; substrate is 90% silt, 5% gravel, and 5% cobble
	7-2	Coho	42	Note: 28 additional age-0 coho captured and released without anesthetic or length measurement.
	7-3	Coho	43	
	7-4	Coho	45	
	7-5	Coho	33	
	7-6	Coho	39	
	7-7	Coho	41	
	7-8	Coho	40	
	7-9	Coho	41	
	7-10	Coho	42	
	7-11	Coho	42	
	7-12	Coho	45	
	7-13	Coho	32	
	7-14	Coho	34	
	7-15	Coho	40	
	7-16	Coho	43	
	7-17	Coho	41	
	7-18	Coho	34	
	7-19	Coho	38	
	7-20	Coho	32	
8	8-1	Cutthroat	91	Downstream of South 176th St., adjacent to cedar tree and lawn area; sample area is 14 by 6 feet; thalweg is 28 inches; substrate is 100% silt and sand

Table 3-15
Des Moines Creek Juvenile Fish Survey

Station	Fish	Species	Fork Length (mm)	Station Description
1	1-1	Coho	35	Approximately 200 yards downstream of Marine View Drive retaining wall; sample area is 30 by 10 feet; thalweg is 6 inches deep; substrate is cobble and gravel with 20% sedimentation
	1-2	Cutthroat	111	
2	2-1	Coho	34	Approximately 170 yards downstream of Marine View Drive retaining wall; sample location is small slackwater pool downstream of a series of boulders; area is 4 by 3 feet; thalweg is 12 inches deep; substrate is 70% cobble, 10% gravel, and 20% sand
	2-2	Coho	38	
	2-3	Coho	34	
	2-4	Coho	38	
	2-5	Coho	36	

Table 3-16
Walker Creek Rapid Bioassessment Results[1]

Characteristic	Parameter	Station 1 Rkm 0.2	Station 2 Rkm 0.7	Station 3 Rkm 1.4	Station 4 Rkm 2.2	Station 5 Rkm 2.8
Water Quality	Temperature (C)	7.6	6.5	7.1	7.2	7.6
	pH	7.88	7.71	7.7	7.88	7.76
	Dissolved Oxygen (mg/L)	12.14	13.32	12.78	12.42	12.41
	Turbidity (NTU)	5	88	4	6	4
	Conductivity (mS/cm)	0.2	0.258	0.234	0.213	0.202
Substrate (% composition)	Bedrock	0	0	3	0	2.5
	Boulder (>256 mm)	0	0	25	0	2.5
	Cobble (64-256 mm)	0	2.5	30	0	0
	Gravel (2-64 mm)	30	35	30	0	5
	Sand (0.06-2 mm/gritty)	65	60	12	90	90
	Silt (0.004-0.06 mm)	5	2.5	0	10	0
	Clay (<0.004 mm/slick)	0	0	0	0	0
Habitat[2]	Epifaunal Substrate/ Cover	14	12	14	4	9
	Pool Substrate (Embeddedness)	16	16	18	8	7
	Pool Variability (Velocity/ Depth Regime)	15	7	15	12	13
	Sediment Deposition	9	7	13	5	4
	Channel Flow Status	12	13	14	19	19
	Channel Alteration	9	15	20	14	7
	Channel Sinuosity (Frequency of Riffles)	4	5	17	5	4
	Bank Stability (L/R)	5/6	7/8	9/7	8/7	9/6
	Vegetative Protection (L/R)	4/7	7/7	9/8	9/6	7/4
	Riparian Vegetation Width (L/R)	1/9	9/5	10/10	10/2	6/2
	Total Score	111	118	164	109	97

1 = Methods follow Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers (EPA 1999).
2 = Initial habitat parameter is for Low Gradient Stream; habitat parameter in parenthesis has been modified for High Gradient Streams. Station 3 is the only high gradient stream section sampled on Walker Creek. Values presented are on a scale of 1-20 with the following categories: 0-5 (poor), 6-10 (marginal), 11-15 (suboptimal), and 16-20 (optimal).

C = Celcius.
mg/L = Milligrams per liter.
mm = Millimeter.
mS/cm = Microsiemens per centimeter.
NTU = Nephelometric Turbidity Unit.
Rkm = River kilometer.

Table 3-17
Miller Creek HSPF Water Volume Comparison

Upper Gage (below Lake Reba)

Water Year	Observed Flow (inches)	Simulated Flow** (inches)	Difference (percent)
1993	6.49	9.44	45.45
1994*	4.23	5.86	38.53
1995*	7.81	11.75	50.45
1996	16.35	19.46	19.02
Total	34.88	46.51	33.34

Lower Gage (near mouth)

Water Year	Observed Flow (inches)	Simulated Flow** (inches)	Difference (percent)
1993	14.78	22.14	49.80
1994*	13.47	15.94	18.34
1995*	20.53	22.42	9.21
1996	36.27	40.44	11.50
Total	85.05	100.94	18.87

**Volumes adjusted to account for missing data due to gage malfunction.*
***Simulated flow from MILL-C calibration model*

Table 3-18
Miller and Walker Creeks HSPF Model Area Summary

Total area by soil type

Model Scenario	Model Name	Till (acre)	Outwash (acre)	Fill (acre)	Wetland (acre)	Impervious (acre)	Total Area (acre)
Calibration	MILL-C	1570.8	2226.6	79.2	99.7	1116.5	5092.8
Predeveloped	MILL-PRE	2345.2	2170.6	0.0	96.1	514.3	5126.2
Land use 94	MILL94	1515.5	2225.7	45.5	108.8	1114.1	5009.6
Land use 04	MILL04	1377.4	2101.2	210.8	94.3	1205.6	4989.3

Percent total area by soil type

Model Scenario	Model Name	Till (percent)	Outwash (percent)	Fill (percent)	Wetland (percent)	Impervious (percent)
Calibration	MILL-C	30.8	43.7	1.6	2.0	21.9
Predeveloped	MILL-PRE	45.7	42.3	0.0	1.9	10.0
Land use 94	MILL94	30.3	44.4	0.9	2.2	22.2
Land use 04	MILL04	27.6	42.1	4.2	1.9	24.2

Table 3-19
Effects of Model Limitations on Flow Control Facilities

Basin	Model Limitation	Effect on Facility Requirements
All	Does not consider storage existing in the watershed to attenuate low-development condition flows	Increases target flow rates and reduces apparent size of flow control facilities needed to meet target flow rates
All	FTABLE inaccuracies	Not determined
Miller Creek	Groundwater supply to stream flow represented by constant flow rate time series	Masks the effect of changes in groundwater recharge upon base flows in stream/reduces apparent need for maintaining low flows
Miller Creek	Inconsistent DEEPFR parameter settings	Not determined, as settings vary widely between model scenarios
Miller Creek	Inconsistent soil type distributions across watershed	Reducing the area of outwash soils in the target flow scenario increases target flow rates and reduces apparent size of flow control facilities needed
Miller Creek	Total watershed area reduced by 2.7 percent from target flow regime model to 2004 conditions model	Reduces peak storm flows and volumes, thereby reducing apparent size of flow control facilities needed to meet target flow rates
Walker Creek	Runway fill not reflected in land use for 2004 conditions model	Reduces peak storm flows and volumes, thereby reducing apparent size of flow control facilities needed to meet target flow rates
Des Moines Creek	Does not use Tyee Pond rain gage data for lower portion of watershed	May increase peak flows in lower reaches of creek, creating apparent need for larger RDF to limit peak flow rates
Des Moines Creek	Inconsistent DEEPFR parameter settings	Reducing DEEPFR setting from calibration (0.9) to 2004 scenario (0.8) model increases groundwater available to supply stream and reduces apparent effect to base flows
Des Moines Creek	Total watershed area reduced by 7 percent from calibration model to 2004 model	Reduces peak storm flows and volumes, thereby reducing apparent size of flow control facilities needed to meet target flow rates

Table 3-20
Septic Discharge Calculations

Middle Reach of Miller Creek		
Total number of septic systems decommissioned	380	
Buy-out area contributory to middle Miller Creek	50%	
Typical septic discharge per person	80	gpd
Persons per household	2.5	
Percent of water supply that becomes secondary recharge	87%	Solly and others, 1993
Estimated average daily discharge in middle Miller Creek basin	33,060	gpd
Potential contribution to baseflow in middle Miller Creek	1	cfd/f

Total Buy-Out Area		
Total number of septic systems decommissioned	380	
Buy-out area contributory	100%	
Typical septic discharge per person	80	gpd
Persons per household	2.5	
Percent of water supply that becomes secondary recharge	87%	Solly and others, 1993
Estimated average daily discharge	66,120	gpd
Area of the buy-out area	12972434	ft^2
Equivalent septic R inches over the buy-out area	3	inches

Table 3-21
Comparison of Watershed Land Use Coverage

Miller Creek/Walker Creek Watershed

Land Use Type	Table F-2 1994 Existing Conditions (acres)	HSPF Model MILL94 1994 Conditions (acres)	Difference in Existing Conditions (acres)	Table F-2 2004 Proposed Conditions (acres)	HSPF Model MILL04 2004 Conditions (acres)	Difference in Proposed Conditions (acres)
Till (forest + grass)	1886.8	1515.5	-371.3	1771.1	1377.4	-393.7
Outwash (forest + grass)	1823.3	2225.7	402.4	1688.4	2101.2	412.8
Fill	79.2	45.5	-33.7	225.7	210.8	-14.9
Wetland	99.7	108.8	9.1	96.6	94.3	-2.3
Effective Impervious Area	1202.2	1114.1	-88.1	1313.0	1205.6	-107.4
Total	5091.2	5009.6	-81.6	5094.8	4989.3	-105.5

Des Moines Creek Watershed

Land Use Type	Table F-2 1994 Existing Conditions (acres)	HSPF Model DM94 1994 Conditions (acres)	Difference in Existing Conditions (acres)	Table F-2 2004 Proposed Conditions (acres)	HSPF Model DM04 2004 Conditions (acres)	Difference in Proposed Conditions (acres)
Till (forest + grass)	1085.7	1088.3	2.6	1011.2	1001.8	-9.4
Outwash (forest + grass)	864.9	870.4	5.5	851.3	850.9	-0.4
Fill	408.3	542.0	133.7	332.8	326.1	-6.7
Wetland	56.7	52.4	-4.3	56.7	50.4	-6.3
Effective Impervious Area [1]	1409.2	1413.9	4.7	1568.7	1642.6	73.9
Total	3824.8	3967.0	142.2	3820.7	3871.8	51.1

[1] *EIA in Des Moines Creek watershed includes areas tributary to the IWS*

Table 3-22
Summary of Impacts to Wetlands within Miller Creek Watershed from the Proposed Third Runway

	Forested		Scrub-shrub		Emergent		Total	
	Perm.	Temp.	Perm.	Temp.	Perm.	Temp.	Perm.	Temp
Slope	2.34	0.56	1.00	0.13	1.10	0.05	4.44	0.74
Slope/Riparian	4.16	0.68	0.52	0.17	2.00	0.22	6.68	1.07
Depression	0.1	0.00	0.04	0.00	1.75	0.00	1.89	0.00
Depression/Riparian	0.09	0.01	0.09	0.01	0.56	0.03	0.74	0.05
Riparian	0	0	0	0	0.13	0.00	0.13	0.00
Total	6.69	1.25	1.65	0.31	5.54	0.30	[illegible]	[illegible]

Perm. = permanent
Temp. = temporary

Table 3-23
Wetland Fill Impacts Associated with the Proposed Third Runway

Wetland	Classification	Total Wetland Size	Fill Effect	Temporary/ (Secondary) Effect	Vegetation Types Effected		
					PFO	PSS	PEM
Miller Creek Watershed Runway Safety Area							
3	Slope	0.56		0.05	-/0.05	-	-
4	Slope	5.00		0.10	-/0.10	-	-
5	Slope	4.63	0.14	0.10	0.07/0.10	0.07	-
New Third Runway							
9	Slope	2.83	0.03	0.03	0.01/0.01	-	0.02/0.02
[redacted]							
12	Slope		0.21		0.04	–	0.17
13	Slope		0.05		-	-	0.05
14	Slope		0.19		0.19	-	-
15	Slope		0.28		-	-	0.28
16	Depression		0.05		-	-	0.05
17	Depression		0.02		-	-	0.02
[redacted]							
21	Slope		0.22		0.22	-	-
22	Slope		0.06		-	0.01	0.05
[redacted]							
24	Depression		0.14		-	-	0.14
25	Depression		0.06		0.06	-	-
26	Depression		0.02		-	-	0.02
W1	Depression		0.10		-	-	0.10
W2	Depression		0.22		0.04	-	0.18
[redacted]							
40	Depression		0.03		-	0.03	-
[redacted]							
A5	Depression		0.03		-	-	0.03
A6	Slope		0.16		0.16	-	-
A7	Slope		0.30		0.30	-	-
[redacted]							
A12	Slope	0.11	0.02	0.03(0.06)	-	0.02/0.03	-
A18	Depression		0.01		-	0.01	-
FW5 and 6	Depression/ Riparian		0.15		-	-	0.15
R1	Riparian	0.17	0.13	0.04	-	-	0.13

a – All effects presented in acres.

PFO- Palustrine Forested
PSS – Palustrine scrub shrub
PEM – Palustrine emergent

Table 4-1
Wetlands Potentially Impacted by Borrow Areas Associated with the Proposed Third Runway[1]

Wetland	Classification	Total Wetland Size	Brief Wetland Description	Ecology Class	Qualitative Assessment
Borrow Area 1					
28	Depression Riparian PEM	35.45	Fairway of the Tyee Golf Course bounded by the Northwest Ponds	II	H- Resident Fish Populations H- Wildlife populations H-Flood Storage H – Nutrient/Sediment Trapping
48	Slope PEM	1.58	Slope wetland located at the edge of the Borrow area	II	M – Wildlife Populations L-M – Export of Organic Carbon and Nutrient/ Sediment Trapping
B11	Depression PEM	0.18	Abandoned Farm pond	III	L-M – Wildlife Populations M- Nutrient/Sediment Trapping
B12	Slope PFO	0.07	Small ravine	III	M- Wildlife Populations L-M – Export of Organic Carbon and Nutrient/ Sediment Trapping
B14	Depression PSS	0.78	Depressional shrub area, extensive Himalayan blackberry present	III	L-M – Wildlife Populations L-M – Flood Storage M – Nutrient/Sediment Trapping
B15a and b	Slope PSS	2.05	Hillside slope shrubby drainage which leads to a larger wetland complex outside of the borrow areas	III	M – Wildlife Populations L-M – Export of Organic Carbon and Nutrient/ Sediment Trapping.

[1] *Does not include Borrow Area 3 wetlands that may receive secondary impacts.*

PFO –Palustrine Forested
PSS – Palustrine Scrub Shrub
PEM – Palustrine Emergent

L – Low
M – Moderate
H – High

- Shading represents wetland effects larger than 1/3 acre from airport fill activities.

Table 4-2
Des Moines Creek HSPF Water Volume Comparison

Upper Gage 11C (upstream of Tyee pond)

Water Year	Observed Flow (inches)	Simulated Flow* (inches)	Difference (percent)
1994	13.32	12.3	-7.66
1995	21.03	22.84	8.61
1996	34.43	31.8	-7.64
Total	68.78	66.94	-2.68

Lower Gage 11D (near mouth)

Water Year	Observed Flow (inches)	Simulated Flow* (inches)	Difference (percent)
1994	9.2	7.96	-13.48
1995	14.8	16.21	9.53
1996	23.2	22.91	-1.25
Total	47.2	47.08	-0.25

**Simulated flow from DM-C calibration model*

AR 021997

Table 4-3
Des Moines Creek HSPF Model Area Summary

Total Area by Soil Type

Model Scenario	Model Name	Till (acre)	Outwash (acre)	Fill (acre)	Wetland (acre)	Impervious (acre)	Total Area (acre)	IWS (acre)	Basin Total (acre)
Calibration	DM-C	1104.8	870.6	408.3	55.4	1411.0	3850.1	315.3	4165.4
Predeveloped	DM-PRE	2078.8	1223.2	0.0	76.7	375.4	3754.0	0.0	3754.0
Land use 94	DM94	1088.3	870.4	542.0	52.4	1121.9	3675.0	292.0	3967.0
Land use 04	DM04	1001.8	850.9	326.1	50.4	1218.6	3447.9	424.0	3871.9

Percent Total Area by Soil Type

Model Scenario	Model Name	Till (percent)	Outwash (percent)	Fill (percent)	Wetland (percent)	Impervious (percent)
Calibration	DM-C	28.7%	22.6%	10.6%	1.4%	36.6%
Predeveloped	DM-PRE	55.4%	32.6%	0.0%	2.0%	10.0%
Land use 94	DM94	29.6%	23.7%	14.7%	1.4%	30.5%
Land use 04	DM04	29.1%	24.7%	9.5%	1.5%	35.3%

Table 4-4
Wetland Impacts Associated with the On-Site Borrow Areas[1]

Wetland	Classification	Total Wetland Size	Fill Effect	Temporary Effect	Vegetation Types Effected		
					PFO	PSS	PEM
Borrow Areas							
28	Depression/ Riparian	35.32	0.07		-	-	0.07
48	Slope	1.58	0.14	0.10	0.03/0.10	-	0.11
B11	Depression		0.18		-	-	0.18
B12	Slope		0.07		–	0.07	-
[redacted]							
B15a and b	Slope	2.05	0.21	0.10	-	0.21/0.10	-

[1] *Does not include Borrow Area 3 wetlands that may receive secondary impacts.*

a – all effect totals presented as acres

PFO- Palustrine Forested
PSS – Palustrine scrub shrub
PEM- Palustrine emergent

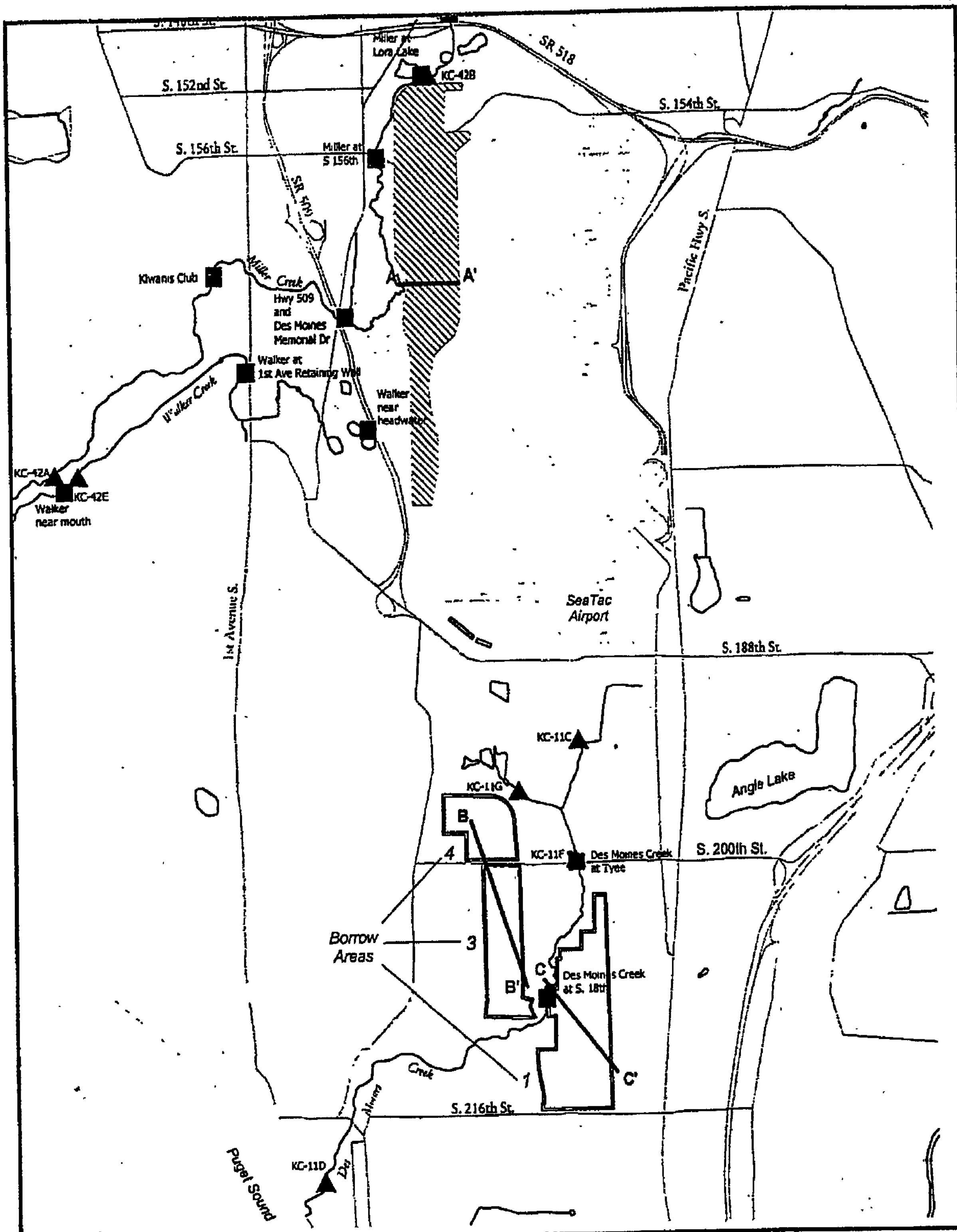
AR 021999

Table 4-5
Summary of Permanent and Temporary Impacts to Wetlands within Des Moines Creek Watershed from Proposed Third Runway

	Forested		Scrub-shrub		Emergent		Total	
	Perm.	Temp.	Perm.	Temp.	Perm.	Temp.	Perm.	Temp
Slope	0.03	0.10	0.28	0.10	0.11	0.00	0.42	0.20
Depression	0.00	0.00	0.55	0.00	0.41	0.00	0.96	0.00
Depression/Riparian	0.00	0.00	0.00	0.00	0.07	0.00	0.07	0.00
Total	0.03	0.10	0.83	0.1	0.59	0.00	[redacted]	

Perm. = permanent
Temp. = temporary

Figures



Legend

Borrow Areas

SeaTac International Airport Structures

Proposed Fill Area

Stream Gage Stations

▲ King County Station

■ Pacific Groundwater Group Station

500 0 500 1000 Feet

Figure 2-1

Vicinity PlanShowing Fill, Borrow Areas, and Stream Gage Stations

SeaTac Runway Fill
Hydrologic Studies
JE9907, ald_seatac_aesl.apr, 5/2000

Pacific Groundwater Group

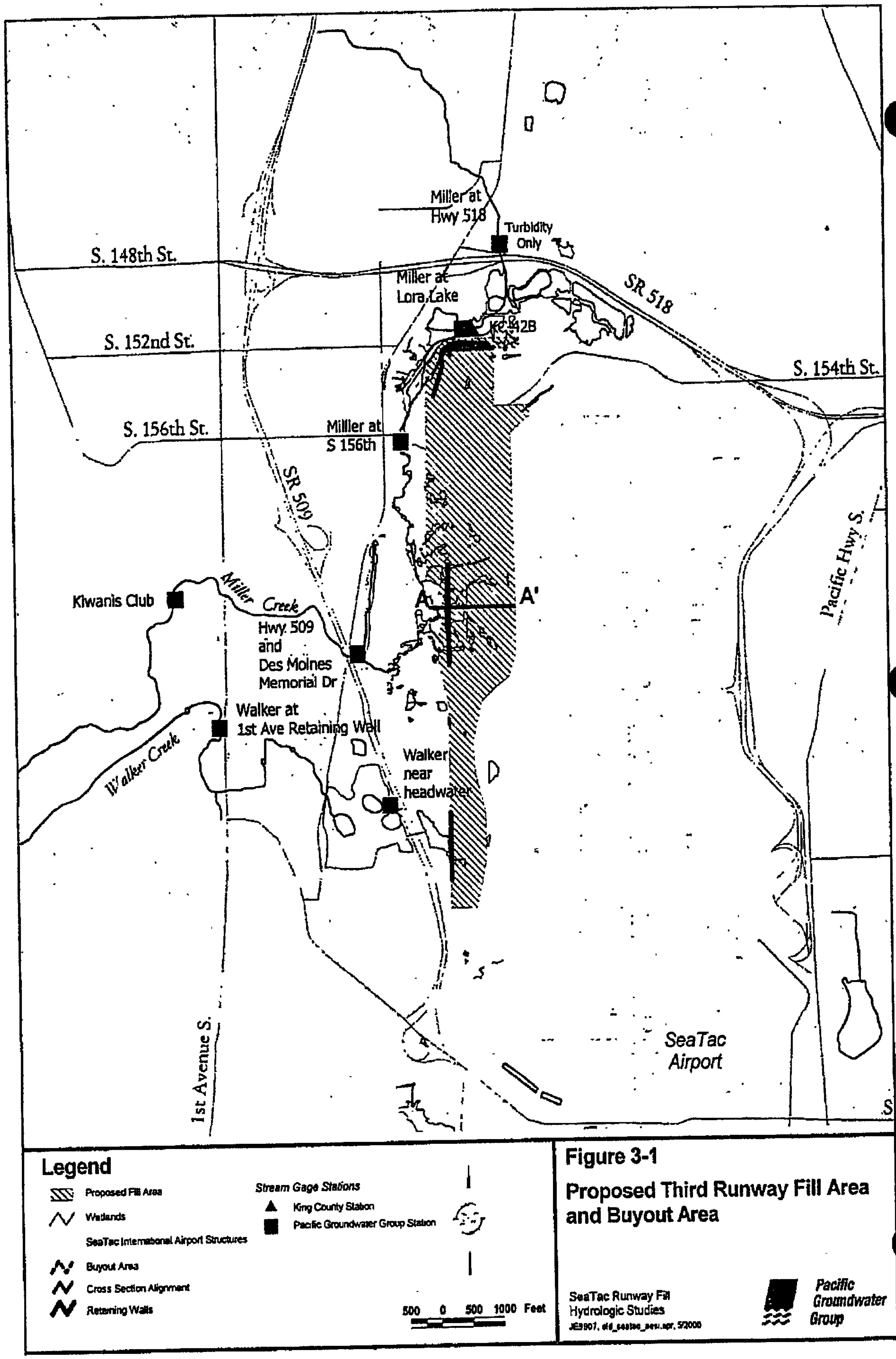
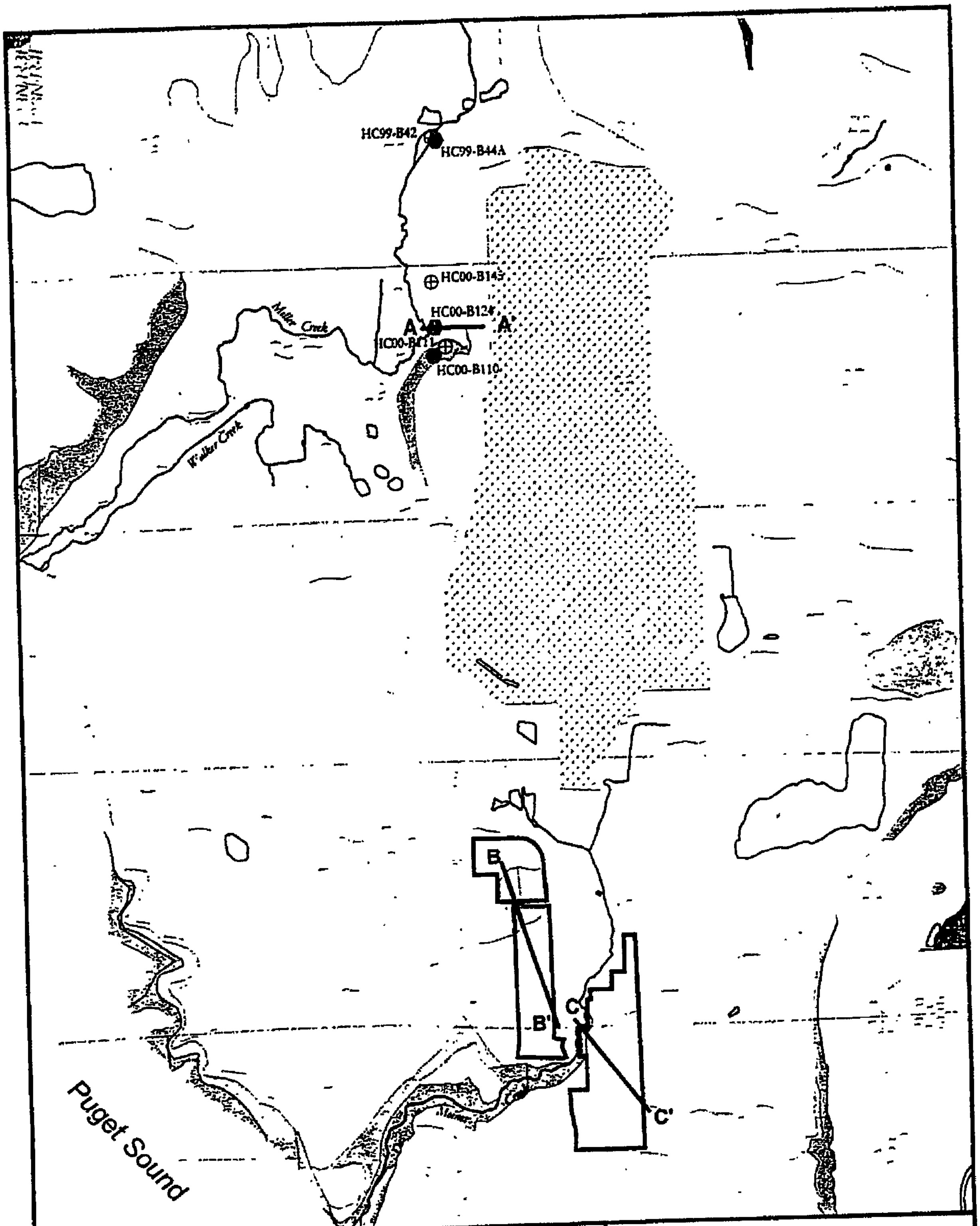


Figure 3-1

Proposed Third Runway Fill Area and Buyout Area



Boring (drilling observed by PGG)
Well (drilling observed by PGG)
Cross Section Alignment
Borrow Areas

Surficial Geology, pre-1998 (Booth & Waldron)

Modified Land & Fill (m)
Wetland Deposits (Qw)
Holocene (Qmw, Qls) and Younger Alluvium (Qyal)
Vashon Recessional Deposits (Qvr, Qvrl)
Vashon Ice-Contact Deposits (Qvi)
Vashon Till (Qvt)
Vashon Advance (Qva)
Pre-Fraser (Coarse-Grained) Deposits (Qpfc, Qpff, Qpfn)

N

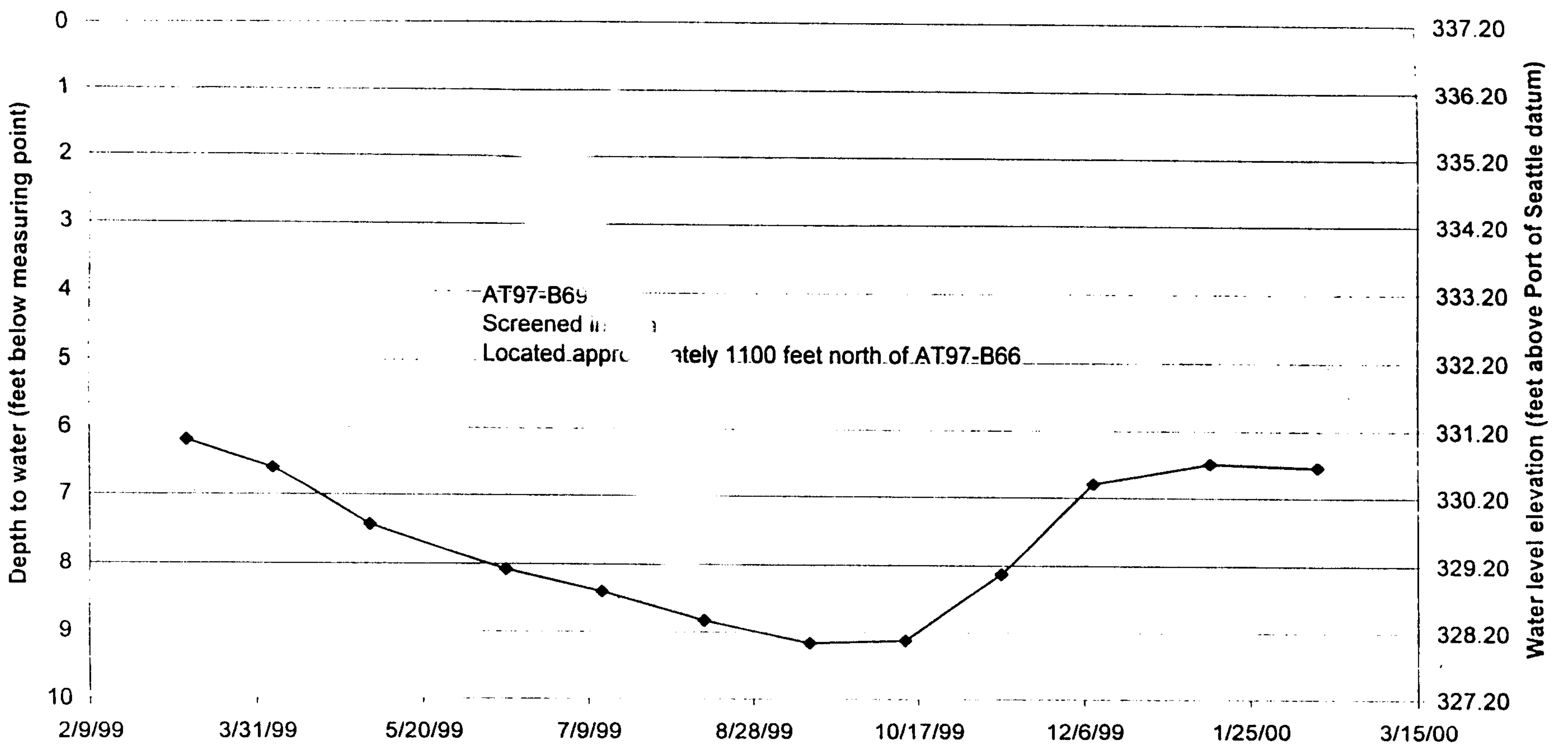
500 0 500 1000 Feet

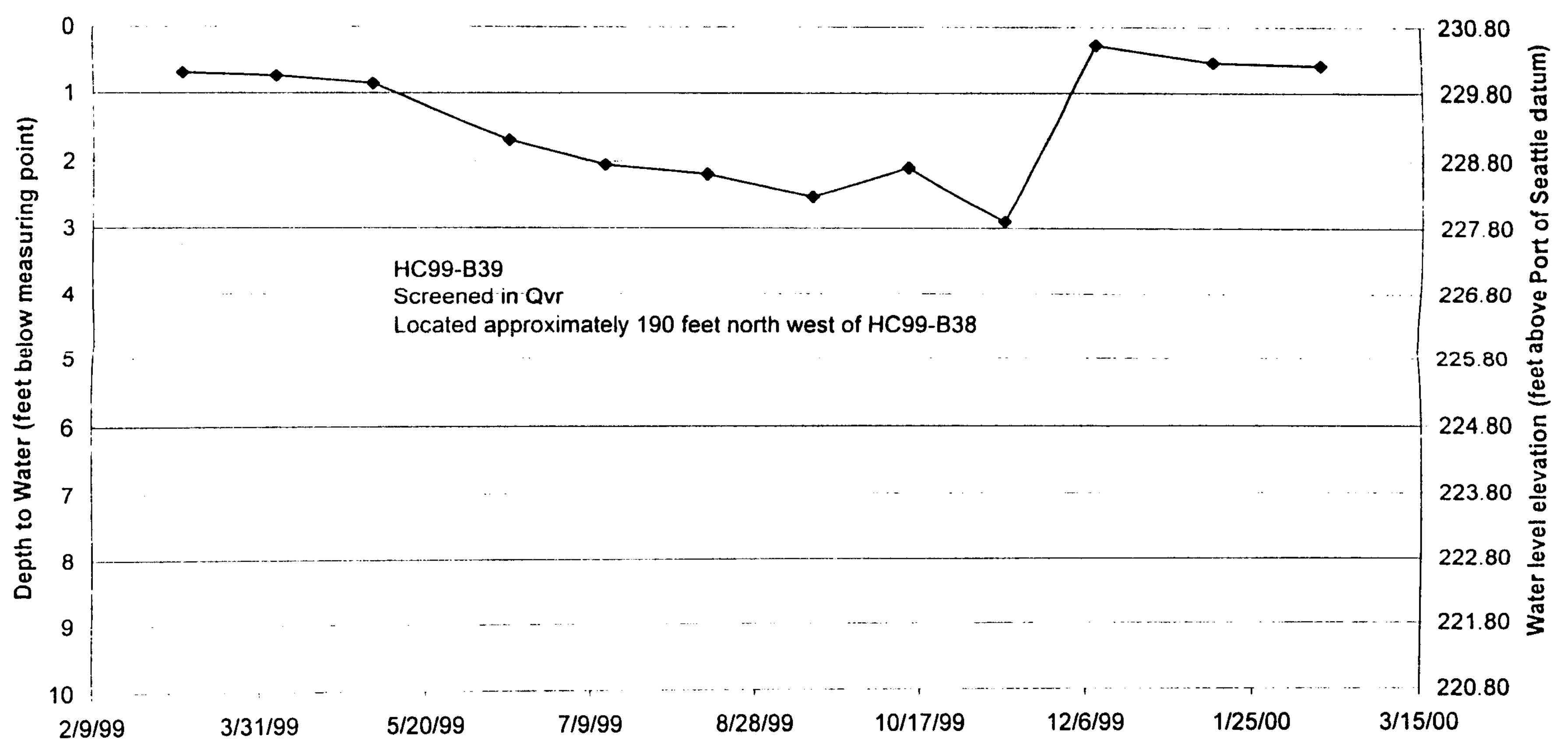
Figure 3-2
Surficial Geology, Borings, and Cross Section Alignments

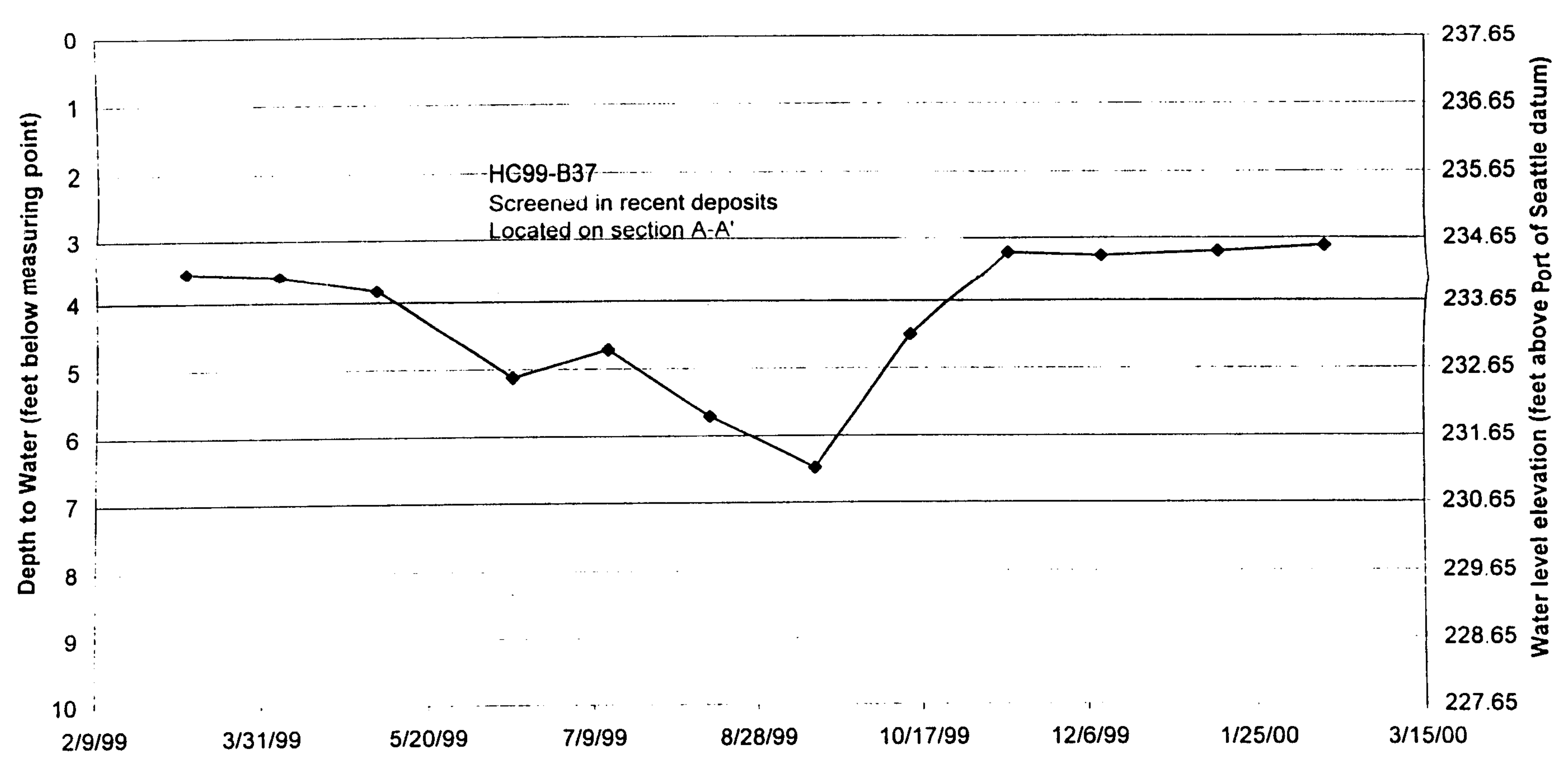
SeaTac Runway Fill
Hydrologic Studies
JE9907, old_seatac_aesi apr, 5/2000

Pacific Groundwater Group

Figure 3-3
Hydrographs







AR 022005

Figure 3-4
Recharge Model Results

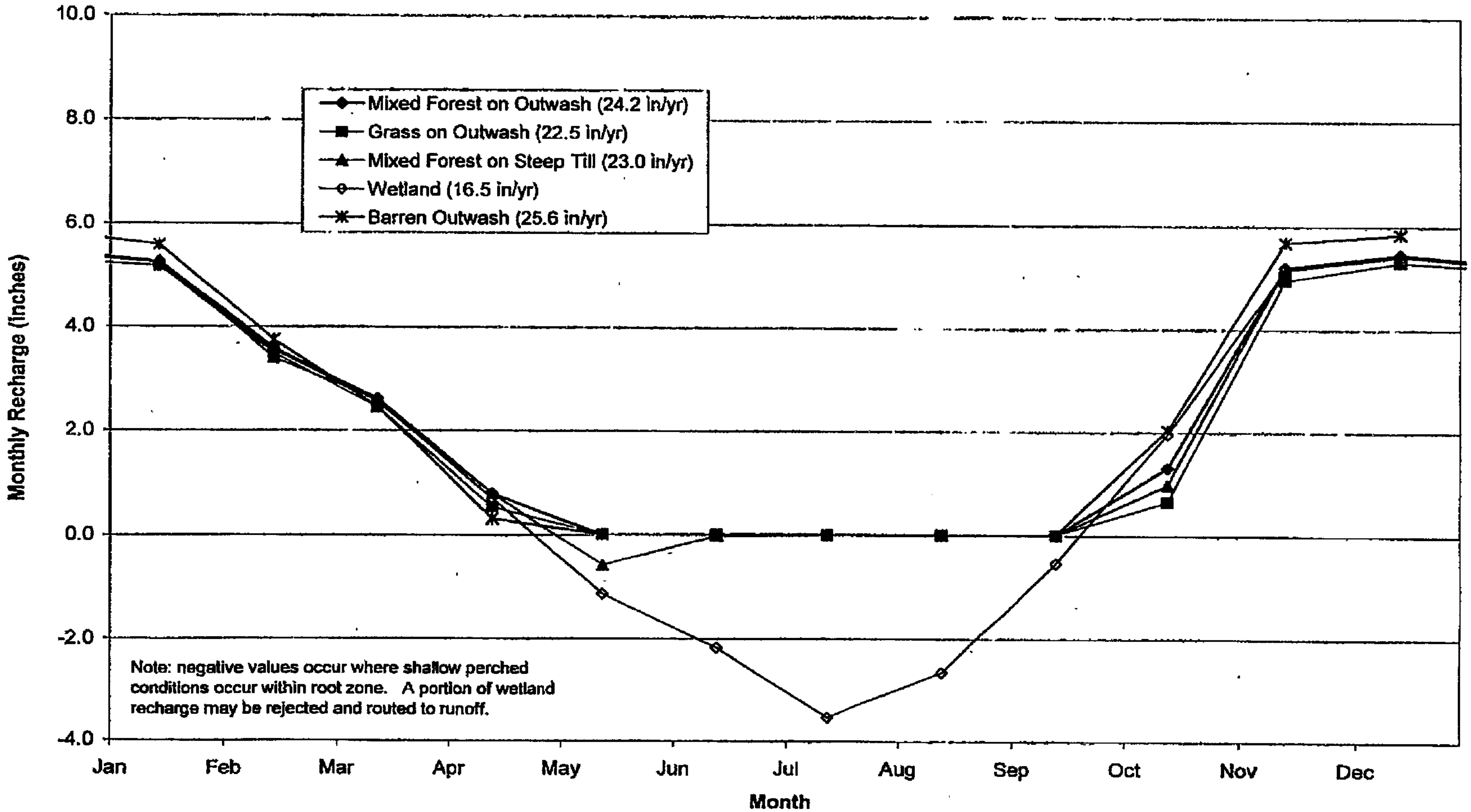
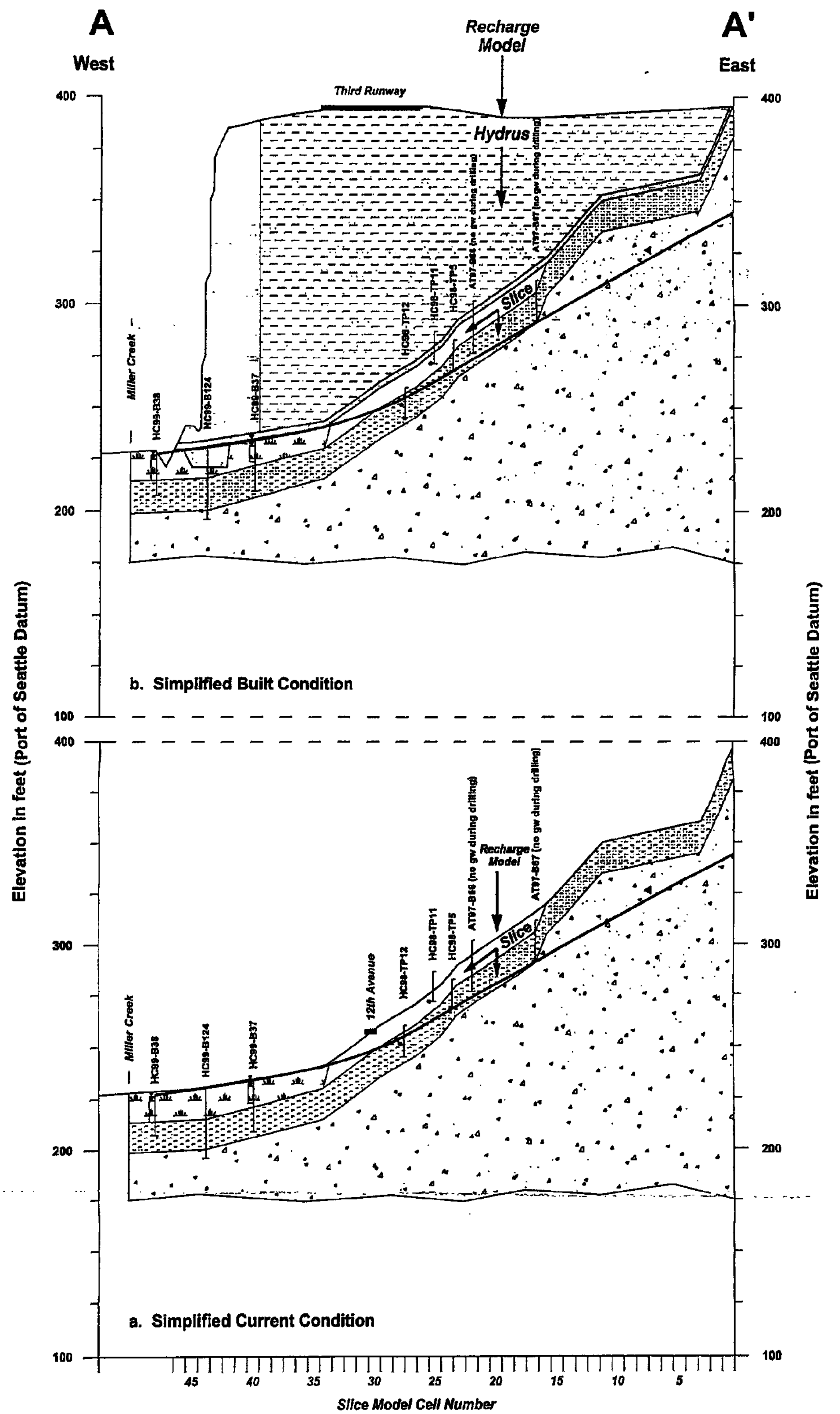


Fig3-4.xls
6/8/00

SeaTac Runway Fill
Hydrologic Studies



Legend

- Groundwater Elevation (high and low 2/99 - 2/2000)
- Groundwater Seepage Elevation
- Conceptual Water Table
- Type 1 Fill
- Type 1 & 2 Fill
- Recent Deposits
- Qvr - Vashon Recessional
- Qvt - Vashon Till
- Qva - Vashon Advance

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

Figure 3-5
Simplified West Wall Cross Section for Modeling

SeaTac Runway Fill Hydrologic Studies
JE 9907, RevisedSection.DWG, 6/2000

Pacific Groundwater Group

AR 022007

Figure 3-6
Results of Slice Model for the Current Condition

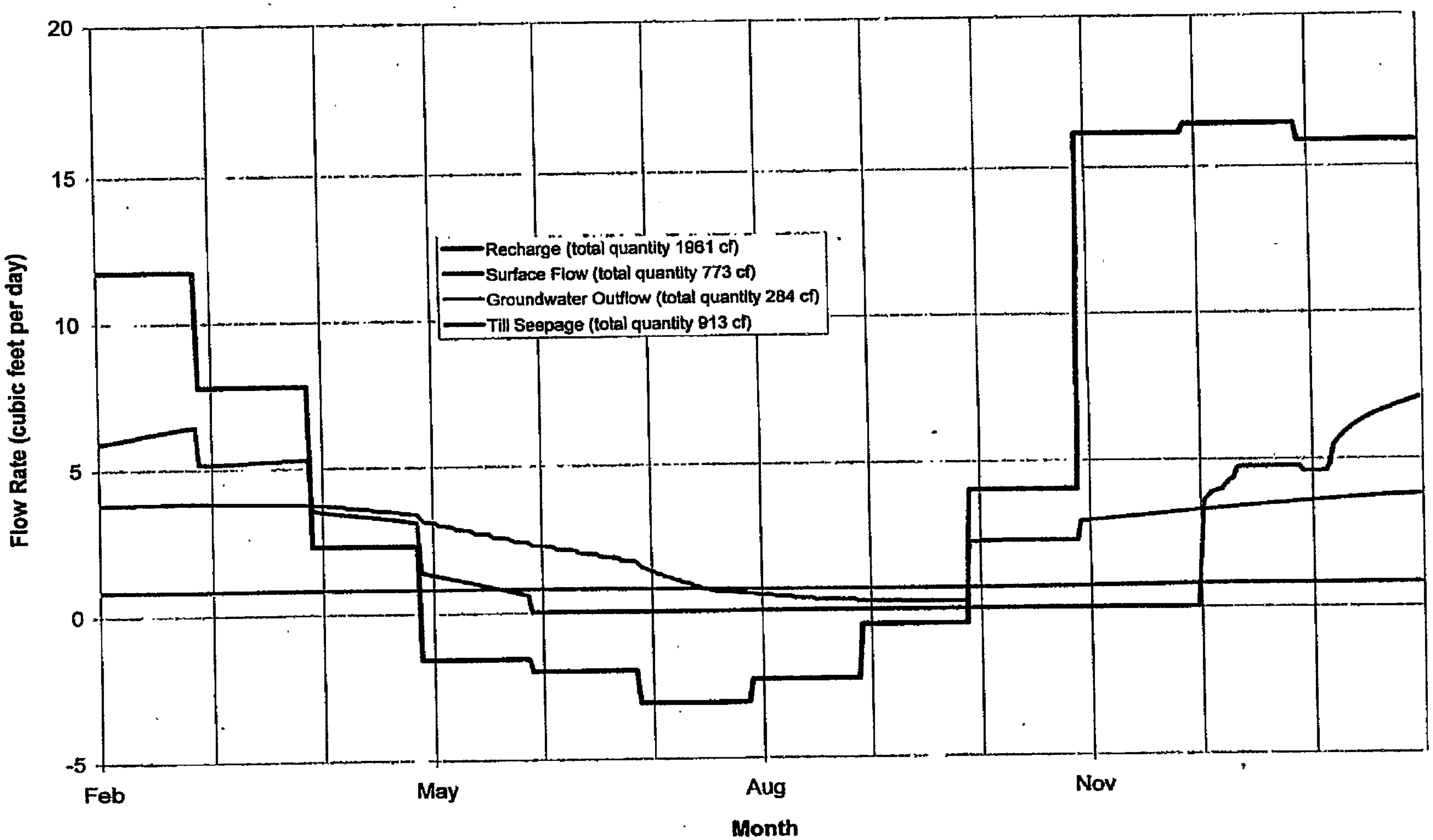
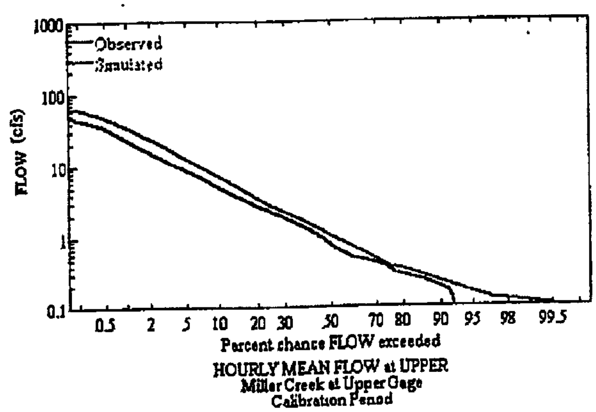


Figure 3-6.xls
6/12/00

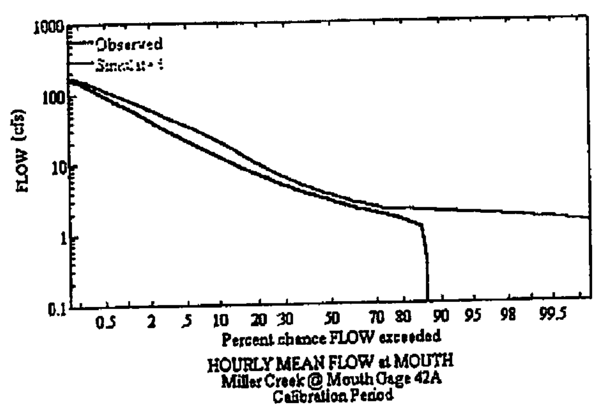
SeaTac Runway Fill
Hydrologic Studies

Figure 3-7
Flow Duration Curves for Miller/Walker Creek - King County Gages

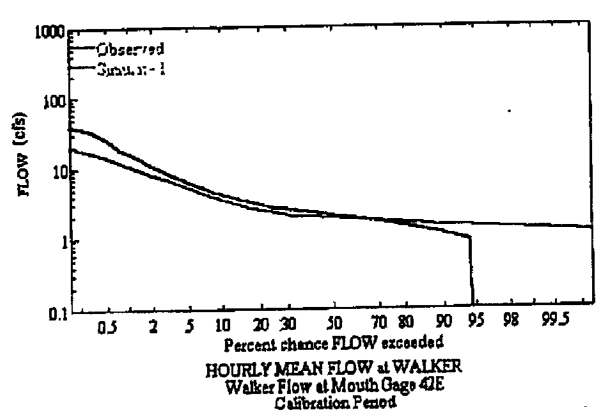
Miller Creek Gage 42B



Miller Creek Gage 42A

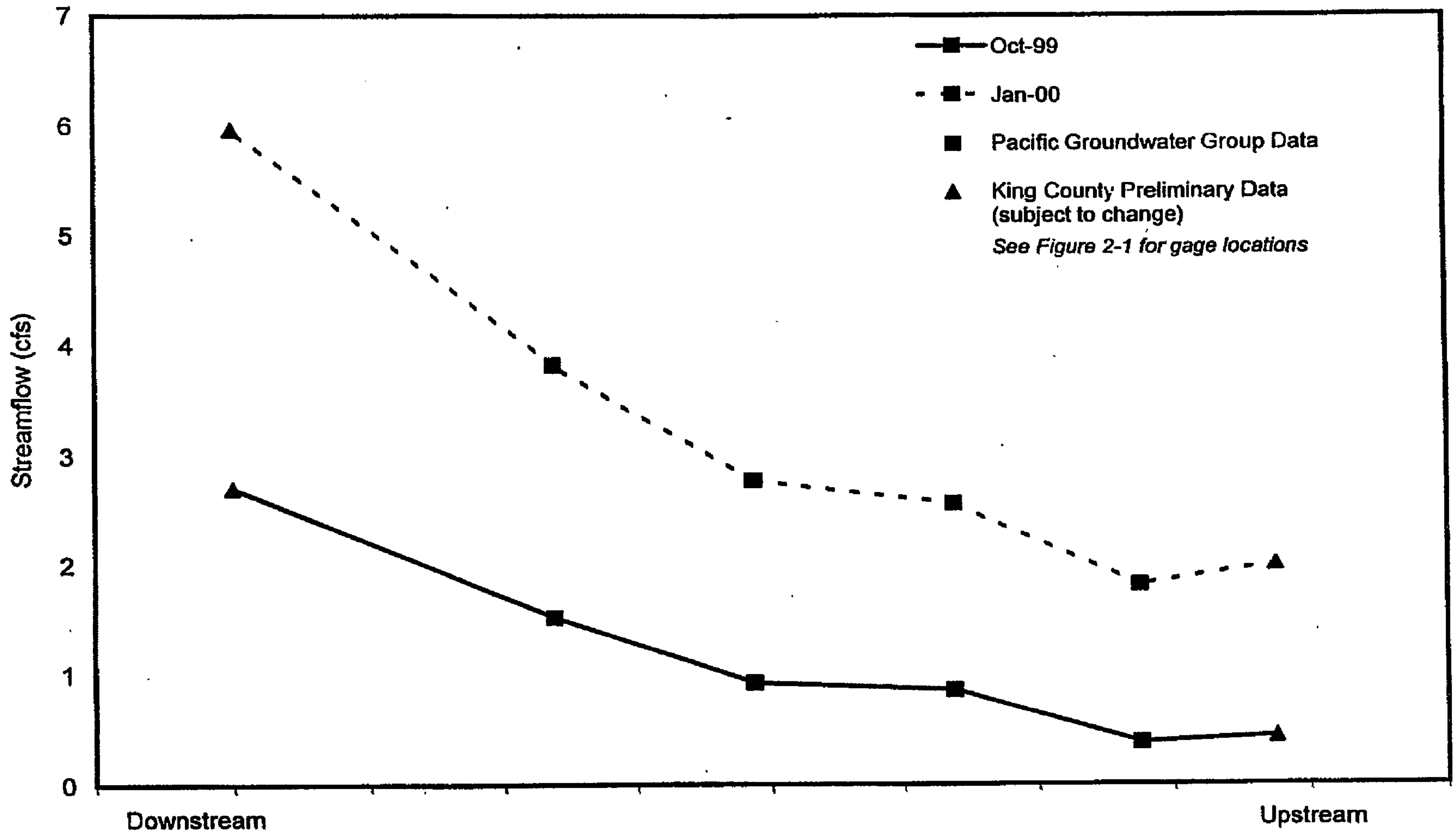


Walker Creek Gage 42E



Simulated values generated using "MILL-C" calibration model

Figure 3-8
Miller Creek Base Flow Gain Survey Results



Figures 4-5 and 3-8.xls
5/11/00

SeaTac Runway Fill
Hydrologic Studies

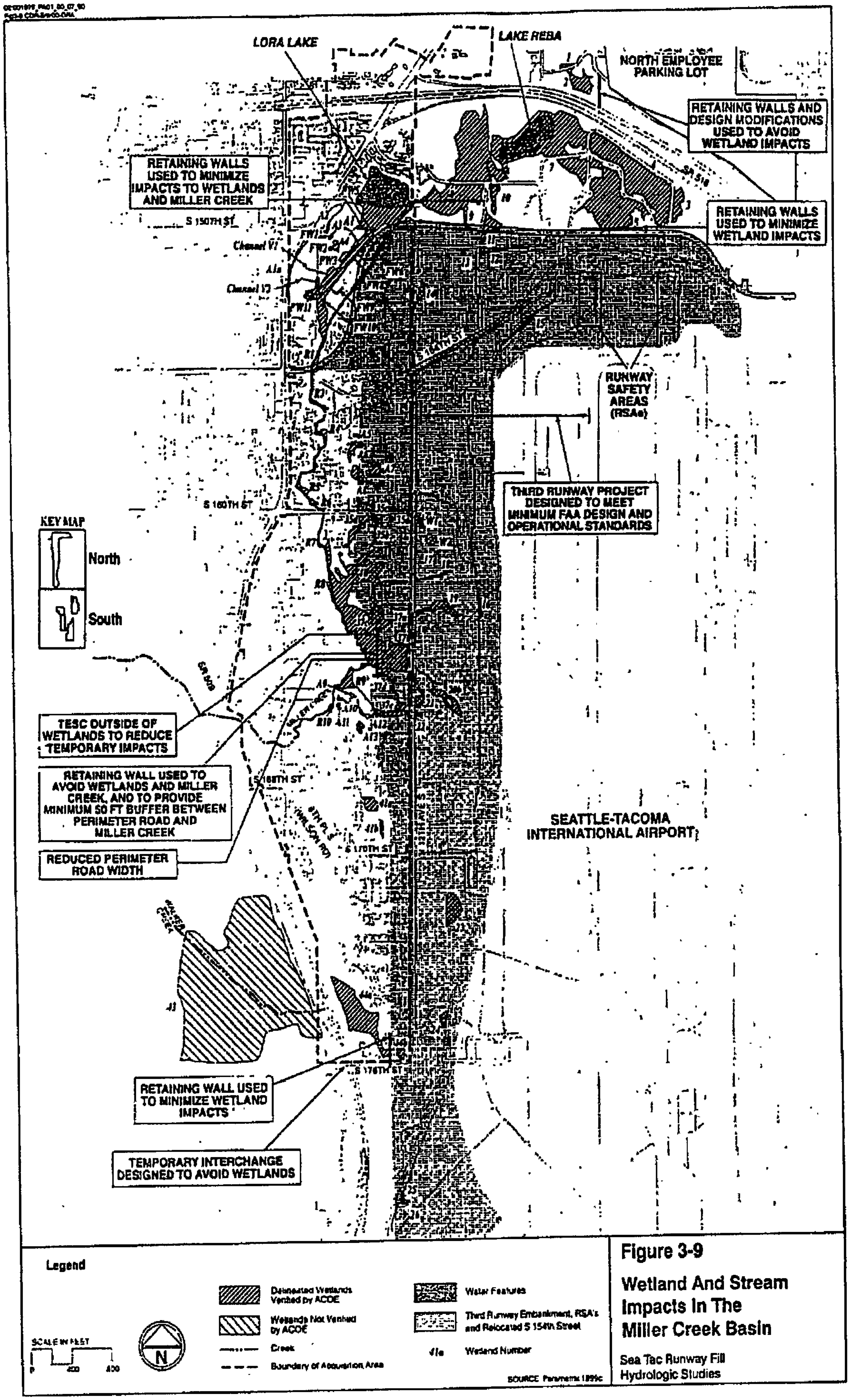
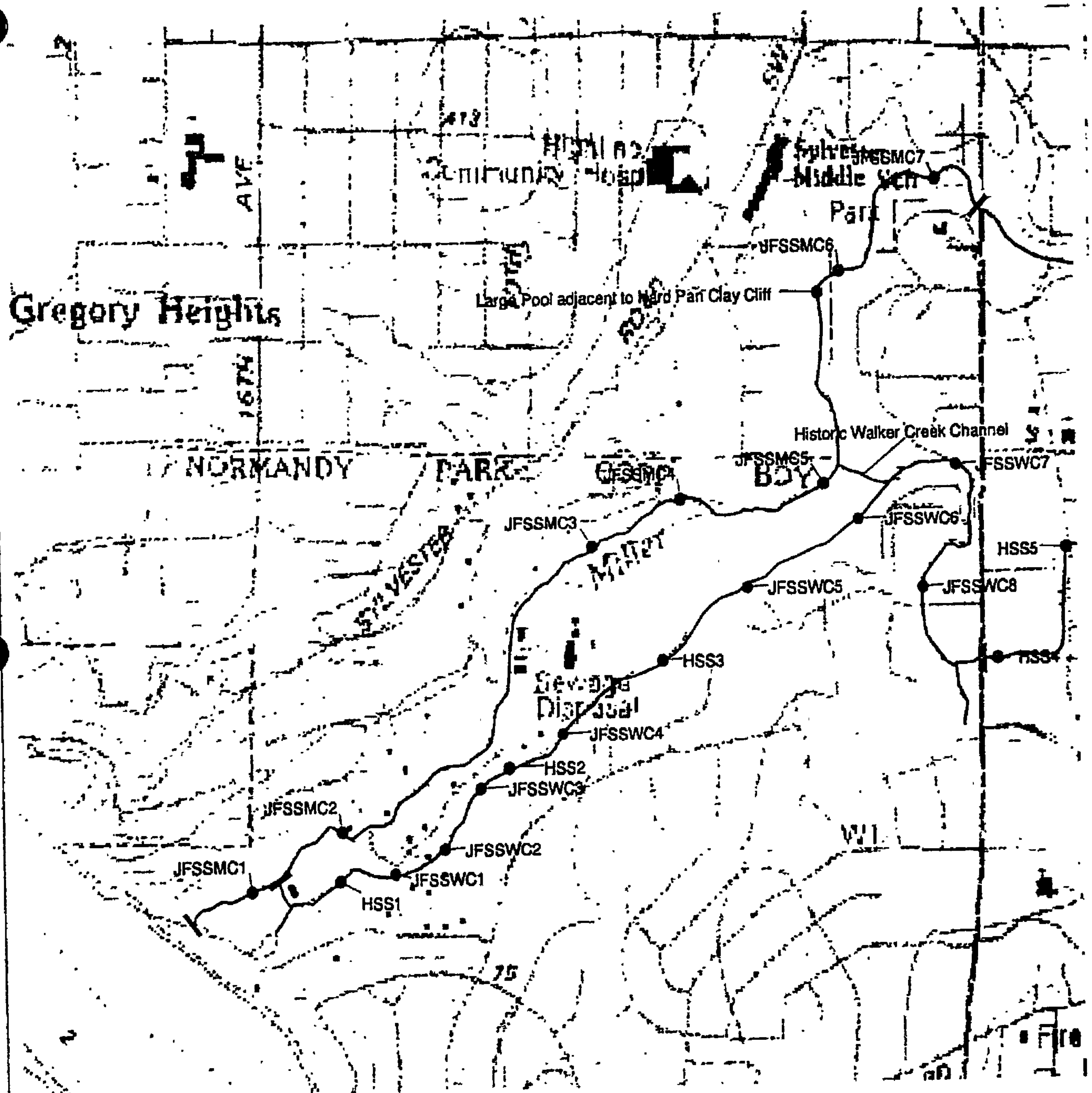


Figure 3-9

Wetland And Stream Impacts In The Miller Creek Basin

Sea Tac Runway Fill Hydrologic Studies



Legend

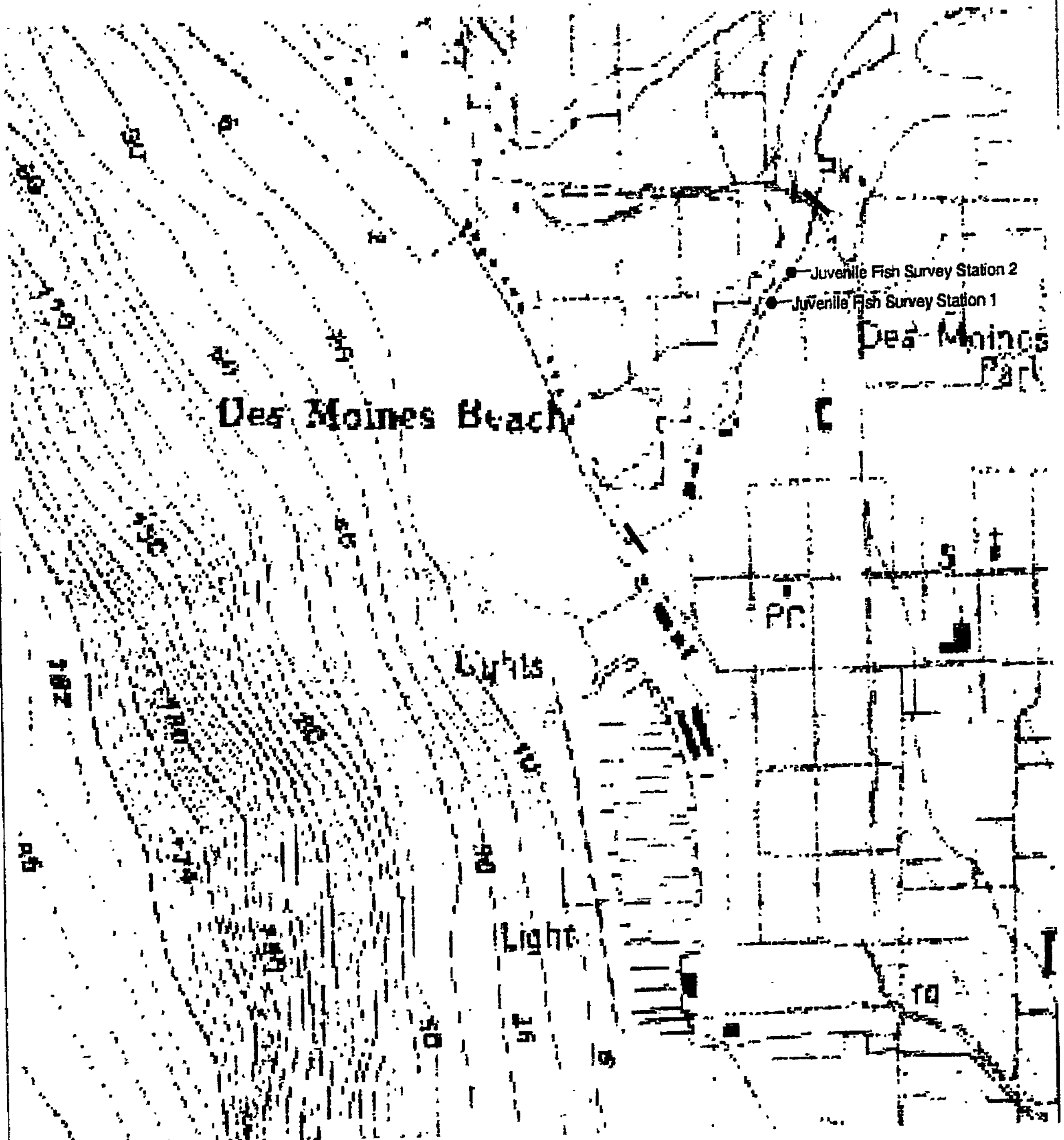
- HSS - Habitat Survey Station
- JFSSMC - Juvenile Fish Survey Station (Miller Creek)
- JFSSWC - Juvenile Fish Survey Station (Walker Creek)
- Carcass Survey Area Boundary

Feet

Figure 3-10

Walker and Miller Creek Biological Sampling Locations

SeaTac Runway Hydrologic Studies



Legend

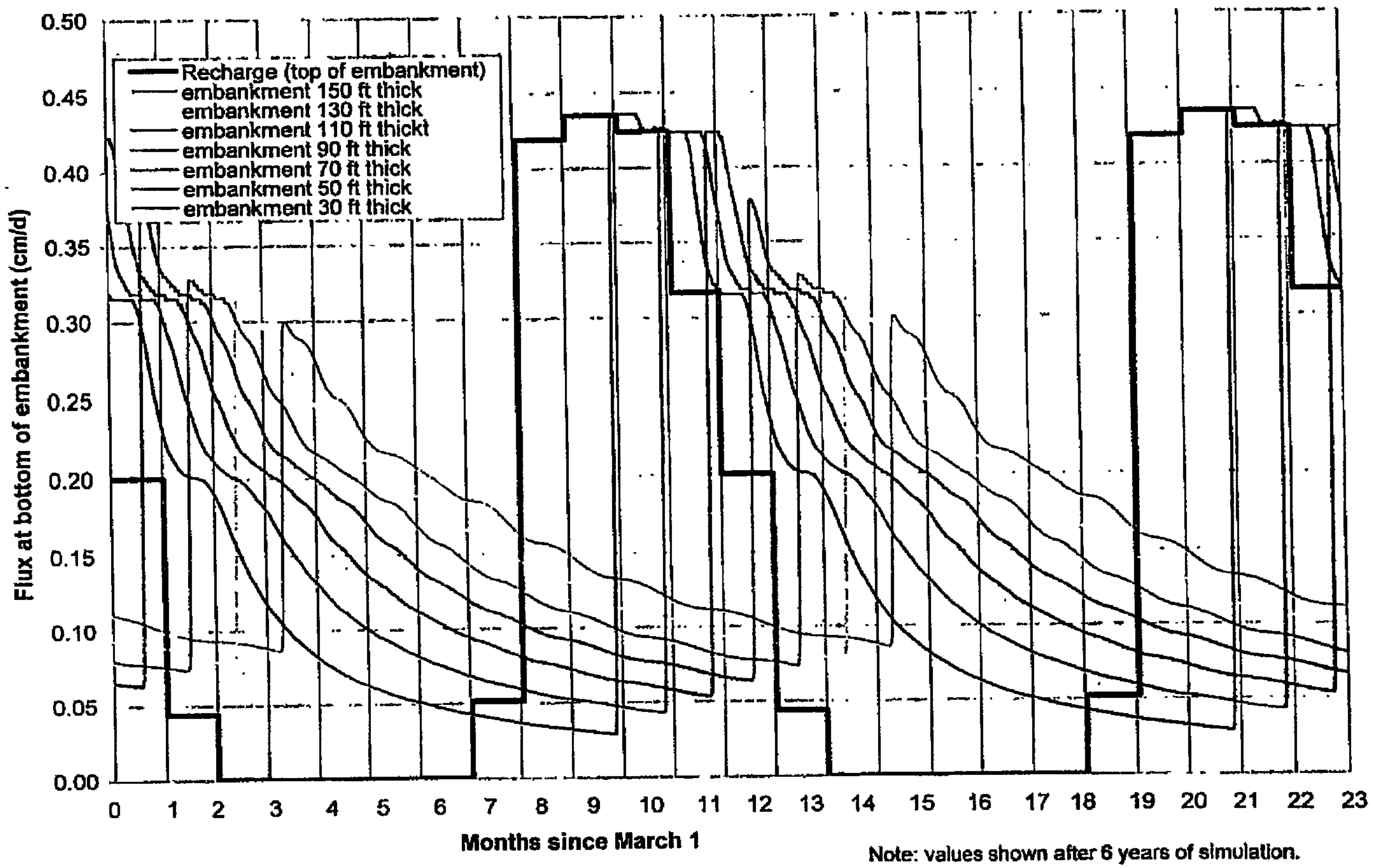
- ● Juvenile Fish Survey Station (Des Moines Creek)
- ▬ Carcass Survey Area Boundary

Figure 3-11

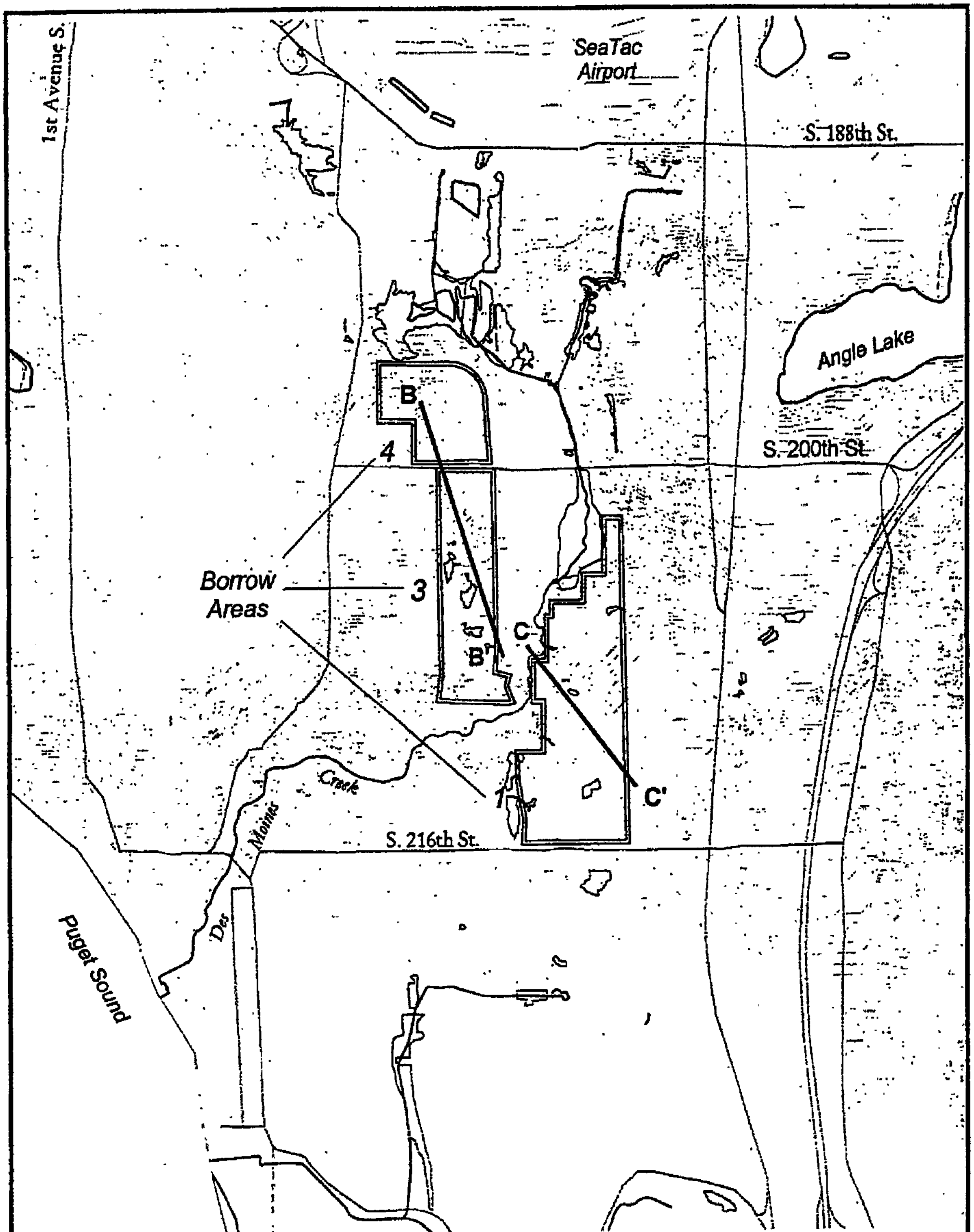
Des Moines Creek
Biological Sampling Locations

SeaTac Runway
Hydrologic Studies

Figure 3-12
Results of Hydrus-2D Modeling of Embankment Fill



Note: values shown after 6 years of simulation.



Legend

- Borrow Areas
- Wetlands
- Cross Section Alignment

Stream Gage Stations

- ▲ King County Station
- ■ Pacific Groundwater Group Station

500 0 500 1000 Feet

Figure 4-1

On-Site Borrow Area Vicinity Plan

SeaTac Runway Fill
Hydrologic Studies
JE9907, old_seatac_aesi apt, 8/2000

Pacific Groundwater Group

Figure 3-13
Results of the Slice Model for the Built Condition

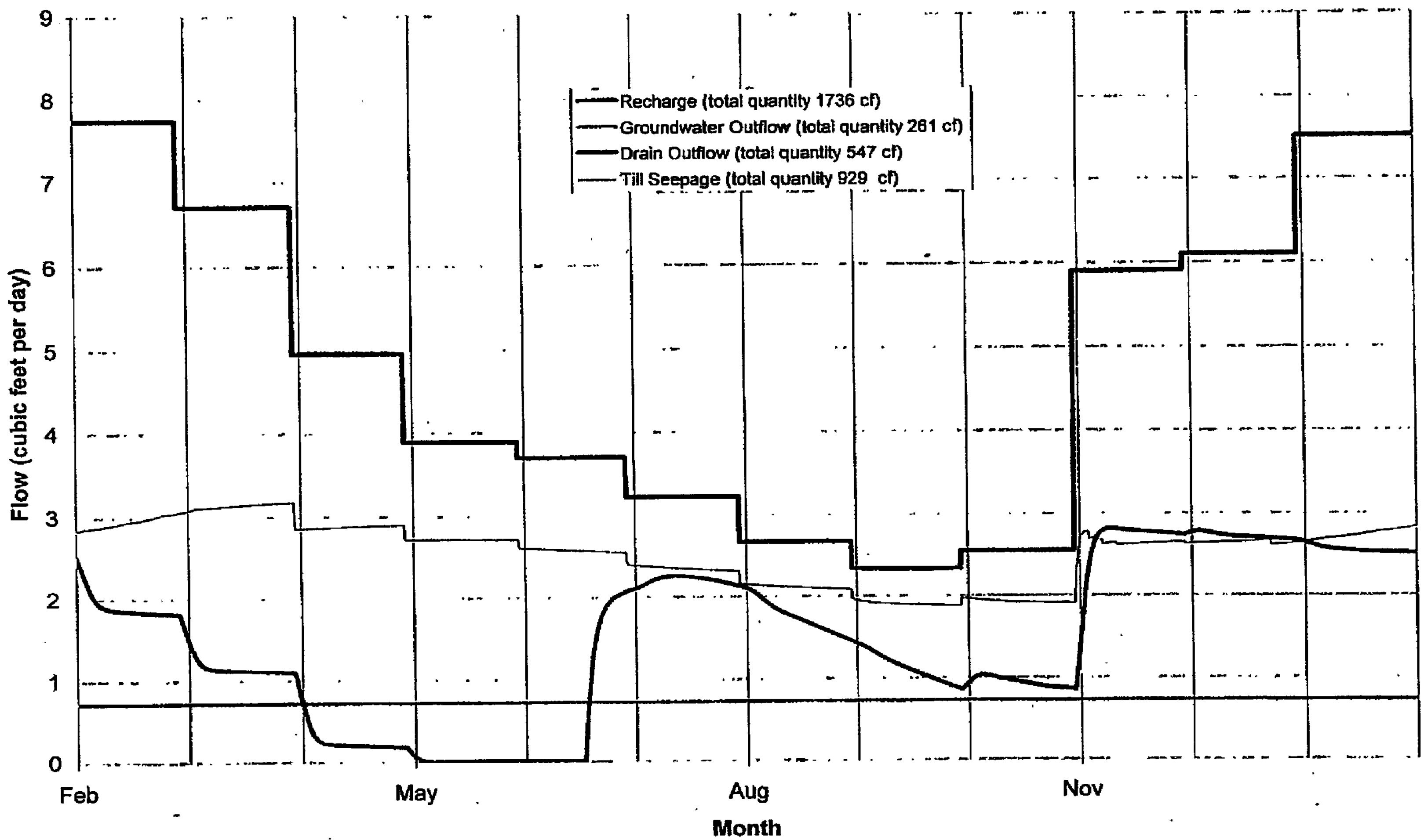
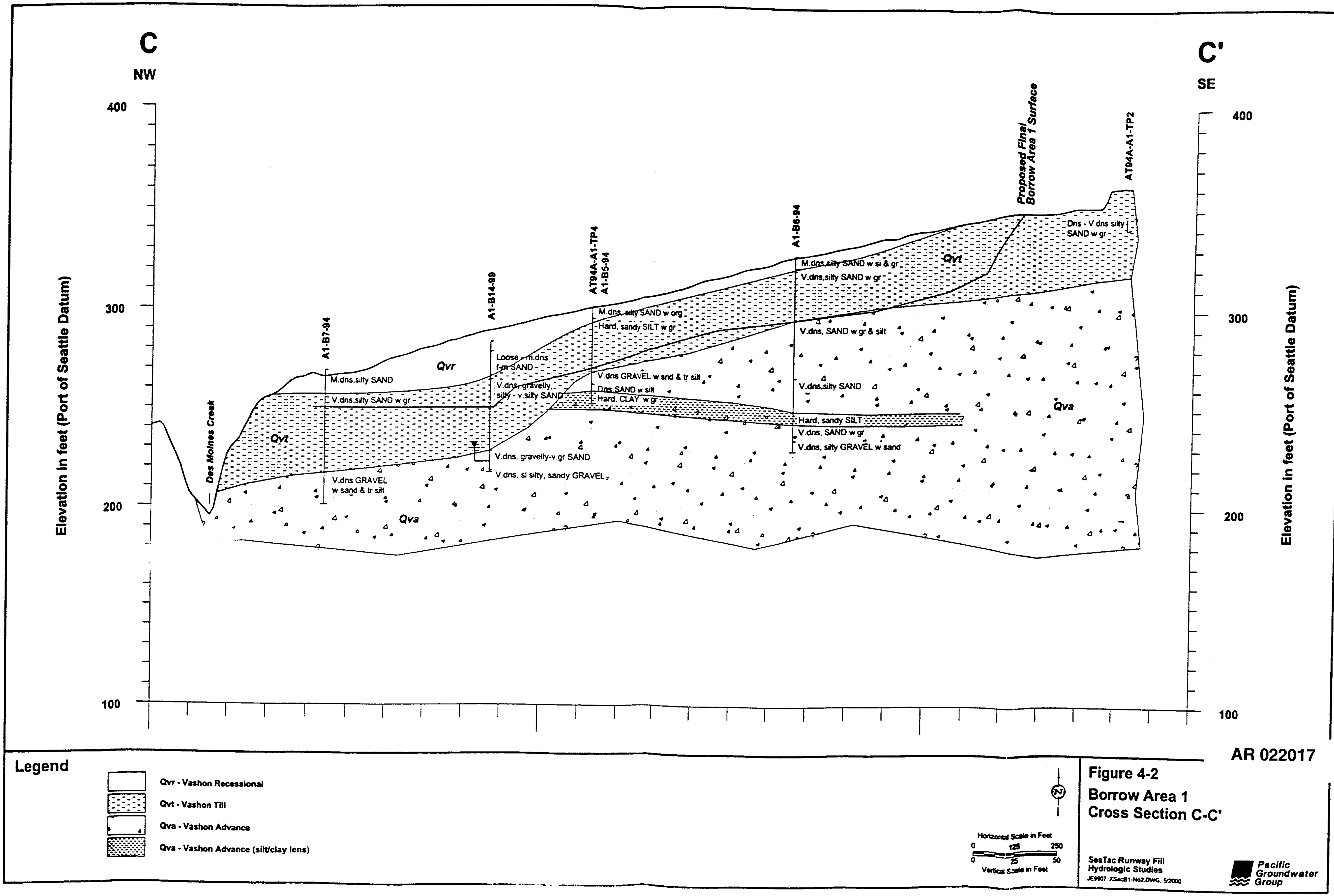


Figure 3-13.xls
6/12/00

SeaTac Runway Fill
Hydrologic Studies


C
NW
C'
SE
Elevation in feet (Port of Seattle Datum)
400
300
200
100
Des Moines Creek
A1-B7-94
A1-B14-99
AT94A-A1-TP4
A1-B5-94
A1-B6-94
Proposed Final Borrow Area 1 Surface
AT94A-A1-TP2
Qvr
Qvt
Qva
M.dns,silty SAND
V.dns,silty SAND w gr
V.dns GRAVEL w sand & tr silt
Loose - m.dns f-m SAND
V.dns, gravelly, silty - v.silty SAND
V.dns, gravelly-v.gr SAND
V.dns, sl silty, sandy GRAVEL
M.dns, silty SAND w org
Hard, sandy SILT w gr
V.dns GRAVEL w snd & tr silt
Dns SAND w silt
Hard, CLAY w gr
M.dns,silty SAND w si & gr
V.dns,silty SAND w gr
V.dns, SAND w gr & silt
V.dns,silty SAND
Hard, sandy SILT
V.dns, SAND w gr
V.dns, silty GRAVEL w sand
Dns - V.dns silty SAND w gr
Legend
Qvr - Vashon Recessional
Qvt - Vashon Till
Qva - Vashon Advance
Qva - Vashon Advance (silt/clay lens)
Horizontal Scale in Feet
0 125 250
0 25 50
Vertical Scale in Feet
N
Figure 4-2
Borrow Area 1
Cross Section C-C'
SeaTac Runway Fill
Hydrologic Studies
JE9907, XSecB1-No2.DWG, 5/2000
Pacific Groundwater Group

AR 022017

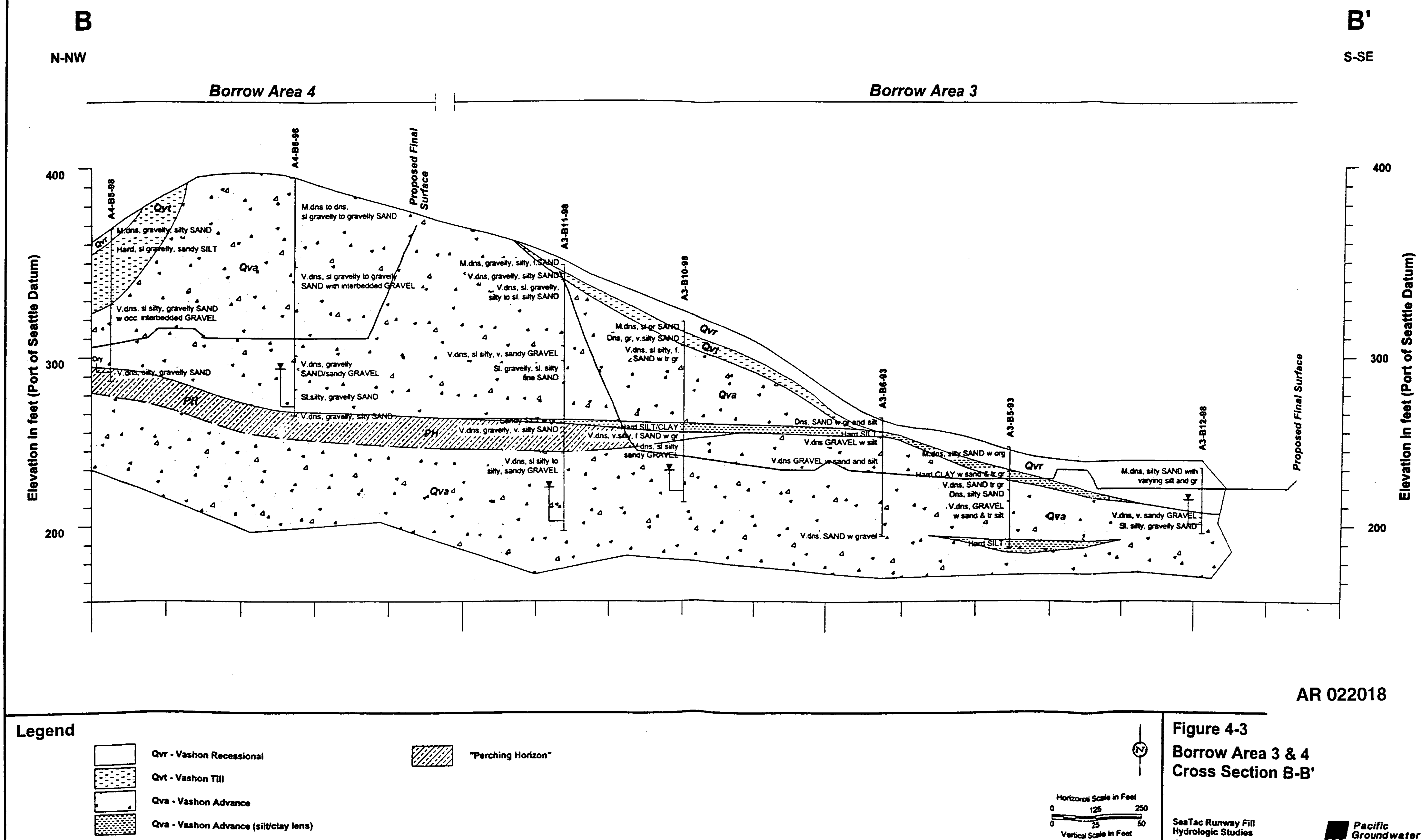


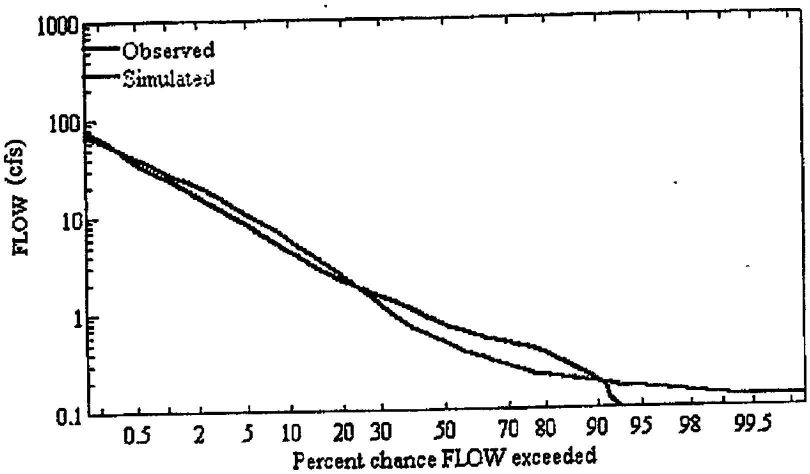
Figure 4-3
Borrow Area 3 & 4
Cross Section B-B'

SeaTac Runway Fill
Hydrologic Studies
JE9907, BA34SEC.DWG, 5/2000

Pacific Groundwater Group

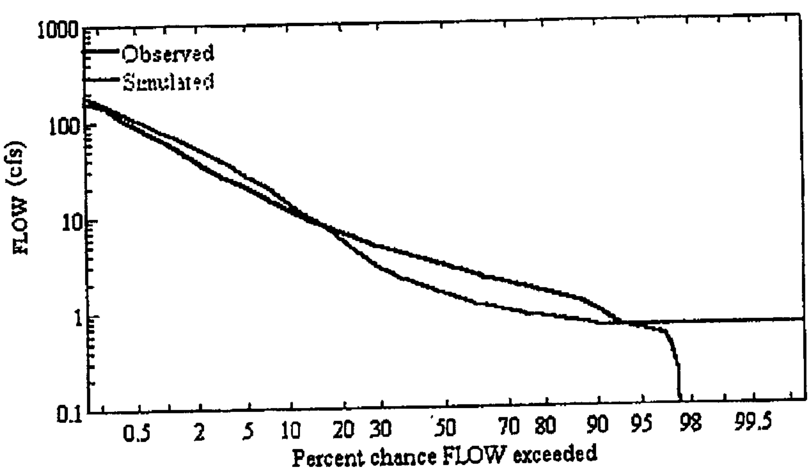
Figure 4-4
Flow Duration Curves for Des Moines Creek - King County Gages

Des Moines Creek Gage 11C



HOURLY MEAN FLOW at UPPER
Des Moines Creek at Upper Gage
Calibration Period

Des Moines Creek Gage 11D



HOURLY MEAN FLOW at MOUTH
Des Moines Creek at Mouth
Calibration Period

Simulated values generated using "MILL-C" calibration model

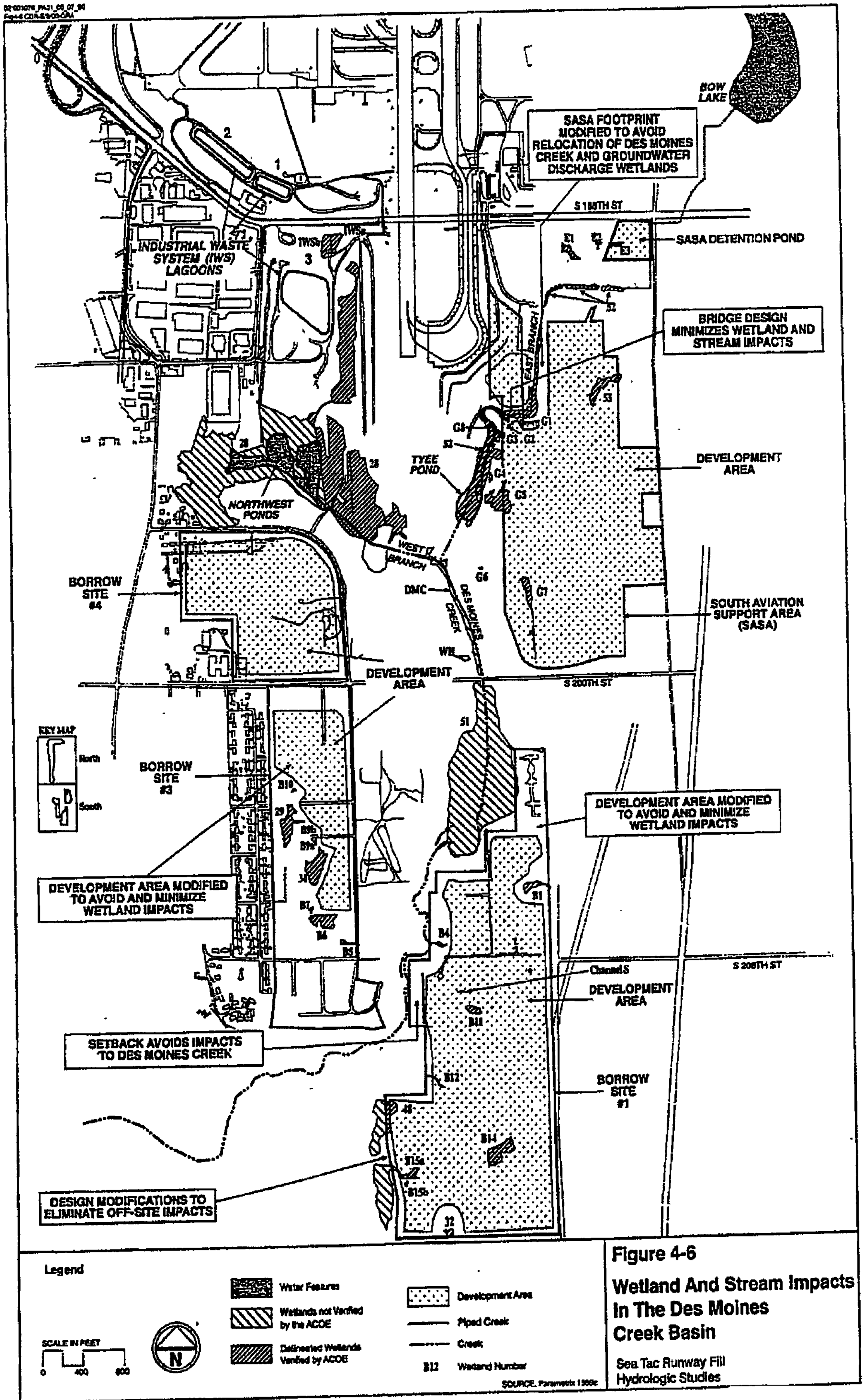
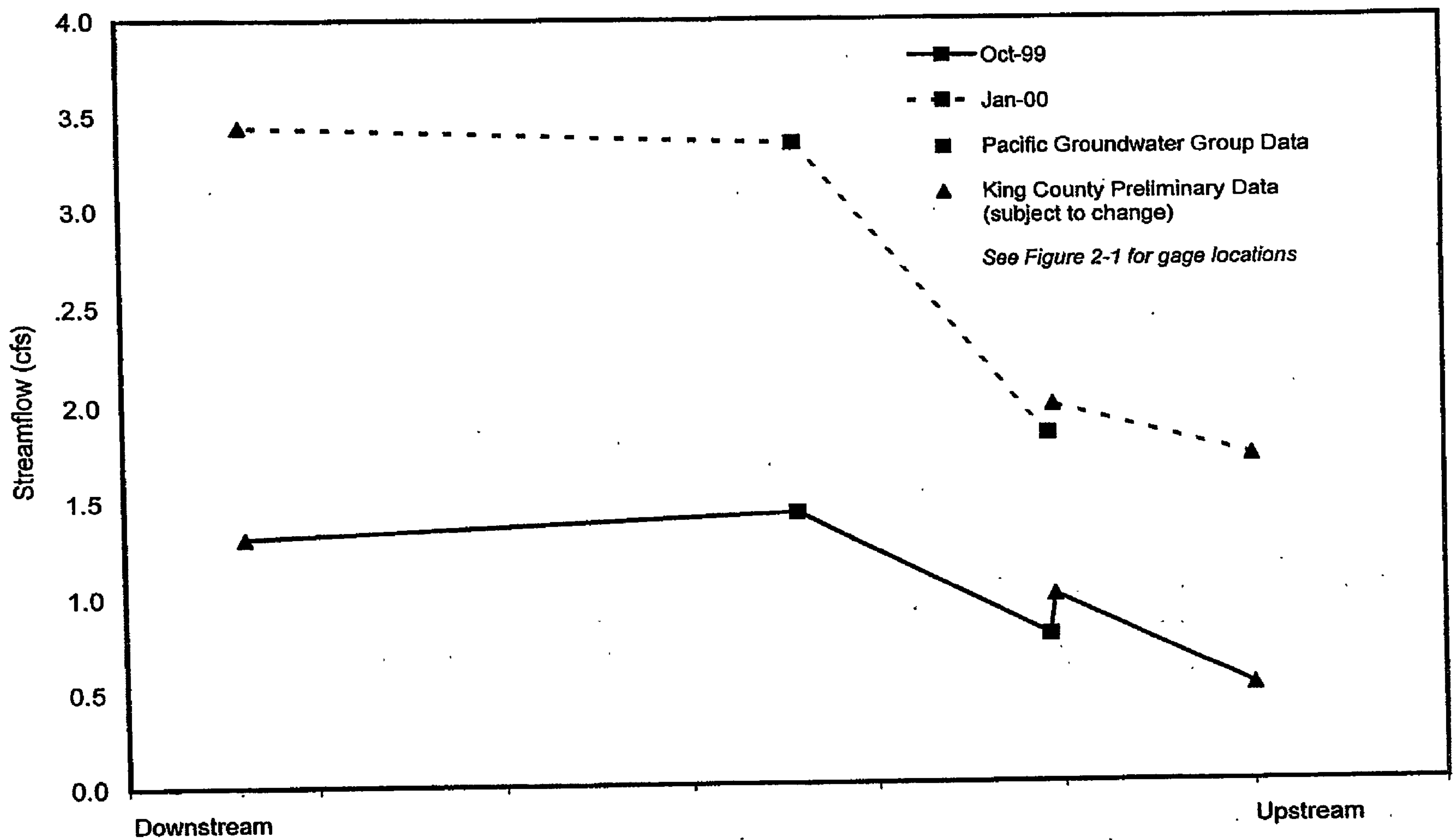


Figure 4-6
Wetland And Stream Impacts In The Des Moines Creek Basin

Sea Tac Runway Fill Hydrologic Studies

Figure 4-5
Des Moines Creek Base Flow Gain Survey Results



Figures 4-5 and 3-8.xls
5/11/00

APPENDIX A

MEMORADUM

TO: File
FROM: Russ Prior
DATE: February 17, 2000

This memorandum describes a field trip completed by Russ Prior of Pacific Groundwater Group on February 10, 2000. The purpose of the trip was to obtain preliminary information regarding privately owned, wells in the buyout area for the proposed expansion of SeaTac Airport.

William Kleindl of Parametrix, Inc. was hired by the Port to accompany Mr. Prior during this field trip. Mr. Kleindl knew the buyout area well and provided thoughtful insight. Such insight included personal knowledge of the previous existence of older houses, which had already been demolished. He had previously observed some wells in the areas we traversed.

The two men covered approximately half of the area using a full day in the field. No attempt was made to look at every house in the areas traversed. In general, they focused on lots that had older (pre-1950) vintage houses. Although, it is known that some wells occur in the basement of some houses in the area, no attempt was made to search the basements of all houses visited. The attached maps indicate the general areas that were traversed.

Wells and Other Subsurface Features

The following list describes the wells that were found by Mr. Prior and Mr. Kleindl on February 10, 2000. The wells were located based on a map provided by Port consultants that documents all parcels in the buyout area. The following list is organized based on those parcel numbers. Please refer to the attached figures.

<u>Parcel 088</u>
This parcel, north of South 156th Way, is in an area which has already had all the houses demolished. The streets still exist but extensive grading and reseeding has been completed. We were led to this area because Port personnel indicated the existence of a water well to Bill via cell-phone. We found several outbuildings in parcel 088 but could not find any evidence of a water well.

<u>Parcel 153</u>
This parcel immediately south of South 156th Way still has a house on it. A dug well exists along the eastern boundary line of the parcel. The well is rectangular and is made of concrete casing. The water level in the well is approximately 2 feet below ground surface.

<u>Parcel 158</u>
Immediately east of Parcel 153, this parcel had a dug well in the front yard. It is a concrete case well approximately 36-inches in diameter with a loose steel lid over the

opening. The depth to the water is approximately 9 feet below ground. This well has been modified at the ground surface to look like a classic well with red brick walls and a small peaked roof set on two wood posts.

Parcel 162
A demolition contractor was working at this house at the time of our visit. He was asked if he knew of any wells in the area and he pointed to the house that he was currently demolishing. This house has a drilled well with 6-inch steel casing. It is still plumbed with a jet pump and connected to a nearby pressure tank. The well is located in the southeast corner of the basement of the house.

Mr. Prior had a conversation with Michael Lowe, a General Superintendent with Westward International, Inc. He was involved in demolishing the house on Parcel 162 at the time of Mr. Prior's field visit. Mr. Prior answered questions regarding the cost and procedures for decommissioning a drilled water well. Mr. Prior indicated that a licensed well driller was needed to decommission the well legally. Mr. Prior indicated that the well should be left as is and that demolition of the southeast corner of the house basement should stop.

Parcel 164
A round depression was observed near a yard faucet in the middle of the back yard of this house. This may be the remnant of a caved-in dug well although, no direct evidence was found. Using a shovel and probing through the loose soil in the center of the depression, no obvious wood cribbing was observed nor were obvious concrete structures around the perimeter.

Parcel 171
Again no direct evidence of a water well was observed and no inquiries were made. However, the yard had evidence of an extensive garden and a domestic well is suspected.

Parcel 174
This parcel has an abandoned house on it. Port personnel indicated to Bill (via cell-phone) the existence of a well near the back door. However, we did not observe it on this day. There is a lot of plywood, old appliances, and other junk in the yard and a well could easily have been missed.

Parcel 175
At the western edge of this parcel a rectangular concrete structure with a wood lid was found. It looks like a dug well from the outside. However, the inside is filled with soil (sandy loam) to about 2 feet below grade. No water was observed and no steel casing was observed. Based on the outside construction and the wood lid, it is believed that it is a water well.

Parcel 176
This parcel was apparently an old farmhouse as indicated by Mr. Kleindl. No direct evidence of a well was found, however, a pressure tank and other plumbing components typical of domestic well installations were observed in a corner of the basement. This

corner was visible from outside through an opened door. Nobody was home at the time of our visit so no direct questions could be asked. It is believed that a water well of some kind exists on this parcel.

Parcel 187
A hole was observed in the grassy back yard of this parcel. The hole had concrete sidewalls and the remnants of wood cribbing on top. It is believed that this is a caved-in dug well.

Parcel 215
A dug well exists in the northeast corner of the house on this parcel. The well is accessible through a 3-foot high door that opens from the outside. The water level is approximately 2 feet below the floor of the basement. The plumbing infrastructure is in place and consists of 3-inch down-hole pipe with two (100-gallon?) pressure tanks.

Parcel 280
A rectangular dug well with concrete walls was observed in the patio area in back of the house in this parcel. The water level was approximately 2 feet below grade.

Parcel 311
A 6-inch diameter drilled well was observed adjacent to a concrete walk just in front of the garage on this parcel. The water level was measured at 55 feet below grade. The remnants of a jet pump were observed on top of the well, otherwise the well head is unprotected at the surface. The stickup of the well is approximately 2 inches. The depth of the well was not measured.

Parcel 312
A 3-foot by 3-foot, freestanding, wood-framed structure exists on this parcel near and slightly higher than Miller Creek. It is not known if this is a pump house for a surface water diversion or a well house. The house was locked and no observations inside could be made.

Parcel 316
This parcel is part of a plant nursery and two wells (both along the southern boundary) were observed on it. The first is located near the eastern end of the property. It is apparently hand dug and is finished with 20-inch (?) concrete casing that sticks up approximately 2 feet. The pressure tank and pumping hardware is still plumbed in and immediately adjacent to the well. The water level in the well is approximately 6 feet blow the top of the casing.

The second well is located on the western portion of the parcel in the flat area close in elevation to Miller Creek. It is a dug well and finished with 36-inch (?) concrete casing that sticks up approximately 1 foot. The water level is about 3 feet below the top of the casing.

Parcel 321

A dug well finished with 36-inch (?) concrete casing is located at the toe of the hillside immediately behind the house on this parcel. The well has a rotten wood lid, which has been damaged. The water level is approximately 2 feet below grade.

Recommendations

We recommend that the Port of Seattle complete a detailed house-to-house search for undocumented wells. An individual with knowledge of water wells should accomplish this work because the type of well construction, depth, and pumping infrastructure are all germane to decommissioning procedures and estimating costs.

The wells should be decommissioned in accordance with WAC 176-160.

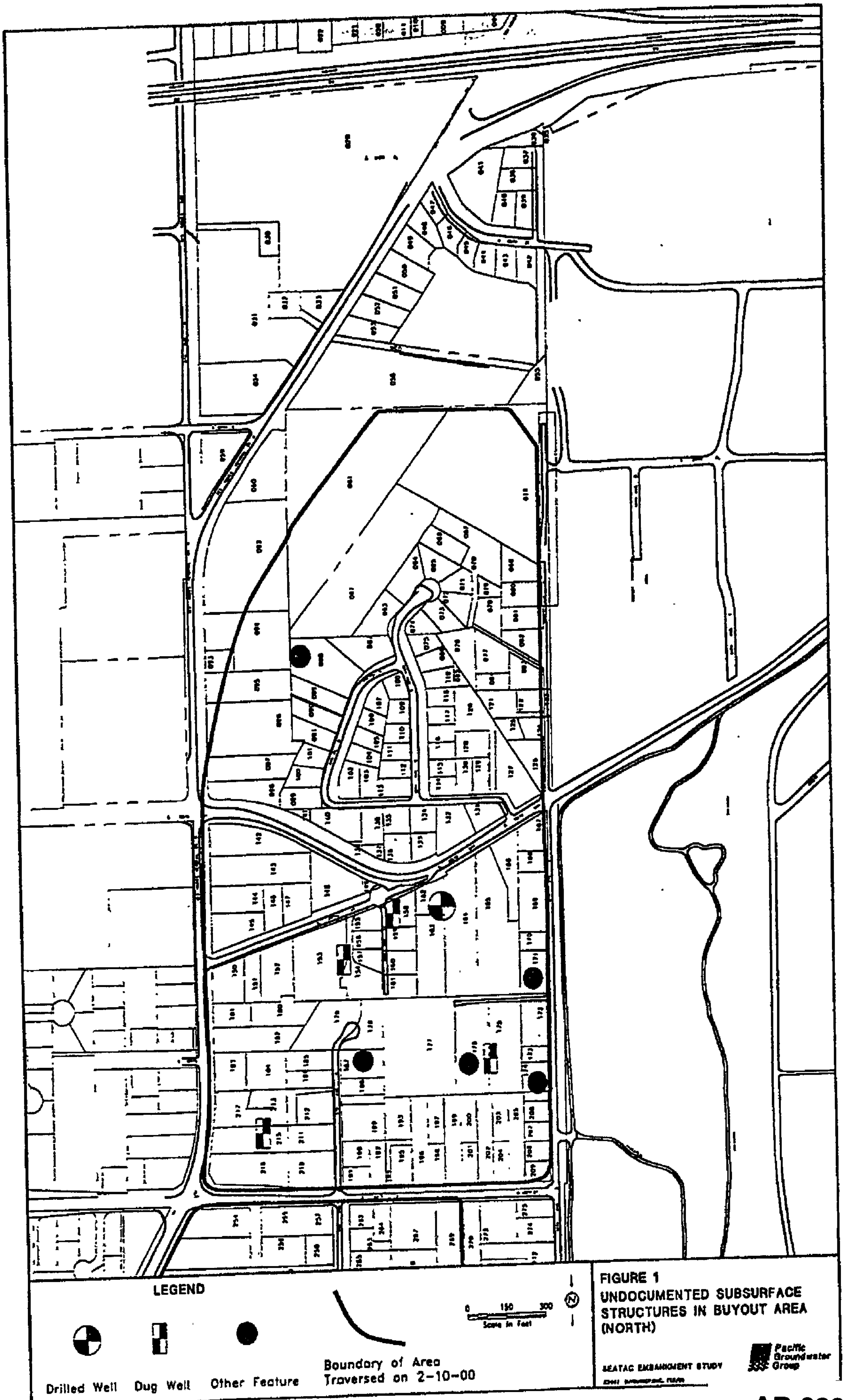
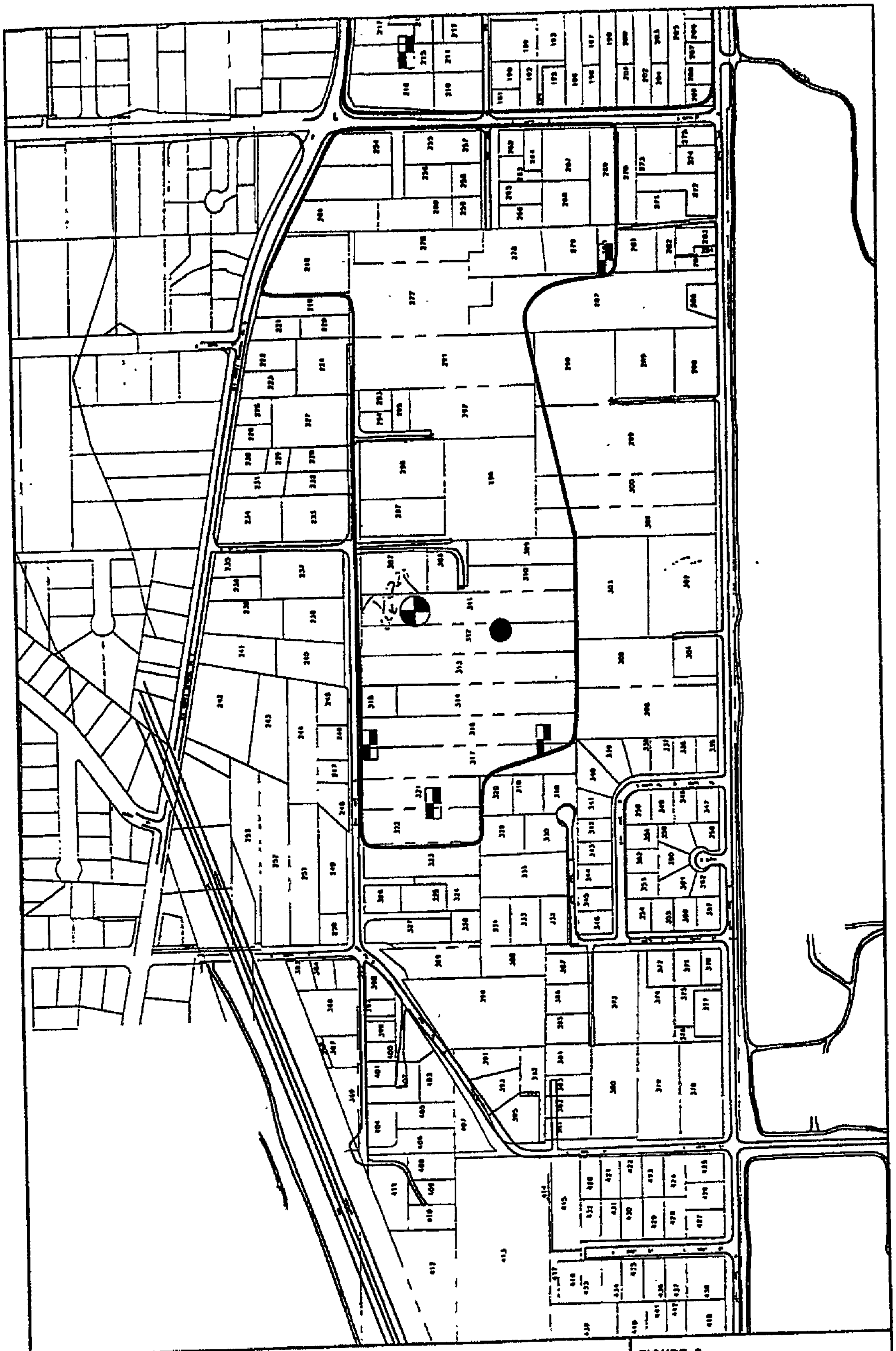


FIGURE 1
UNDOCUMENTED SUBSURFACE STRUCTURES IN BUYOUT AREA (NORTH)

SEATAC EMBANKMENT STUDY

Pacific Groundwater Group



LEGEND

Drilled Well

Dug Well

Other Feature

Boundary of Area Traversed on 2-10-00

0 150 300

Scale in Feet

FIGURE 2
UNDOCUMENTED SUBSURFACE STRUCTURES IN BUYOUT AREA (MIDDLE)

SEATAC EMBANKMENT STUDY

Pacific Groundwater Group

APPENDIX B

Appendix B
Pacific Groundwater Group Recharge Model

The following three computer-based groundwater models were used for this project:

- Pacific Groundwater Group Recharge Model
- Hydrus-2D
- Finite Difference slice model (slice model)

The recharge model was used to calculate groundwater recharge for the current and post construction conditions at the proposed third runway fill and borrow sources south of the runways. Hydrus was used to model the movement of water between the root zone and the water table assuming construction of the runway fill. The slice model was used to accumulate and move recharge downgradient under current and built conditions, to the Miller Creek riparian wetlands. At the borrow source areas, only the recharge model was used. This appendix describes the input and functions of the recharge model. The main text presents basic characterization data, model results, and interpretation.

1 Method

A proprietary spreadsheet model developed by Pacific Groundwater Group was used to estimate monthly and annual recharge. The spreadsheet model is based on algorithms used in the "Deep Percolation Model" developed by the USGS (Bauer, 1996 and Bauer & Vaccaro, 1987). PGG's model employs a daily water budget to track soil moisture, perched conditions over till, runoff, snow-pack storage, and interception loss. The model estimates daily potential evapotranspiration using either the Blaney-Criddle (SCS, 1970) or Priestly-Taylor (1972) method, and calculates actual evapotranspiration as a function of soil texture and available moisture in the root zone. All water passing through the root zone is attributed to shallow recharge. When a till layer is included, the model tracks an overlying, perched water table and allows for both downward vertical seepage through the till ("deep recharge") and shallow "perched subflow" above the till. When the water table extends into the root zone, shallow recharge equals additions or withdrawals to the shallow aquifer. If the water table reaches the land surface, potential recharge is rejected and routed to the runoff term. Runoff is also modeled based on a fixed percentage of precipitation. Running the model for consecutive identical years allows simulation of a cyclic steady state. The model can be calibrated to runoff, saturation above the till, deep recharge, perched subflow, and snow-pack storage.

Observations of soil and cover conditions were used to identify five "recharge classes" based on unique combinations of land cover and surficial geology at the proposed fill and borrow areas. Land cover was broken into three categories (grass, mixed forest, and barren). Mixed forest was modeled as half-coniferous trees and half-deciduous trees. A surficial geologic map (Booth and Waldren, in press) and local boring logs were considered in identifying three soil types for the proposed fill and borrow areas: glacial outwash, glacial till, and wetland.

At the fill area, the model was applied to a slice of ground proposed to change from current conditions to fill. Along that slice, impervious surfaces were limited to 12th Avenue for the current condition and the proposed third runway for the built condition. Runoff was assumed to be 100 percent from these impervious surfaces, with no secondary infiltration. No impervious surfaces were modeled at the borrow areas, where the model was applied to the borrow area footprints.

The following five recharge classes for the proposed fill and borrow areas were used (current and post construction conditions included, and impervious not included).

	outwash	till	wetland
grass cover	class 1	not used	class 5 (2/3 grass)
mixed forest cover	class 2	class 4	class 5 (1/3 forest)
barren	class 3	not used	not used

The fill was modeled as grass on outwash. Wetlands were modeled as 1/3 forest and 2/3 grass growing on fine-grained soils with a high water table. Post-borrow conditions were modeled as barren and grass on outwash.

The recharge calculation methods for wetlands differed from the other classes. Because portions of the root zone remain saturated year-round in the modeled riparian wetlands, water is always available for transpiration and is unimpeded by soil-moisture tension. For this reason, wetland recharge was simply calculated as precipitation minus potential evapotranspiration (R=P-PET for wetlands). Therefore, for wetland classes, negative recharge was calculated during the summer months of low precipitation and high potential evapotranspiration.

For all but the wetlands, the recharge analysis considered the water-holding capacities of existing soils using a term called available water capacity (AWC). AWC is measured in inches of water, and is the difference between field capacity and wilting point. Values of AWC published in the King County Soil Survey (Soil Conservation Service, 1973) were used for Alderwood and Everett soils, the prominent types derived from till and outwash soils, respectively. AWC for wetland soils were derived from the Snohomish soil series data. Another major discriminating factor is that Alderwood soils are underlain by a consolidated till stratum, typically encountered 24 to 40 inches below land surface (Soil Conservation Service, 1973) that may perch groundwater and therefore affect actual evapotranspiration. **Table B-1** summarizes the AWC profiles of the major soil types. For each depth range, the modeled AWC value is the midpoint of the published AWC range.

Monthly precipitation and temperature averages were derived for Seatac Airport. **Table B-2** shows the climatic input data for the model.

Table B-11 - Recharge / Water Balance for the SeaTac Project Area - Grass on Outwash

Vegetation Data	
Type of Land Cover	grass
Rooting Depth	24 in
Priestly Taylor "Alpha"	N/A
Average Annual Fractional Foliar Cover	N/A
Average Annual Foliar Interception Capacity	N/A

Weather Station Data	
Nearest Weather Station	Seatac Airport
Average Precipitation	37.9 in/yr
Avg Annual Temperature	59.3 °F
Latitude	47.46 °N
Longitude	-121.72 °W
Elevation	300 feet msl

Soil and Water Data		
Avg. Soil Available Water Capacity (AWC)	0.08	inch/inch within root zone, based on SCS soil descriptions.
Ratio of Site:Weather-Station Precipitation	100%	of official station, based on PGG linear regression analysis.
Resulting "Effective" Precipitation (P)	37.9	in/yr (annual average)
Portion of "P" going to immediate runoff*	0%	of effective precipitation, based on high permeability of soils
Rate of Snow Ablation (SA)	N/A	
Snowmelt Rate Coefficient	N/A	
Depth to Till (Not Used in Model)	100	
Till Thickness (Not Used in Model)	10	
Vertical Hydraulic Conductivity of Till	N/A	
Specific Yield of Perched Aquifer	N/A	
Darcy Flow Coefficient for Perched Aquifer	N/A	

Method of Estimating Potential Evapotranspiration: Blaney Criddle (BC)
Priestly Taylor Canopy Interception: Not Modeled
Snowpack: Not Modeled
Till Perching: Not Modeled

RECHARGE CALCULATOR:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS	
Evaporation Estimates														
Monthly Temp (T, °F)	39.6	42.9	45.2	49.3	55.4	60.4	64.8	64.8	60.4	52.4	45.0	40.6	51.8	Avg. T, °F
Monthly Temp (T, °C)	4.2	6.0	7.3	9.6	13.0	15.8	18.2	18.2	15.8	11.3	7.2	4.8	11.0	Avg. T, °C
Blaney Criddle Crop Factor (k)	0.49	0.57	0.73	0.85	0.90	0.92	0.92	0.92	0.87	0.79	0.67	0.55	0.77	(Avg k)
Blaney Criddle % of Annual Light (d)	0.084	0.065	0.082	0.091	0.103	0.105	0.106	0.097	0.084	0.078	0.064	0.061	1.00	Avg d)
Priestly Taylor Net Radiation (RN)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(RN)
Potential Evapotranspiration (PET)	0.46	0.68	1.27	2.04	3.29	4.20	5.02	4.63	3.21	1.85	0.90	0.53	28.07	(PET)
Water Balance														
Effective Precipitation (P)	5.64	4.16	3.69	2.53	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.86	(P)
Interception Loss (IL)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(IL)
Average Snowpack Storage (SS)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	---	(SS)
Snowpack Ablation (SA)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(SA)
Snowmelt (SM)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(SM)
AvailableThroughfall (ATF)	5.64	4.16	3.69	2.53	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.86	(ATF)
Runoff (RO)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(RO)
Infiltration (I)	5.64	4.16	3.69	2.63	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.86	(I)
Average Soil Moisture in Soil Profile (SW)	2.01	2.00	1.98	1.95	1.36	0.82	0.38	0.17	0.56	1.65	1.99	2.00	1.40	(SW)
Soil Moistue Deficit (PET-P)	0.00	0.00	0.00	0.00	1.66	2.76	4.26	3.53	1.43	0.00	0.00	0.00	13.63	(PET-P)
Actual Evapotranspiration (AET)	0.46	0.68	1.27	2.04	2.44	1.69	1.26	1.13	1.18	1.56	0.90	0.53	15.35	(AET)
Shallow Recharge (RS)**	5.17	3.49	2.44	0.52	0.00	0.00	0.00	0.00	0.00	0.63	4.95	5.30	22.50	(RS)
Perched Subflow (PS)***	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(PS)
Deep Recharge (RD)***	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(RO)

ANNUAL SUMMARY	P	IL	SM	ATF	RO	I	PET	AET	RS	PS	RD
	37.86	N/A	N/A	37.86	0.00	37.86	28.07	15.35	22.50	N/A	N/A

NOTES:
All values used in the Evaporation Estimates, Water Balance, and Annual Summary are in inches unless otherwise noted.
Abbreviations used in the annual summary are defined in the Evaporation Estimates and Water Balance.
* Modeled runoff consists of the sum of the fixed percentage of effective precipitation going to runoff and any infiltration rejected when saturation reaches the land surface.
** For the non-perched condition, shallow recharge is the water that exits the bottom of the root zone. For the perched condition, it is the water added to the shallow, perched aquifer.
Shallow recharge can be negative if perched conditions extend up into the root zone and plant transpiration removes significant amounts of water from the shallow aquifer.

Table B-12 - Recharge / Water Balance for the SeaTac Project Area - Deciduous Forest on Outwash

Vegetation Data

Type of Land Cover	deciduous forest
Rooting Depth	60 in
Priestly Taylor "Alpha"	N/A
Average Annual Fractional Foliar Cover	N/A
Average Annual Foliar Interception Capacity	N/A

Weather Station Data

Nearest Weather Station	Seatac Airport
Average Precipitation	37.9 in/yr
Avg Annual Temperature	59.3 °F
Latitude	47.45 °N
Longitude	-121.72 °W
Elevation	300 feet msl

Soil and Water Data

Avg. Soil Available Water Capacity (AWC)	0.06	inch/inch within root zone, based on SCS soil descriptions.
Ratio of Site:Weather-Station Precipitation	100%	of official station, based on PGG linear regression analysis.
Resulting "Effective" Precipitation (P)	37.9	in/yr (annual average)
Portion of "P" going to immediate runoff*	0%	of effective precipitation, based on high permeability of soils
Rate of Snow Ablation (SA)	N/A	
Snowmelt Rate Coefficeint	N/A	
Depth to Till (Not Used in Model)	100	
Till Thickness (Not Used in Model)	10	
Vertical Hydraulic Conductivity of Till	N/A	
Specific Yield of Perched Aquifer	N/A	
Darcy Flow Coefficient for Perched Aquifer	N/A	

Method of Estimating Potential Evapotranspiration: Blaney Criddle (BC)   **Priestly Taylor Canopy Interception:** Not Modeled   **Snowpack:** Not Modeled   **Till Perching:** Not Modeled

RECHARGE CALCULATOR:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS	
Evaporation Estimates														
Monthly Temp (T, °F)	39.6	42.9	45.2	49.3	55.4	60.4	64.8	64.8	60.4	52.4	45.0	40.6	51.8	Avg. T, °F
Monthly Temp (T, °C)	4.2	6.0	7.3	9.6	13.0	15.8	18.2	18.2	15.8	11.3	7.2	4.8	11.0	Avg. T, °C
Blaney Criddle Crop Factor (k)	0.17	0.25	0.40	0.63	0.88	0.98	0.95	0.82	0.54	0.30	0.19	0.15	0.52	(Avg k)
Blaney Criddle % of Annual Light (d)	0.064	0.065	0.082	0.091	0.103	0.105	0.108	0.097	0.084	0.076	0.064	0.061	1.00	Avg d)
Priestly Taylor Net Radiation (RN)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(RN)
Potential Evapotranspiration (PET)	0.16	0.30	0.69	1.51	3.21	4.36	5.19	4.12	1.99	0.70	0.25	0.15	22.66	(PET)
Water Balance														
Effective Precipitation (P)	5.64	4.16	3.69	2.53	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.86	(P)
Interception Loss (IL)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(IL)
Average Snowpack Storage (SS)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	---	(SS)
Snowpack Ablation (SA)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(SA)
Snowmelt (SM)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(SM)
AvailableThroughfall (ATF)	5.64	4.16	3.69	2.53	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.86	(ATF)
Runoff (RO)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(RO)
Infiltration (I)	5.64	4.16	3.69	2.53	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.86	37.86	(I)
Average Soil Moisture in Soil Profile (SW)	3.41	3.41	3.40	3.37	2.78	2.12	1.36	1.14	1.80	3.19	3.41	3.42	2.73	(SW)
Soil Moistue Deficit (PET-P)	0.00	0.00	0.00	0.00	1.58	2.94	4.42	3.03	0.22	0.00	0.00	0.00	12.18	(PET-P)
Actual Evapotranspiration (AET)	0.16	0.30	0.69	1.51	2.48	2.16	1.54	0.91	0.78	0.83	0.25	0.15	11.52	(AET)
Shallow Recharge (RS)**	5.48	3.86	3.01	1.05	0.00	0.00	0.00	0.00	0.00	1.64	5.60	5.70	26.34	(RS)
Perched Subflow (PS)***	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(PS)
Deep Recharge (RD)***	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(RO)

ANNUAL SUMMARY	P	IL	SM	ATF	RO	I	PET	AET	RS	PS	RD
	37.86	N/A	N/A	37.86	0.00	37.86	22.66	11.52	26.34	N/A	N/A

NOTES:
All values used in the Evaporation Estimates, Water Balance, and Annual Summary are in inches unless otherwise noted.
Abbreviations used in the annual summary are defined in the Evaporation Estimates and Water Balance.
* Modeled runoff consists of the sum of the fixed percentage of effective precipitation going to runoff and any infiltration rejected when saturation reaches the land surface.
** For the non-perched condition, shallow recharge is the water that exits the bottom of the root zone. For the perched condition, it is the water added to the shallow, perched aquifer.
Shallow rech[illegible]an be negative if perched conditions extend up into the root zone and plant transpiration remo[illegible]gnificant amounts of water from the shallow aquifer.

Runoff was assumed negligible for recharge modeling of pervious surfaces. Factors contributing to low runoff are the coarse fill texture, low slopes, and forest cover. Although runoff is low, an assumption of zero for all pervious classes imparts some inaccuracy to the recharge predictions.

Plant potential evapotranspiration (PET) was calculated with the method of Blaney-Criddle. Grass was assigned a root depth of 24 inches in accordance with the USGS Deep Percolation Model used for to southwest King County (Woodward et al, 1995). Coniferous trees and deciduous trees were assigned rooting depths of 36 and 60 inches, respectively, except on till where all rooting depths were specified at 30 inches. Soil evaporation was calculated for the assumed barren borrow sites (down to a depth of 12 inches) with the method of Priestly-Taylor (1972).

Crop factors are used in the model to account for the plant-specific amounts of potential evapotranspiration. Interception (capture of precipitation by leaves and needles) is a part of actual evapotranspiration. Interception was not explicitly modeled because the Blaney-Criddle equation does not accommodate interception parameters. However, interception loss is known to be high in coniferous forests of the Pacific Northwest during wintertime, when advective loss of intercepted moisture can dominate evapotranspiration (Bauer & Mastin, 1997; pers. comm., Black, 1999). During the drier months (May through September), crop factors can be derived for conifers by multiplying the crop factor for grass by the ratio of Priestly Taylor "alpha" values measured for conifers and grass (0.73 and 1.26, respectively). The "alpha" parameter was developed for dry leaf transpiration based on stomatal resistance. Current methods of ET estimation have not fully developed suitable means for estimating advective losses during winter months. For these months, the best recourse for estimating forest ET is believed to be use of high-end, measured crop factors (pers. comm, Black, 1999). In this case, Blaney-Criddle crop factors for alfalfa were used between November and March, and for grass during April and October. Alfalfa has one of the highest crop factors, and grass is also relatively high (Dunne & Leopold, 1978).

Actual soil evaporation and plant evapotranspiration were calculated as a function of daily soil moisture availability, soil texture, and potential ET based on functions employed in the USGS recharge model (Bauer & Vaccaro, 1987). In general, reduced soil moisture reduces evaporation and transpiration because the remaining moisture is held with greater tension in the soil and unsaturated hydraulic conductivities are reduced.

Solar radiation data, required for the Priestly-Taylor method, were obtained from measurements made at the Seatac station. The data are maintained and reported by the National Renewable Energy Laboratory (NREL) as part of the National Solar Radiation Database, and represent a period of 1961-1990. Maximum observed daily clear sky solar radiation was not measured, but was derived from measured extraterrestrial solar radiation by applying a ratio of 0.73 (after Giles and others, 1984). The radiation data are presented in **Table B-3**. The recharge model employed a Priestly-Taylor alpha coefficient of 1.0. While a value of 1.26 is considered standard for wet surfaces, evaporation from soils (E_s) is less than evaporation from free surfaces (E_o). E_s/E_o ratios reported in the literature range from 60% to 90% (Jensen et al, 1990). Sensitivity analysis showed that varying the alpha coefficient by ±0.27 around 1.0 resulted in PET values which varied by +27% and −15%, however resulting recharge values varied by only +6% and −3%.

2 Recharge Estimation Results

PGG's recharge model was used to estimate monthly recharge for each recharge class. Soil property, plant, climatic, and other pertinent data were input, and the model was run for each recharge class independently. For classes with no underlying till a single model run allowed definition of the daily, monthly, and annual soil-moisture water balance. For upland till, multiple runs were required during which the vertical permeability (K_v) of the till and the "Darcy flow coefficient" of the perched aquifer (a composite term for horizontal permeability (K_h) times gradient (i) per unit-width) were adjusted to match simplified site conditions (presence and absence of perched water).

Recharge for outwash areas is summarized as percolation to a presumed deep water table, below the root zone. Roots cannot extract water from the saturated zone in that case and recharge is therefore either positive or zero. Recharge in upland till areas is summarized as percolation to a presumed perched water table, which may be within the root zone. Recharge in till areas includes shallow perched subflow and deep percolation. When the water table is within the root zone, negative recharge may occur because roots may access water from below the water table (ie: more than the water stored in the unsaturated state above the water table). This condition occurred in the till upland, where the root zone was modeled to extend down to the till layer at a depth of 30 inches.

In the wetland areas where the water table is always within the root zone, recharge was approximated as simply P-PET. This approach was appropriate because the recharge model output was intended for use in the slice model, which rejects recharge when the water table is at land surface, and correctly attributes the rejected recharge as runoff.

Table B-4 shows the monthly and annual estimates of recharge predicted by the model and described above. Details of output from the recharge spreadsheet model for each recharge class is provided in **Tables B-5 through B-13.** Recharge for the mixed cover classes were calculated based on weighting of the discrete cover classes (example: wetlands were calculated as one-third grass-covered wetland and two-third mix-forest wetlands). Therefore, **Tables B-5 through B-13** do not include the exact numbers used for mixed-cover modeling. **Figure 3-4**, in the main body of the report, provides a graphical representation of total recharge calculated for the different classes over time.

Table B-4 and **Figure 3-4** (main text) show that predicted recharge for the wetter months is similar between all classes, but that the presence of moisture and saturation within the root zone causes negative recharge (net ET) for the till and wetland classes. Recharge is greatest in the barren condition as a result of low AET.

The recharge estimates for grass on outwash were imported to the Hydrus-2D model discussed in Appendix C for modeling of infiltration through the variably saturated third runway fill. All values except the barren condition were imported into appropriate locations in the "current conditions" version of the slice model, which assumed no lag for vertical flow to the water table.

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Table B-1
Available Water Capacities for Modeled Soils

Everett Series		Alderwood Series		Snohomish Series (wetland)	
Depth Range	AWC	Depth Range	AWC	Depth Range	AWC
0-17 in	0.08-0.1	0-27 in	0.09-0.11	0-17	0.20-0.24
17-32 in	0.06-0.08	Below 27 in	till	17-27	0.35-0.40
32-60 in	0.02-0.04			27-60	0.80-0.1

AR 022038

Table B-2
Climatic Data for Modeling

Month	Precipitation (inches)	Average Daily Max Temp (°F)	Avgerage Daily Min Temp (°F)
Jan	5.64	44.6	34.6
Feb	4.16	49.0	36.7
Mar	3.69	52.2	38.1
Apr	2.53	57.4	41.2
May	1.63	64.3	46.4
Jun	1.44	69.4	51.3
Jul	0.77	75.1	54.5
Aug	1.10	74.7	54.8
Sep	1.77	69.4	51.3
Oct	3.41	59.4	45.3
Nov	5.87	50.4	39.5
Dec	5.85	45.4	35.8
Annual	37.86		

AR 022039

Table B-3
Solar Radiation Data for Modeling

Month	Extraterrestrial solar radiation (MJ m^{-2} d^{-1})	Maximum observed daily clear sky solar radiation (MJ m^{-2} d^{-1})	Daytime incoming solar radiation (MJ m^{-2} d^{-1})
January	10.99	8.02	3.54
February	16.53	12.07	5.96
March	24.49	17.88	10.18
April	32.82	23.96	14.70
May	39.14	28.57	19.16
June	41.88	30.57	20.91
July	40.51	29.58	21.84
August	35.30	25.77	18.56
September	27.71	20.23	13.57
October	19.42	14.18	8.00
November	12.66	9.25	4.19
December	9.54	6.96	2.89

AR 022040

Table B-4
Recharge for Cover and Soil Classes based on Recharge Model for SeaTac Area

Month	Outwash Mixed Forest	Outwash Grass (and fill)	Till Mixed Forest	Grass & Mixed Forest Wetland (saturated)	Barren Outwash
January	5.26	5.17	5.18	5.23	5.58
February	3.58	3.49	3.56	3.55	3.75
March	2.62	2.44	2.60	2.55	2.45
April	0.78	0.52	0.75	0.68	0.30
May	0.00	0.00	-0.92	-1.14	0.00
June	0.00	0.00	-1.08	-2.19	0.00
July	0.00	0.00	-0.85	-3.56	0.00
August	0.00	0.00	0.06	-2.67	0.00
September	0.00	0.00	0.82	-0.55	0.00
October	1.29	0.63	2.22	1.95	2.03
November	5.20	4.95	5.22	5.15	5.68
December	5.46	5.30	5.46	5.42	5.84
Annual	24.19	22.50	23.04	14.43	25.64

AR 022041

Table B-5 - Recharge for the SeaTac Project Area - Coniferous Forest on Highly Saturated Area (Wetland)

Vegetation Data	
Type of Land Cover	mature conifers
Rooting Depth	36 in
Priestly Taylor "Alpha"	N/A
Average Annual Fractional Foliar Cover	N/A
Average Annual Foliar Interception Capacity	N/A

Weather Station Data	
Nearest Weather Station	Seatac Airport
Average Precipitation	37.9 in/yr
Avg Annual Temperature	59.3 °F
Latitude	47.45 °N
Longitude	-121.72 °W
Elevation	300 feet msl

Soil and Water Data		
Avg. Soil Available Water Capacity (AWC)	0.23	inch/inch within root zone, based on SCS soil descriptions.
Ratio of Site:Weather-Station Precipitation	100%	of official station, based on PGG linear regression analysis.
Resulting "Effective" Precipitation (P)	37.9	in/yr (annual average)
Portion of "P" going to immediate runoff*	0%	of effective precipitation, based on high permeability of soils
Rate of Snow Ablation (SA)	N/A	
Snowmelt Rate Coefficient	N/A	
Depth to Till Layer	10	feet, based on generalized cross section.
Thickness of Till Layer	10	feet, based on generalized cross section.
Vertical Hydraulic Conductivity of Till	1E-09	ft/day, based on empirical maximization of wetland saturatio
Specific Yield of Perched Aquifer	0.45	based on consideration of peat properties.
Darcy Flow Coefficient for Perched Aquifer	0.000001	based on empirical maximization of wetland saturation.

Method of Estimating Potential Evapotranspiration: Blaney Criddle (BC)

Priestly Taylor Canopy Interception: Not Modeled

Snowpack: Not Modeled

Till Perching: Modeled

RECHARGE CALCULATOR:

Evaporation Estimates	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS	
Monthly Temp (T, °F)	39.6	42.9	45.2	49.3	55.4	60.4	64.8	64.8	60.4	52.4	45.0	40.6	51.8	Avg. T, °F
Monthly Temp (T, °C)	4.2	6.0	7.3	9.6	13.0	15.8	18.2	18.2	15.8	11.3	7.2	4.8	11.0	Avg. T, °C
Blaney Criddle Crop Factor (k)	0.63	0.73	0.86	0.85	0.52	0.53	0.53	0.53	0.50	0.80	0.76	0.64	0.66	(Avg k)
Blaney Criddle % of Annual Light (d)	0.064	0.065	0.082	0.091	0.103	0.105	0.106	0.097	0.084	0.076	0.064	0.061	1.00	Avg d)
Priestly Taylor Net Radiation (RN)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(RN)
Potential Evapotranspiration (PET)	0.60	0.87	1.49	2.04	1.89	2.41	2.89	2.66	1.84	1.88	1.05	0.62	20.23	(PET)

Table B6 - Recharge for the SeaTac Project Area - Grass on Highly Saturated Area (Wetland)

Vegetation Data	
Type of Land Cover	grass
Rooting Depth	24 in
Priestly Taylor "Alpha"	N/A
Average Annual Fractional Foliar Cover	N/A
Average Annual Foliar Interception Capacity	N/A

Weather Station Data	
Nearest Weather Station	Seatac Airport
Average Precipitation	37.9 in/yr
Avg Annual Temperature	59.3 °F
Latitude	47.45 °N
Longitude	-121.72 °W
Elevation	300 feet msl

Soil and Water Data		
Avg. Soil Available Water Capacity (AWC)	0.27	inch/inch within root zone, based on SCS soil descriptions.
Ratio of Site:Weather-Station Precipitation	100%	of official station, based on PGG linear regression analysis.
Resulting "Effective" Precipitation (P)	37.9	in/yr (annual average)
Portion of "P" going to immediate runoff*	0%	of effective precipitation, based on high permeability of soils
Rate of Snow Ablation (SA)	N/A	
Snowmelt Rate Coefficieint	N/A	
Depth to Till Layer	10	feet, based on generalized cross section.
Thickness of Till Layer	10	feet, based on generalized cross section.
Vertical Hydraulic Conductivity of Till	1E-09	ft/day, based on empirical maximization of wetland saturatio
Specific Yield of Perched Aquifer	0.45	based on consideration of peat properties.
Darcy Flow Coefficient for Perched Aquifer	0.000001	based on empirical maximization of wetland saturation.

Method of Estimating Potential Evapotranspiration: Blaney Criddle (BC)

Priestly Taylor Canopy Interception: Not Modeled

Snowpack: Not Modeled

Till Perching: Modeled

RECHARGE CALCULATOR:

Evaporation Estimates	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS	
Monthly Temp (T, °F)	39.6	42.9	45.2	49.3	55.4	60.4	64.8	64.8	60.4	52.4	45.0	40.8	51.8	Avg. T, °F
Monthly Temp (T, °C)	4.2	6.0	7.3	9.6	13.0	15.8	18.2	18.2	15.8	11.3	7.2	4.8	11.0	Avg. T, °C
Blaney Criddle Crop Factor (k)	0.49	0.57	0.73	0.85	0.90	0.92	0.92	0.92	0.87	0.79	0.67	0.55	0.77	(Avg k)
Blaney Criddle % of Annual Light (d)	0.064	0.065	0.082	0.091	0.103	0.105	0.106	0.097	0.084	0.076	0.064	0.061	1.00	Avg d)
Priestly Taylor Net Radiation (RN)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(RN)
Potential Evapotranspiration (PET)	0.46	0.68	1.27	2.04	3.29	4.20	5.02	4.63	3.21	1.85	0.90	0.53	28.07	(PET)

Table B-7 - Recharge for the SeaTac Project Area - Decidous Forest on Highly Saturated Area (Wetland)

Vegetation Data

Type of Land Cover	deciduous forest
Rooting Depth	60 in
Priestly Taylor "Alpha"	N/A
Average Annual Fractional Foliar Cover	N/A
Average Annual Foliar Interception Capacity	N/A

Weather Station Data

Nearest Weather Station	Seatac Airport
Average Precipitation	37.9 in/yr
Avg Annual Temperature	59.3 °F
Latitude	47.45 °N
Longitude	-121.72 °W
Elevation	300 feet msl

Soil and Water Data

Avg. Soil Available Water Capacity (AWC)	0.17	inch/inch within root zone, based on SCS soil descriptions.
Ratio of Site:Weather-Station Precipitation	100%	of official station, based on PGG linear regression analysis.
Resulting "Effective" Precipitation (P)	37.9	in/yr (annual average)
Portion of "P" going to immediate runoff	0%	of effective precipitation, based on high permeability of soils
Rate of Snow Ablation (SA)	N/A	
Snowmelt Rate Coefficient	N/A	
Depth to Till Layer	10	feet, based on generalized cross section.
Thickness of Till Layer	10	feet, based on generalized cross section.
Vertical Hydraulic Conductivity of Till	1E-09	ft/day, based on empirical maximization of wetland saturatio
Specific Yield of Perched Aquifer	0.45	based on consideration of peat properties.
Darcy Flow Coefficient for Perched Aquifer	0.000001	based on empirical maximization of wetland saturation.

Method of Estimating Potential Evapotranspiration: Blaney Criddle (BC)
Priestly Taylor Canopy Interception: Not Modeled
Snowpack: Not Modeled
Till Perching: Modeled

RECHARGE CALCULATOR:

Evaporation Estimates	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS	
Monthly Temp (T, °F)	39.6	42.9	45.2	49.3	55.4	60.4	64.8	64.8	60.4	52.4	45.0	40.6	51.8	Avg. T, °F
Monthly Temp (T, °C)	4.2	6.0	7.3	9.6	13.0	15.8	18.2	18.2	15.8	11.3	7.2	4.8	11.0	Avg. T, °C
Blaney Criddle Crop Factor (k)	0.17	0.25	0.40	0.63	0.88	0.96	0.95	0.82	0.54	0.30	0.19	0.15	0.52	(Avg k)
Blaney Criddle % of Annual Light (d)	0.064	0.065	0.082	0.091	0.103	0.105	0.108	0.097	0.084	0.076	0.064	0.061	1.00	Avg d)
Priestly Taylor Net Radiation (RN)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(RN)
Potential Evapotranspiration (PET)	0.16	0.30	0.69	1.51	3.21	4.38	5.19	4.12	1.99	0.70	0.25	0.15	22.66	(PET)

Table B-8 - Recharge / Water Balance for the SeaTac Projec Area - Deciduous Forest on Till

Vegetation Data	
Type of Land Cover	deciduous forest
Rooting Depth	30 in
Priestly Taylor "Alpha"	N/A
Average Annual Fractional Foliar Cover	N/A
Average Annual Foliar Interception Capacity	N/A

Weather Station Data	
Nearest Weather Station	Seatac Airport
Average Precipitation	37.9 in/yr
Avg Annual Temperature	59. °F
Latitude	47.45 °N
Longitude	-121 72 °W
Elevation	308 feet msl

Soil and Water Data		
Avg Soil Available Water Capacity (AWC)	0.10	inch/inch within root zone, based on SCS soil descriptions
Ratio of Site:Weather-Station Precipitation	100%	of official station, based on PGG linear regression analysis.
Resulting "Effective" Precipitation (P)	37.9	in/yr (annual average)
Portion of "P" going to immediate runoff*	0%	of effective precipitation, based on high permeability of soils
Rate of Snow Ablation (SA)	N/A	
Snowmelt Rate Coefficient	N/A	
Depth to Till Layer	25	feet, based on
Thickness of Till Layer	10	feet, based on ______
Vertical Hydraulic Conductivity of Till	0.008	ft/day, based on calib. to hydrograph below
Porosity of Perched Aquifer	0.37	based on ______
Darcy Flow Coefficient for Perched Aquifer	0	based on empirical adjustment.

Method of Estimating Potential Evapotranspiration: Blaney Criddle (BC)
Priestly Taylor Canopy Interception: Not Modeled
Snowpack: Not Modeled
Till Perching: Modeled

RECHARGE CALCULATOR:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS	
Evaporation Estimates														
Monthly Temp (T, °F)	39.8	42.9	45.2	49.3	55.4	60.4	64.8	64.8	60.4	52.4	45.0	40.6	51.8	Avg T, °F
Monthly Temp (T, °C)	4.2	6.0	7.3	9.6	13.0	15.8	18.2	18.2	15.6	11.3	7.2	4.8	11.0	Avg. T, °C
Blaney Criddle Crop Factor (k)	0.17	0.25	0.40	0.63	0.88	0.96	0.95	0.82	0.54	0.30	0.19	0.15	0.52	(Avg k)
Blaney Criddle % of Annual Light (d)	0.064	0.065	0.082	0.091	0.103	0.105	0.106	0.097	0.084	0.076	0.064	0.061	1.00	Avg d)
Priestly Taylor Net Radiation (RN)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(RN)
Potential Evapotranspiration (PET)	0.16	0.30	0.69	1.51	3.21	4.38	5.19	4.12	1.99	0.70	0.25	0.15	22.66	(PET)
Water Balance														
Effective Precipitation (P)	5.84	4.16	3.69	2.53	1.83	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.86	(P)
Interception Loss (IL)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(IL)
Average Snowpack Storage (SS)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	***	(SS)
Snowpack Ablation (SA)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(SA)
Snowmelt (SM)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(SM)
Available Throughfall (ATF)	5.84	4.16	3.69	2.53	1.83	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.86	(ATF)
Runoff (RO)	0.00	0.35	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	(RO)
Infiltration (I)	5.84	3.80	3.69	2.53	1.83	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.50	(I)
Average Soil Moisture in Soil Profile (SW)	8.87	9.88	9.55	7.97	4.38	1.47	0.73	0.60	1.19	2.65	4.34	6.79	4.84	(SW)
Soil Moisture Deficit (PET-P)	0.00	0.00	0.00	0.00	1.58	2.94	4.42	3.03	0.22	0.00	0.00	0.00	12.18	(PET-P)
Actual Evapotranspiration (AET)	0.16	0.30	0.69	1.51	3.21	2.65	1.37	0.81	0.91	0.64	0.25	0.15	12.76	(AET)
Shallow Recharge (RS)**	5.47	3.51	3.00	1.04	-0.93	0.00	0.00	0.00	0.00	1.35	5.60	5.70	24.74	(RS)
Perched Subflow (PS)***	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(PS)
Deep Recharge (RD)***	3.81	3.36	3.69	3.41	2.91	0.00	0.00	0.00	0.00	1.35	3.02	3.39	24.74	(RO)

ANNUAL SUMMARY	P	IL	SM	ATF	RO	I	PET	AET	RS	PS	RD
	37.86	N/A	N/A	37.86	0.36	37.50	22.66	12.76	24.74	0.00	24.74

NOTES:
All values used in the Evaporation Estimates, Water Balance, and Annual Summary are in inches unless otherwise noted.
Abbreviations used in the annual summary are defined in the Evaporation Estimates and Water Balance.
* Modeled runoff consists of the sum of the fixed percentage of effective precipitation going to runoff and any infiltration rejected when saturation reaches the land surface.
** For the non perched condition, shallow recharge is the water that exits the bottom of the root zone. For the perched condition, it is the water added to the shallow, perched aquifer.
Shallow recharge can be negative if perched conditions extend up into the root zone and plant transpiration removes significant amounts of water from the shallow aquifer.
*** Deep recharge is water that flows through the till layer. Perched subflow is lateral, saturated flow above the till layer to adjacent discharge points.

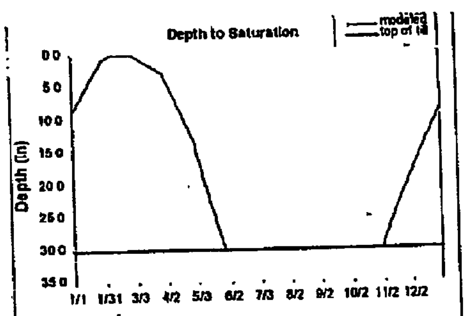

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Table B-9 - Recharge / Water Balance for the SeaTac Project Area - Coniferous Forest on Till

Vegetation Data	
Type of Land Cover	mature conifers
Rooting Depth	30 in
Priestly Taylor "Alpha"	N/A
Average Annual Fractional Foliar Cover	N/A
Average Annual Foliar Interception Capacity	N/A

Weather Station Data	
Nearest Weather Station	Seatac Airport
Average Precipitation	37.9 in/yr
Avg Annual Temperature	59. °F
Latitude	47.45 °N
Longitude	-121.72 °W
Elevation	300 feet msl

Soil and Water Data		
Avg Soil Available Water Capacity (AWC)	0.10	inch/inch within root zone, based on SCS soil descriptions.
Ratio of Site Weather-Station Precipitation	100%	of official station, based on PGG linear regression analysis
Resulting "Effective" Precipitation (P)	37.9	in/yr (annual average)
Portion of "P" going to immediate runoff	0%	of effective precipitation, based on high permeability of soils
Rate of Snow Ablation (SA)	N/A	
Snowmelt Rate Coefficient	N/A	
Depth to Till Layer	2.5	feet, based on
Thickness of Till Layer	10	feet, based on ________.
Vertical Hydraulic Conductivity of Till	0.007	ft/day, based on calib to saturation hydrograph below
Porosity of Perched Aquifer	0.37	based on ________.
Darcy Flow Coefficient for Perched Aquifer	0	based on empirical adjustment.

Method of Estimating Potential Evapotranspiration: Blaney Criddle (BC)

Priestly Taylor Canopy Interception: Not Modeled

Snowpack: Not Modeled

Till Perching: Modeled

RECHARGE CALCULATOR:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS	
Evaporation Estimates														
Monthly Temp (T, °F)	39.6	42.9	45.2	49.3	55.4	60.4	64.6	64.8	60.4	52.4	45.0	40.8	51.8	Avg T, °F
Monthly Temp (T, °C)	4.2	6.0	7.3	9.6	13.0	15.8	18.2	18.2	15.8	11.3	7.2	4.8	11.0	Avg T, °C
Blaney Criddle Crop Factor (k)	0.63	0.73	0.88	0.85	0.52	0.53	0.63	0.53	0.60	0.80	0.74	0.64	0.68	(Avg k)
Blaney Criddle % of Annual Light (d)	0.064	0.065	0.082	0.091	0.103	0.105	0.106	0.097	0.084	0.076	0.064	0.061	1.00	Avg d)
Priestly Taylor Net Radiation (RN)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(RN)
Potential Evapotranspiration (PET)	0.60	0.87	1.49	2.04	1.89	2.41	2.89	2.66	1.84	1.88	1.05	0.62	20.23	(PET)
Water Balance														
Effective Precipitation (P)	5.64	4.16	3.69	2.53	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.88	(P)
Interception Loss (IL)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(IL)
Average Snowpack Storage (SS)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	---	(SS)
Snowpack Ablation (SA)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(SA)
Snowmelt (SM)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(SM)
AvailableThroughfall (ATF)	5.64	4.16	3.69	2.53	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.88	(ATF)
Runoff (RO)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(RO)
Infiltration (I)	5.64	4.16	3.69	2.53	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.88	(I)
Average Soil Moisture in Soil Profile (SW)	8.46	9.57	8.23	7.47	4.71	2.51	1.50	1.07	1.48	2.62	4.09	6.35	4.90	(SW)
Soil Moisture Deficit (PET P)	0.00	0.00	0.00	0.00	0.26	0.97	2.12	1.56	0.07	0.00	0.00	0.00	4.98	(PET-P)
Actual Evapotranspiration (AET)	0.60	0.87	1.49	2.04	1.89	2.38	1.71	1.16	0.89	1.72	1.06	0.62	16.52	(AET)
Shallow Recharge (RS)**	5.04	3.29	2.20	0.52	-0.24	-0.05	0.00	0.00	0.00	0.58	4.79	5.21	21.34	(RS)
Perched Subflow (PS)***	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(PS)
Deep Recharge (RD)***	3.12	2.92	3.20	2.94	2.78	0.25	0.00	0.00	0.00	0.58	2.82	2.92	21.34	(RD)

ANNUAL SUMMARY	P	IL	SM	ATF	RO	I	PET	AET	RS	PS	RD
	37.88	N/A	N/A	37.88	0.00	37.88	20.23	16.82	21.34	0.00	21.34

NOTES:
All values used in the Evaporation Estimates, Water Balance, and Annual Summary are in inches unless otherwise noted
Abbreviations used in the annual summary are defined in the Evaporation Estimates and Water Balance
* Modeled runoff consists of the sum of the fixed percentage of effective precipitation going to runoff and any infiltration rejected when saturation reaches the land surface.
** For the non perched condition, shallow recharge is the water that exits the bottom of the root zone. For the perched condition, it is the water added to the shallow, perched aquifer. Shallow recharge can be negative if perched conditions extend up into the root zone and plant transpiration removes significant amounts of water from the shallow aquifer.
*** Deep recharge is water that flows through the till layer. Perched subflow is lateral, saturated flow above the till layer to adjacent discharge points.

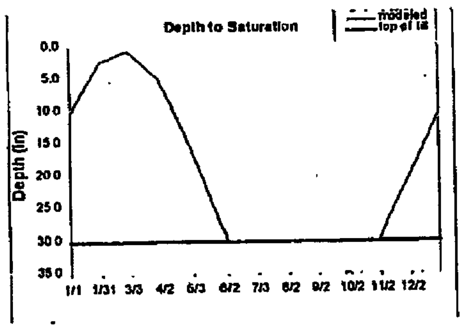

Table B-10 - Recharge / Water Balance for the SeaTac Project Area - Coniferous Forest on Outwash

Vegetation Data

Type of Land Cover	mature conifers
Rooting Depth	38 in
Priestly Taylor "Alpha"	N/A
Average Annual Fractional Foliar Cover	N/A
Average Annual Foliar Interception Capacity	N/A

Weather Station Data

Nearest Weather Station	Seatac Airport
Average Precipitation	37.9 in/yr
Avg Annual Temperature	59.3 °F
Latitude	47.45 °N
Longitude	-121.72 °W
Elevation	300 feet msl

Soil and Water Data

Avg. Soil Available Water Capacity (AWC)	0.08	inch/inch within root zone, based on SCS soil descriptions.
Ratio of Site:Weather-Station Precipitation	100%	of official station, based on PGG linear regression analysis.
Resulting "Effective" Precipitation (P)	37.9	in/yr (annual average)
Portion of "P" going to immediate runoff*	0%	of effective precipitation, based on high permeability of soils
Rate of Snow Ablation (SA)	N/A	
Snowmelt Rate Coefficient	N/A	
Depth to Till (Not Used in Model)	100	
Till Thickness (Not Used in Model)	10	
Vertical Hydraulic Conductivity of Till	N/A	
Specific Yield of Perched Aquifer	N/A	
Darcy Flow Coefficient for Perched Aquifer	N/A	

Method of Estimating Potential Evapotranspiration: Blaney Criddle (BC)

Priestly Taylor Canopy Interception: Not Modeled

Snowpack: Not Modeled

Till Perching: Not Modeled

RECHARGE CALCULATOR:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS	
Evaporation Estimates														
Monthly Temp (T, °F)	39.6	42.9	45.2	49.3	55.4	60.4	64.8	64.8	60.4	52.4	46.0	40.6	51.8	Avg. T, °F
Monthly Temp (T, °C)	4.2	6.0	7.3	9.6	13.0	15.8	18.2	18.2	15.8	11.3	7.2	4.8	11.0	Avg. T, °C
Blaney Criddle Crop Factor (k)	0.63	0.73	0.88	0.85	0.52	0.53	0.53	0.53	0.50	0.80	0.78	0.64	0.66	(Avg k)
Blaney Criddle % of Annual Light (d)	0.064	0.066	0.082	0.091	0.103	0.105	0.108	0.097	0.084	0.076	0.064	0.061	1.00	Avg d)
Priestly Taylor Net Radiation (RN)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(RN)
Potential Evapotranspiration (PET)	0.60	0.87	1.49	2.04	1.89	2.41	2.69	2.66	1.84	1.88	1.05	0.62	20.23	(PET)
Water Balance														
Effective Precipitation (P)	5.64	4.16	3.69	2.53	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.86	(P)
Interception Loss (IL)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(IL)
Average Snowpack Storage (SS)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	---	(SS)
Snowpack Ablation (SA)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(SA)
Snowmelt (SM)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(SM)
AvailableThroughfall (ATF)	5.64	4.16	3.69	2.53	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.86	(ATF)
Runoff (RO)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(RO)
Infiltration (I)	5.64	4.16	3.69	2.53	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.86	(I)
Average Soil Moisture in Soil Profile (SW)	2.88	2.87	2.65	2.63	2.52	2.15	1.43	1.18	1.84	2.52	2.67	2.68	2.28	(SW)
Soil Moistue Deficit (PET-P)	0.00	0.00	0.00	0.00	0.26	0.97	2.12	1.56	0.07	0.00	0.00	0.00	4.98	(PET-P)
Actual Evapotranspiration (AET)	0.60	0.87	1.49	2.04	1.81	1.95	1.57	0.97	1.07	1.77	1.05	0.62	15.82	(AET)
Shallow Recharge (RS)**	5.04	3.30	2.22	0.51	0.00	0.00	0.00	0.00	0.00	0.95	4.80	5.21	22.04	(RS)
Perched Subflow (PS)***	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(PS)
Deep Recharge (RD)***	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(RO)

ANNUAL SUMMARY	P	IL	SM	ATF	RO	I	PET	AET	RS	PS	RD
	37.86	N/A	N/A	37.86	0.00	37.86	20.23	15.82	22.04	N/A	N/A

NOTES:
All values used in the Evaporation Estimates, Water Balance, and Annual Summary are in inches unless otherwise noted.
Abbreviations used in the annual summary are defined in the Evaporation Estimates and Water Balance.
* Modeled runoff consists of the sum of the fixed percentage of effective precipitation going to runoff and any infiltration rejected when saturation reaches the land surface.
** For the non-perched condition, shallow recharge is the water that exits the bottom of the root zone. For the perched condition, it is the water added to the shallow, perched aquifer.
Shallow recharge can be negative if perched conditions extend up into the root zone and plant transpiration removes significant amounts of water from the shallow aquifer.

Table B-13 - Recharge / Water Balance for the SeaTac Project Area - Barrren Outwash

Vegetation Data	
Type of Land Cover	barren
Rooting Depth	12 in
Priestly Taylor "Alpha"	1
Average Annual Fractional Foliar Cover	N/A
Average Annual Foliar Interception Capacity	N/A

Weather Station Data	
Nearest Weather Station	Seatac Airport
Average Precipitation	37.9 in/yr
Avg Annual Temperature	59.3 °F
Latitude	47.45 °N
Longitude	-121.72 °W
Elevation	300 feet msl

Soil and Water Data		
Avg. Soil Available Water Capacity (AWC)	0.08	inch/inch within root zone, based on SCS soil descriptions.
Ratio of Site:Weather-Station Precipitation	100%	of official station, based on PGG linear regression analysis.
Resulting "Effective" Precipitation (P)	37.9	in/yr (annual average)
Portion of "P" going to immediate runoff*	0%	of effective precipitation, based on high permeability of soils
Rate of Snow Ablation (SA)	N/A	
Snowmelt Rate Coefficient	N/A	
Depth to Till (Not Used in Model)	100	
Till Thickness (Not Used in Model)	20	
Vertical Hydraulic Conductivity of Till	N/A	
Specific Yield of Perched Aquifer	N/A	
Darcy Flow Coefficient for Perched Aquifer	N/A	

Method of Estimating Potential Evapotranspiration: Priestly Taylor (PT)

Priestly Taylor Canopy Interception: Not Modeled

Snowpack: Not Modeled

Till Perching: Not Modeled

RECHARGE CALCULATOR:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS	
Evaporation Estimates														
Monthly Temp (T, °F)	39.6	42.9	45.2	49.3	55.4	60.4	64.8	64.6	60.4	52.4	45.0	40.6	51.8	Avg. T, °F
Monthly Temp (T, °C)	4.2	6.0	7.3	9.6	13.0	15.8	18.2	18.2	15.8	11.3	7.2	4.8	11.0	Avg. T, °C
Blaney Criddle Crop Factor (k)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(Avg k)
Blaney Criddle % of Annual Light (d)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Avg d)
Priestly Taylor Net Radiation (RN)	0.23	1.64	4.81	6.31	11.74	13.28	13.83	11.17	7.12	3.03	0.65	-0.12	6.35	(RN)
Potential Evapotranspiration (PET)	0.06	0.42	1.27	2.27	3.60	4.17	4.73	3.81	2.24	0.89	0.17	0.00	23.61	(PET)
Water Balance														
Effective Precipitation (P)	5.64	4.16	3.69	2.53	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.86	(P)
Interception Loss (IL)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(IL)
Snowpack Storage (SS)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	---	(SS)
Snowpack Ablation (SA)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(SA)
Snowmelt (SM)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(SM)
AvailableThroughfall (ATF)	5.64	4.16	3.69	2.53	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.86	(ATF)
Runoff (RO)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(RO)
Infiltration (I)	5.64	4.16	3.69	2.53	1.63	1.44	0.77	1.10	1.77	3.41	5.87	5.85	37.86	(I)
Soil Moisture in Root Zone (SW)	0.96	0.94	0.92	0.86	0.40	0.29	0.28	0.29	0.43	0.89	0.95	0.96	0.68	(SW)
Soil Moistue Deficit (PET-P)	0.00	0.00	0.00	0.00	1.97	2.73	3.98	2.71	0.47	0.00	0.00	0.00	11.84	(PET-P)
Actual Evapotranspiration (AET)	0.06	0.42	1.27	2.27	2.20	1.47	0.80	1.07	1.62	0.89	0.17	0.00	12.22	(AET)
Shallow Recharge (RS)*	5.58	3.75	2.45	0.30	0.00	0.00	0.00	0.00	0.00	2.03	5.66	5.84	25.64	(RS)
Perched Subflow (PS)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(PS)
Deep Recharge (RD)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(RO)

ANNUAL SUMMARY	P	IL	SM	ATF	RO	I	PET	AET	RS	PS	RD
	37.86	N/A	N/A	37.86	0.00	37.86	23.61	12.22	25.64	N/A	N/A

NOTES:
All values used in the Evaporation Estimates, Water Balance, and Annual Summary are in inches unless otherwise noted.
Abbreviations used in the annual summary are defined in the Evaporation Estimates and Water Balance.
* Modeled runoff consists of the sum of the fixed percentage of effective precipitation going to runoff and any infiltration rejected when saturation reaches the land surface.
** Shallow recharge is water that flows either to the shallow water table or through the bottom of the root zone (infiltration minus actual evapotranspiration from soil).
Deep recharge is water that flows through the till layer. Perched subflow is lateral, saturated flow above the till layer to adjacent discharge points.

APPENDIX C

Appendix C
Proposed Third Runway Fill Vadose Zone Modeling with Hydrus-2D

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Central values of the ranges passing the sieves were selected to represent the Groups' textures. Groups 1 and 2 were combined to represent "Type 1" fill described by Hart Crowser (1999) in designing the embankment where the Hydrus model was applied. "Type 2" fill of Hart Crowser was assumed to have the texture of Group 3 fill in **Table C-1**. Type 1 soils have few fines, whereas Type 2 soils are siltier. Passing ranges for sieve numbers 10 and 200 were interpolated from the combined textures of Groups 1 and 2 to supply the modeling requirement for percent gravel (USDA - retained by U.S. No 10 sieve) and percent silt and clay (passing U.S. No 200 sieve).

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Using the percentages of Type 1 and 2 fills in the general embankment; and the percentages of fines, sand, and gravel calculated for Type 1 and 2 fills; we calculated the following average bulk texture for the general embankment:

- General Embankment Percent Gravel 56%
- General Embankment Percent Sand 28%
- General Embankment Percent Silt and Clay 16%

These texture groups were further considered to form two media:

1. an inactive gravel fraction through which water typically does not move, surrounded by
2. an active matrix of sand and fines through which most unsaturated flow occurs.

The gravel fraction was rounded to 55 percent of the bulk general embankment volume from the 56 percent calculated above. The sand-plus-fines matrix was considered to be the remaining 45 percent. The sand-plus-fines matrix was calculated to be composed of an average of 63 percent sand and 37 percent silt; clay was assumed to be absent.

Hydrus-2D supports the U. S. Soil Salinity Laboratory's "neural network" computer program "Rosetta" to estimate soil-moisture characteristic curves and hydraulic conductivity distributions based on grain-size distributions. Rosetta draws upon the USDA's "UNSODA" soil property database[1] to derive relationships between easily measured grain-size fractions, bulk density, and other information and the key parameters required to approximate soil-moisture characteristic curves and unsaturated hydraulic conductivity distributions using the methods of van Genuchten (1980) and Mualem (1976). The maximum allowable bulk density of 2.0 grams per cubic centimeter (UNSODA 2.0) was used to represent the sand-plus-silt matrix. Appendix **Figures C-1 and C-2** show the predicted soil-moisture characteristic curve and unsaturated hydraulic conductivity distribution for the model of the general embankment fill matrix.

Appendix **Figures C-3 and C-4** present plots of texture for soil samples collected from the Phase I fill and the Maury Island gravel deposit. **Figure C-3** presents analyses of *whole samples from the Phase I fill only* and shows that the 55 percent gravel fraction and 16 percent fines fraction calculated for the general embankment by this method is near the middle of the range observed. However, most samples were observed to be coarser than the modeled fill. **Figure C-4** presents analysis of *the sand and fines fractions from Phase I and Maury Island samples*, and shows that the fraction of silt-plus-clay, as a percentage of the matrix, varied widely in the samples. The value of 36 percent (16/(16+28)) calculated for the general embankment by this method is near the middle of the range observed in Phase I soils, and falls between the values for "type 1" and "type 2" fills as it should. However, most field samples were measured to have a lower silt content than the modeled fill.

3 Modeling of Active and Inactive Fill Portions

The sand and silt matrix was modeled as an evenly distributed 45 percent of the general fill and all water flow was assumed to occur within this *active* matrix. To maintain a water balance while modeling water flow only through the active matrix, recharge values for grass on outwash (from the Hydrus model) were divided by 0.45 and used as the upper boundary condition flux in Hydrus. This can be viewed as forcing any precipitation percolating into clusters of gravel particles to be absorbed by the surrounding sand-and-silt matrix somewhere within the embankment. The output at the bottom of the Hydrus model was then multiplied by 0.45 to maintain a long-term water flux equal to grass-on-outwash recharge.

The gravel fraction was modeled as inactive because:

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

[1] The UNSODA database catalogs soil properties based upon textural and hydraulic property testing from 790 soil samples.

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

In a related model limitation, recharge is simulated as a constant for a given month. Recharge actually occurs as discrete precipitation events. The Hydrus model developed for the embankment fill does not predict saturation of the fill, whereas at least surface saturation could occur during intense precipitation events.

4 Design of Hydrus-2D Model

The Hydrus-2D model was setup to simulate seven portions of the proposed fill that differ in thickness only (see **Figure 3-5** of the main text for thickness variation). The analyses required only a one-dimensional simulation, and Hydrus-2D's finite element grid was set up to most closely approximate a purely 1-D solution. Two columns of nodes were specified with a horizontal separation of 15 cm (6 inches). The upper and lower 150 cm (6 feet) of the profile were assigned relatively detailed nodal definition, with vertical nodal spacings gradually increasing from 1 cm (0.4 inches) at the land surface and water table to 5 cm (2 inches). Between these high-definition top and bottom zones, vertical spacings transitioned to a maximum value of 15 cm (6 inches). Nodes representing the land surface were specified flux boundaries. The bottom two nodes were assigned the "water table" boundary condition, which is a constant head boundary equal to elevation head. "Observation nodes" were specified every 50 feet in the vertical profile, from which hydrographs of water content (or head) vs. time were extracted. Time-series data for volumetric flow rates exiting the bottom of the model domain at the water table boundary nodes could also be extracted.

Modeled hydraulic properties for the fill matrix were generated with Rosetta, based on the percentages of sand, silt and clay discussed in Section 2 of this appendix. Rosetta provides estimates of five parameters used to generate the soil moisture characteristic curve of **Figure C-1**: saturated water content, residual water content, "alpha", "N", and "M" (van Genuchten, 1980). Rosetta also provides an estimate of saturated hydraulic conductivity and a factor "L" used to relate the characteristic curve to the unsaturated hydraulic conductivity curve (Mualem, 1976). A default "L" value of 0.5 was assigned by Rosetta in Hydrdus-2D, and was used in this analysis. **Table C-3** presents the hydraulic parameters generated by Rosetta for the general fill matrix. The saturated hydraulic conductivity calculated by Rosetta was 1.35×10^{-4} cm/sec. This value is near the middle of the range presented in Freeze and Cherry (1979) for silty sand. It is near the high end of the reported glacial till range and lower than the clean sand and gravel ranges reported by Freeze and Cherry (1979).

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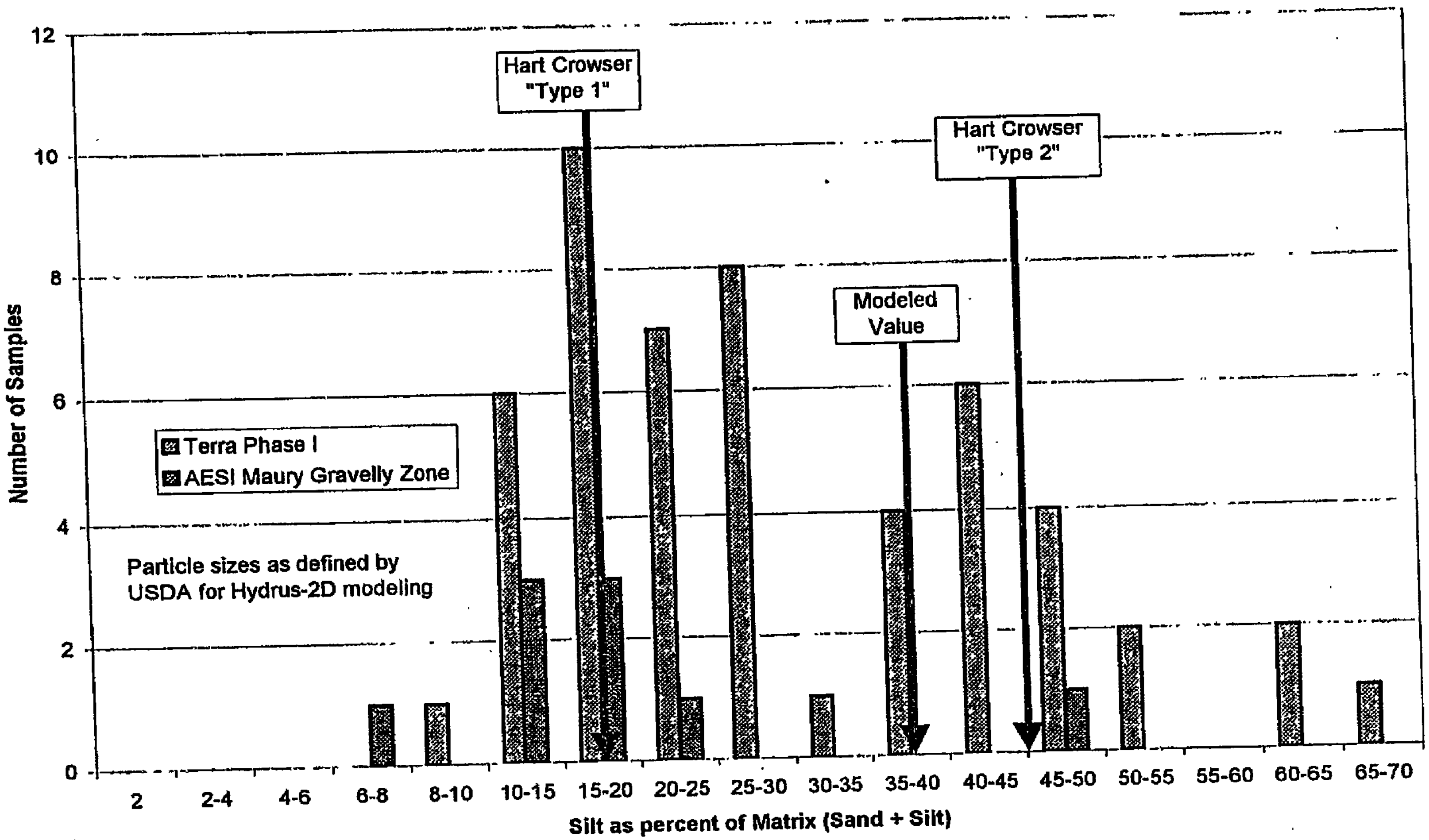
Figure C-4
Comparison of Silt vs Sand Fractions



Silt Comp ChartSeaTacDB-2.xls

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flow in the embankment. Experience with testing saturated hydraulic conductivity of soils similar in texture to the modeled fill suggests that the Rosetta-calculated value is too low for the general embankment fill; however, the reason for this discrepancy is the presence of large pores associated with gravels. Large pores associated with gravel deposits dominate saturated flow but are the first to become inactive as drainage occurs.

5 Modeling Approach

A transient simulation was performed in order to reach a "cyclic steady state" of annual water-content fluctuation within the fill. Cyclic steady state means that seasonal variations are the same for each successive year. Monthly stress periods were used, and monthly recharge estimates were applied to the top of the model. For each modeled fill thickness, hydrographs of water flux at the water table were used to identify that recurrent fluctuations occurred and therefore that a cyclic steady state had been reached (**Figure 3-12** of the main text). The cyclic fluxes at the water tables were multiplied by 0.45 to maintain mass balance (see Section 3 above), and exported to the Finite Difference Slice Model (**Appendix E**).

6 References

Freeze R. A. and J.A. Cherry, 1979, Groundwater, Prentice-Hall, Englewood Cliffs, New Jersey

Mualem, Y. 1976. A new model for predicting the hydraulic conductivity of unsaturated porous media, Water Resources Research, 12(3), 513-522.

Silliman S.E., and A.L. Wright, 1988, Stochastic Analysis of Paths of High Hydraulic Conductivity in Porous Media, Water Resources Research, Vol. 24, No. 11

Simunek, J., Senjna, M., van Genuchten, M. Th., 1999. Hydrus-2D/Meshgen-2D - Simulating Water Flow and Solute Transport in Two-Dimensional Variably Saturated Media, Version 2.0 dated April 1999, U.S. Salinity Laboratory, USDA/ARS. Distributed by International Groundwater Modeling Center

van Genuchten, M. Th. 1980. A closed form equation for predicting the hydraulic conductivity of unsaturated soils, Soil Science Society of America Journal, 44, 892

Table C-1
Particle Size Distributions Specified for Phase I Fill

	Sieve Size	Percent Passing Lower Limit	Percent Passing Upper Limit	*Central Value of Range*
Group 1	6-inch	100		
	3-inch	70	97	*83.5*
	3/4-inch	50	77	*63.5*
	U.S. No 4	30	50	*40*
	U.S. No 10 (sand)	*13*	*28*	*20.5*
	U.S. No 40	3	15	*9*
	U.S. No 200 (silt and clay)	0	5	*2.5*
Group 2	6-inch	100		
	3-inch	70	97	*83.5*
	3/4-inch	50	85	*67.5*
	U.S. No 4	30	65	*47.5*
	U.S. No 10 (USDA sand)	*14*	*43*	*28.5*
	U.S. No 40	5	30	*17.5*
	U.S. No 200 (silt and clay)	0	12	*6*
Group 3[2]	6-inch	100		
	U.S. No 4	50	95	*72.5*
	U.S. No 10 (USDA sand)	*31*	*73*	*52*
	U.S. No 40	20	60	*40*
	U.S. No 200 (silt and clay)	12	35	*23.5*
Combined Groups 1 and 2[3]	*U.S. No 10 (USDA sand)*			*24.5*
	U.S. No 200 (silt and clay)			*4.25*

[2] Soil Group 3 is "Type 2" fill as defined in Appendix B to the Wetland Functional Assessment and Impact Analysis by Parametrix in 1999 (Geotechnical Engineering Report, 404 Permit Support, Third Runway Embankment Sea-Tac International Airport, Hart Crowser 1999).
[3] Soil Groups 1 and 2 comprise "Type 1" soils as defined in Appendix B to the Wetland Functional Assessment and Impact Analysis by Parametrix, 1999 (Geotechnical Engineering Report, 404 Permit Support, Third Runway Embankment Sea-Tac International Airport, Hart Crowser 1999).

Table C-2
Calculations on Embankment Composition

Cross Sectional Area of Type 1 fill Zone Near West Wall	~18,000	sq ft (in section)
Cross Sectional Area of General Embankment	~85,000	sq ft (in section)
Total Embankment Type 1 fill	40%	Hart Crowser, 1999
Total Embankment Type 2 fill	60%	Hart Crowser, 1999
West Wall Zone Type 1 fill content	100%	Hart Crowser, 1999
West Wall Zone Type 2 fill content	0%	Hart Crowser, 1999
General Embankment Type 1 Fill Content	~30%	Calculated
General Embankment Type 2 Fill Content	~70%	Calculated

Table C-3 Summary of Hydraulic Parameters Used for Fill Matrix in the Hydrus-2D Model

Sand Fraction of matrix	0.63
Silt Fraction of matrix	0.37
Clay Fraction of matrix	0
Saturated Volumetric Water Content of matrix	0.25
Residual Volumetric Water Content of matrix	0.02
"alpha" (1/cm)	0.088
"N"	1.35
Saturated Hydraulic Conductivity (cm/sec) of matrix	1.35×10^{-4}

Figure C-1
Soil Moisture Characteristic Curve for General Embankment Matrix

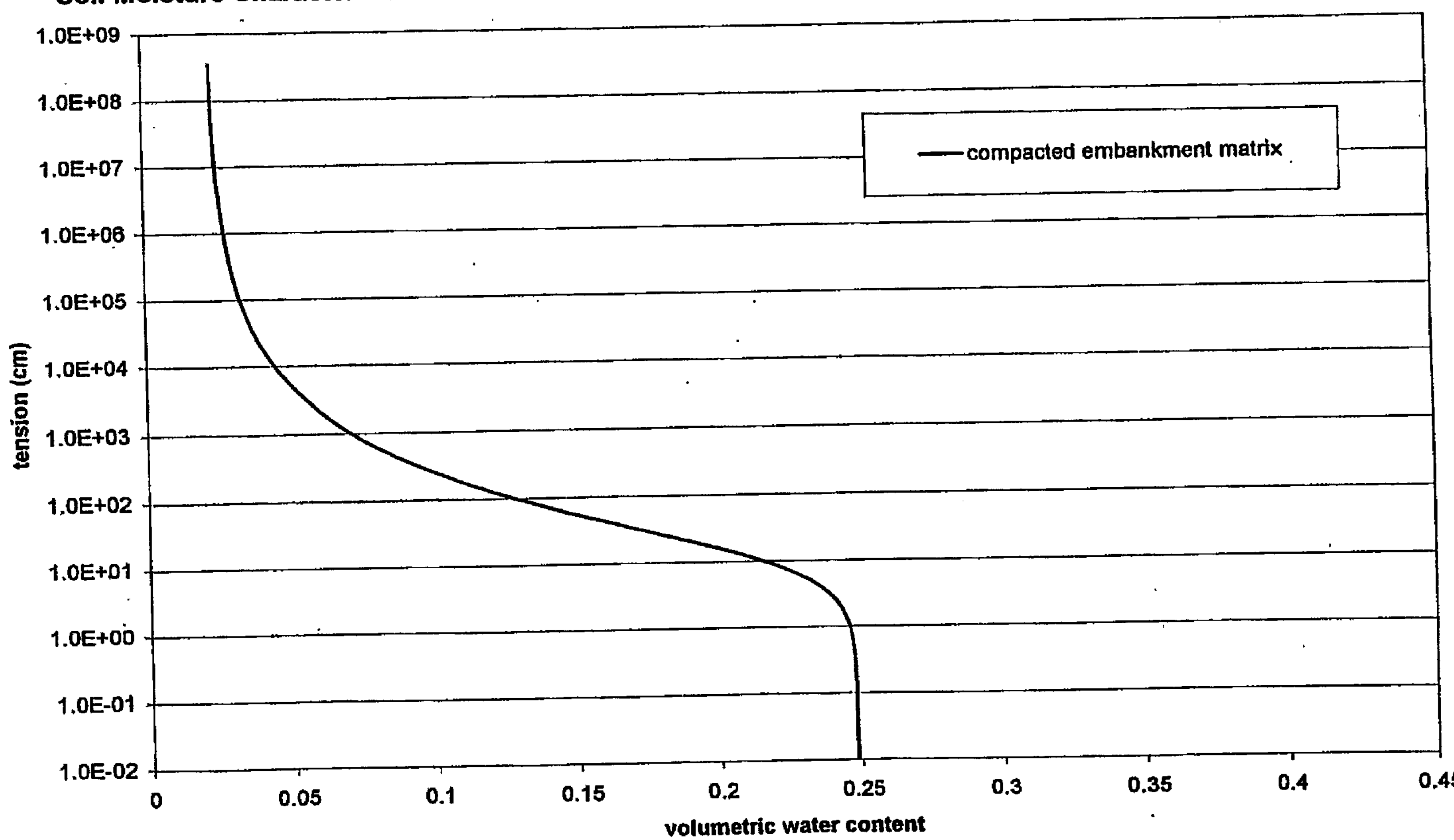
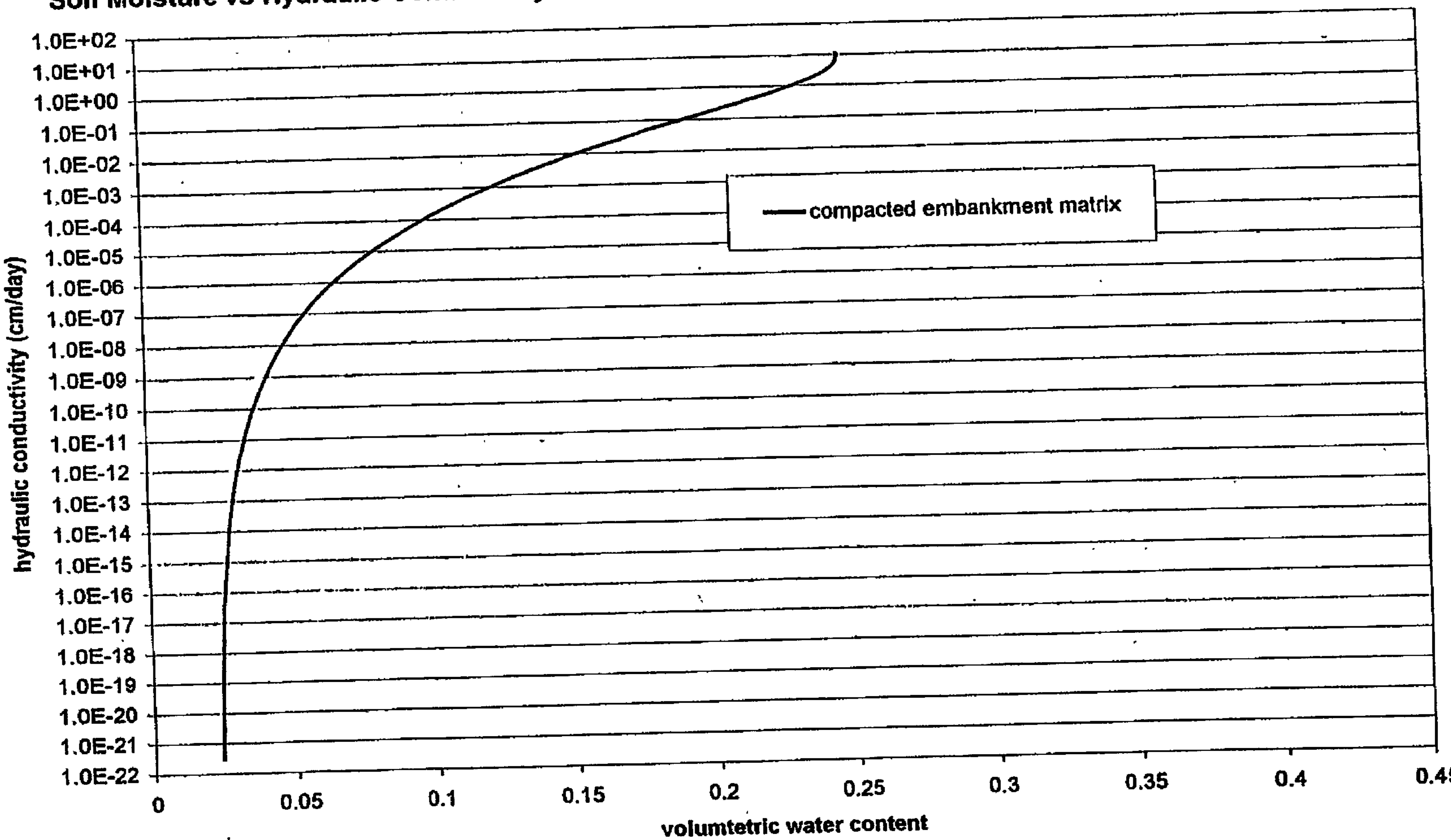


Figure C-2
Soil Moisture vs Hydraulic Conductivity for General Embankment Matrix



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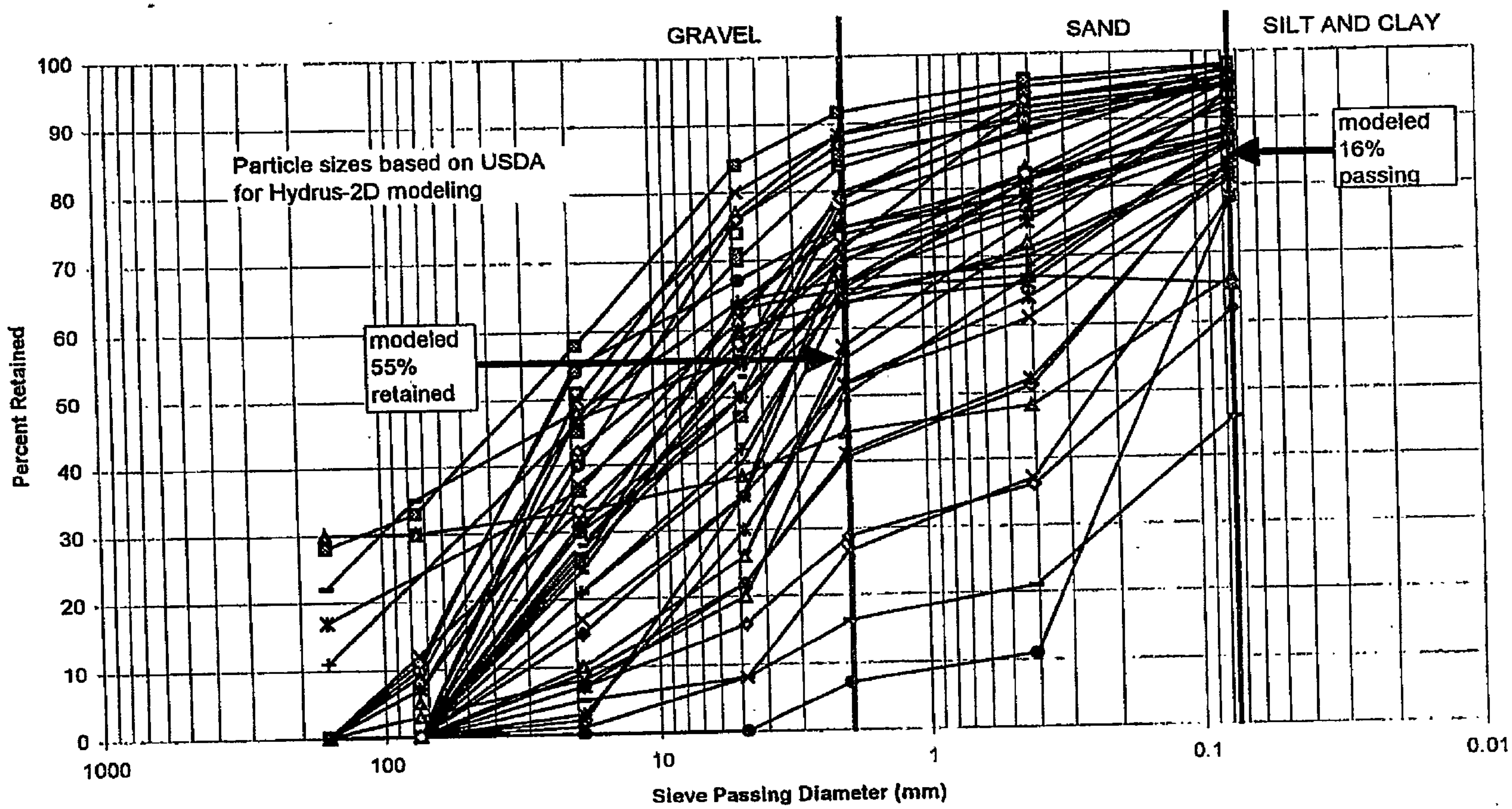
KcurveHydrus Soils.xls

Figure C-3
Grain Size Analyses of Whole Samples from Phase 1 Fill



APPENDIX D

MEMORADUM

TO: File
FROM: Russ Prior
DATE: 4-12-00
RE: Geologic Interpretations by AESI

The purpose of this memorandum is to document a review of the SeaTac area geologic interpretation by AESI. Their interpretation provides the conceptual model, which is the basis for a proposed multi-layered groundwater model.

Russell Prior of Pacific Groundwater Group reviewed the following documents:

- STIA Ground Water Study, Model Boundary Presentation, (No Date), Associated Earth Sciences, Inc. and S.S. Papadopulos and Assoc., Inc (figures only)

- Map of buyout area showing water supply wells

- 1999 Hydrogeologic Characterization Report, City of Auburn, by Pacific Groundwater Group, Cross-section A-A' (based on USGS interpretation)

- Geologic Map by Booth and Waldron (in press), digitized by AESI

General Comments

In general, the geologic interpretation is made difficult because maps do not have labeled wells. This is true for the contour maps showing the elevations and thicknesses of the various units and also for the map (Figure 4) showing the location of the cross-section lines. At the very least the maps should be presented with section lines for easier location of wells used in the interpretation. Figure 4 should present topography rather than streets.

In several cases the contouring of the top of the hydrostratigraphic layers does not coincide with the cross sections. It is not known how the contours were generated for each layer. Were they generated based on top elevations picked off of the cross-sections or were they generated directly from point data?

There are many instances where the cross-sections and the contour maps are not consistent. Many of the inconsistencies exist near the ends of the cross-sections. Some of these inconsistencies are indicated below but there is no attempt to document all of them herein.

Specific Comments on Cross-Sections

Cross-Section B-B'
At the Des Moines Creek crossing, cross-section B-B' indicates that layer C2 crops out. This is consistent with recent mapping completed by Booth and Waldron (in press).

However, it is not consistent with USGS mapping and cross-sections (Woodward, et al) where Vashon Advance is mapped.

Cross-section B-B' shows a general pinching-out of the upper horizons to the south. Most notably, horizon C1 is shown to pinch-out completely at KCWD75 Well #1. In general, this pinching-out of horizon C1 is understood to be based on the Booth interpretation. However, this interpretation presents some difficulties. For instance it requires interpreting blue clay encountered in wells 23N4E22N1 and 22N4E09P1 differently. Both wells encountered blue clay at elevation 200 feet. In well 22N1, this blue clay is interpreted to be F2 yet in 09P1 this blue clay is interpreted to be F3. Not only are these two units encountered at the same elevation, they are also approximately the same thickness.

There is also a problem with consistency between the southern portion of cross-section B-B' and the contour map showing the thickness and top of Layer C1. Why do any contours exist for unit C1 thickness in an area that is interpreted to have none on the cross-section?

Cross-Section C-C'
On the west end of this section a deep boring log exists that has Layer C2 labeled on the east side and Layer F2 labeled on the west. This is assumed to be a typographical error.

Cross-Section D-D'
On the Duwamish River bluff (middle to southern portion of the section) there must be a typo. It indicates Layer C1 overlaying Layer F1. It is assumed that this is intended to be Layer C0.

Cross-Section E-E'
The southern end of this cross-section indicates that layer C1 does not exist. This interpretation is inconsistent with Booth and Waldron's mapping, which indicates the presence of Qva underneath Vashon Till. If correctly interpreted to be Layer C1, then the next layer down (Well 22N4E20L1) would be Layer C2 to be consistent with the mapping.

Cross-Section F-F'
On the eastern end of this section, the top of Layer C2 reaches an elevation of over 400 feet. However, the contouring of the top of Layer C2 does not show this. The same location in Figure 12 shows a maximum elevation of C2 at around 300 to 320 feet. It is not clear if the contouring depicts the top of the water table in this vicinity.

Cross-Section H-H'
The western portion of cross-section H-H' does not appear to be consistent with the geologic mapping of Booth and Waldron. On the bluff west of Miller Creek, the geologic map indicates that the Pre-Fraser fine-grained deposit crops out. The cross-section depicts this bluff as underlain by Layer F2, which correlates with Transitional Beds.

The implication of the geologic mapping is that the Vashon Advance (C1) does not exist in the eastern portion of the upland west of Miller Creek. However, AESI's Figure 7 indicates a thickness on the order of 50 feet here.

Structure Contour Maps

The contour maps that depict the thickness and top elevation for the hydrostratigraphic units appear to have been generated by computer and are based on limited point data. The contours are characterized by many closed contours (highs and lows) around specific data points. The effect is one of many independent "hills" and "holes" which are likely not real. If the pre-Vashon topography looked similar to today then there should be a general north-south system of ridges. Such is not the case with the contour maps. Use of a purely digital process to generate the maps contributes to a non-geologic interpretation.

There appears to be an area where the contours are wrong. This area is in the southern portion of cross-section B-B'. In comparing the contour maps for the top elevations of units C1 and C2, the top of unit C1 is indicated as lower than that of C2. This relationship is not possible and is likely a relict of the contouring technique.

Map Showing Location of Domestic Wells

A map provided by AESI shows the location of several domestic water supply wells in the vicinity immediately west of the airport. Several of the wells shown are either incorrectly located or incorrectly labeled. Two wells in Section 31 (T23NR4E) provide examples. Well 23N4E31H1 is located in the NE ¼ of the NE ¼ of the section. This well should either be relabeled or relocated to the SE ¼ of the NE ¼. A well, labeled 23N4E32F2, is in the SE ¼ of the NE ¼ of section 31. This well should be relabeled or belongs in the SE ¼ of the NW ¼ of section 32.

This map was apparently generated from wells that have well logs on file with the Department of Ecology. It is clear that AESI's map does not include all of the domestic water supply wells. This finding is based on a one day field visit, which traversed about half of the buyout area. During this visit, two drilled wells and eight dug wells were located. The map provided by AESI indicates only two wells in the buyout area, one of which is either mis-located or mislabeled.

This map shows only a small area of the total model domain. If a similar number of mis-located or mislabeled wells exist in other parts of the model domain, then there could be some problems with the geologic interpretation.

APPENDIX E

Appendix E
Finite Difference Models of Proposed Third Runway Fill Area

The following three computer-based groundwater models were used for this project:

- Pacific Groundwater Group Recharge Model
- Hydrus-2D
- Finite Difference slice model (slice model)

The recharge model was used to calculate recharge for the current and post construction conditions at the proposed third runway fill and borrow sources south of the runways. Hydrus was used to model the movement of water between the root zone and the water table beneath the runway fill. The slice model was used to accumulate and move recharge downgradient under current and built conditions, to the Miller Creek riparian wetlands. This appendix describes the input and functions of the slice model. The main text presents basic characterization data, model results, and interpretation.

1 Method Overview

The slice model was used to simulate groundwater flow for both the current and built conditions. Two versions of the model were constructed to represent expected differences in flow system geometry and hydraulic properties. The slice model is based on a quasi-two-dimensional finite-difference formulation of the partial differential equation describing transient groundwater flow through a saturated medium. Model cells were only connected to laterally adjacent neighbors as opposed to overlying or underlying cells – thus the quasi-two-dimensional nature of the model. Each model cell can contain up to three different "soil layers", differing in thickness and hydraulic conductivity. The bottom elevation of each cell is defined by the top of the till layer, and downward flow through the till can be simulated. For each cell, the model also specifies storage coefficient and recharge per time-step. The model assumes unconfined flow (variable transmissivity) under horizontal gradients defined by head differences between adjacent cells. The model was implemented in Microsoft Excel, using direct (explicit) methods to solve the finite-difference equation.

Recharge inflow to the slice model was estimated with the recharge and Hydrus models. The recharge model calculates the amount and timing of shallow groundwater recharge percolating through the root zone based on a daily soil moisture budget. Estimates of recharge from the recharge model are appropriate to describe water-table inflows where the depths to water are relatively shallow. This was the case for the current condition, where shallow till is modeled to occur within 10 feet of the land surface, and wetlands (where present) maintain saturation at near the land surface year-round. Monthly recharge estimates from the recharge model were used as input to the slice model under the current condition. For the built condition, Hydrus-2D was used to predict changes in the timing of recharge from the land surface as it moves downward through the embankment vadose zone. Hydrus is a finite-element, variably saturated flow model which uses Richard's Equation to simulate unsaturated flow. Output from the recharge model was used as input to the Hydrus model, and output from Hydrus was used as input to the slice model.

2 Slice Model Geometry

Figures 3-5a and b of the main text show the geometry and simplified geology of the modeled cross sections (slices). The bottom axis of that figure shows the model cell numbers. The current condition geology has been simplified into the following layers and materials. The till and subsoil layers are shown on main text **Figure 3.5a.**

- surface soils (2.5 feet thick everywhere)
- wetland and outwash subsoils (7.5 feet thick, not present on the east)
- glacial till (10 feet thick everywhere)

For estimating lateral flow and accumulation of recharge, the model explicitly simulated both soil layers present above the till. The surface soil layers are derived from wetland conditions on the west, outwash sediments in the center, and very shallow glacial till on the east. Subsoil materials were not present in the eastern model domain, due to the shallow presence of till. The layers were divided into model cells with a horizontal dimension of 25 feet.

To model the built condition, the surficial soils were removed and a 4-foot drain layer was added above the scraped land surface as designed by Hart Crowser (1999). The drain was modeled as a third soil layer present within each model cell. In the eastern model domain, only the drain layer and the till was assumed present due to removal of surficial soils.

3 Material Properties

Material properties were assigned in accordance with the conceptual model presented in Section 3.2.2 of the main text.

Under the current condition, surficial soils derived from wetland conditions were assigned a hydraulic conductivity of 1 ft/day, whereas soils derived from till and outwash were assigned hydraulic conductivities of 4 ft/day. These values are near the low end of permeability ranges reported for Snohomish (wetland), Alderwood (till), and Everett (outwash) soils by the SCS for King County (Soil Conservation Service, 1973). Outwash subsoils were modeled with a hydraulic conductivity of 6 feet per day. Wetland subsoils were assumed to consist of 33 percent sandy outwash and 67 percent fine-grained and peaty soils with a resulting hydraulic conductivity of 2.65 ft/day. Glacial till was modeled with a vertical hydraulic conductivity of 0.004 ft/day, except below the wetlands where it was artificially set to zero to prevent deep percolation in that area where groundwater discharges. The drain layer added for the built condition was modeled with a hydraulic conductivity of 300 ft/day. The embankment fill properties are not explicitly modeled in the slice model because they are modeled in Hydrus-2D. Specific yield was equal to 0.3 everywhere.

4 Inflow and Outflow

The explicit formulation of the finite difference equation calculates inflows and outflow to each model cell for each time-step of the transient simulation. Under the current condition, the following inflows and outflow were simulated for each model cell:

Inflows:

- recharge to the water table
- groundwater flow from adjacent (upgradient) model cell
- infiltration of surface flow from adjacent (upgradient) model cell

Outflows:

- downward seepage through underlying till
- groundwater flow to adjacent (downgradient) model cell
- surface flow to downgradient model cell

The slice model simulated the occurrence of surface flow when inflows to a cell during any time-step were greater than maximum outflows plus available storage. The portion of available inflows that could not be accommodated in the subsurface was passed on to the next downgradient cell as surface flow. Because there was no term for surface storage, any surface flows generated were assumed to pass through the model domain during a single time-step. Under the built condition, the surface flow terms were removed because the drain layer could accommodate all predicted inflows. Because the drain layer is buried beneath the embankment, all flow remains in the subsurface.

Recharge inflow to the water table was specified on a cell-by-cell basis based on the results of the recharge model (for the current condition) and the results of the Hydrus model (for the built condition). **Table E-1** shows the recharge conditions assigned to the classes of model cells used for the current condition simulation. Also for the current condition, **Table E-2** shows the classes assigned to each model cell and **Table E-3** shows the monthly recharge values assigned to each class.

For the built condition, recharge inflows to the water table were based on Hydrus model output for various embankment thicknesses. Each model cell was assigned to one of eight recharge schedules depending on whether the overlying embankment thickness was closest to 0, 30, 50, 70, 90, 110, 130, or 150 feet. **Table E-4** presents a summary of cell type information for the built simulation, **Table E-5** shows variables for individual model cells for the built condition including embankment modeled thickness, and **Table E-6** presents the monthly values of recharge for each generalized category of embankment thickness. It should be noted that all model cells beneath the 225-foot wide runway (cells 26 through 34) received zero recharge, and cells within the western retaining wall of the embankment were assigned a recharge schedule consistent with zero time-lag through the vadose zone. Recharge is assumed to pass quickly through the western Type-1 fill section due to its low fines content. It should also be noted that the recharge schedule for each model cell is independent of its neighbor. Modeling in Hydrus did not include simulation of lateral interaction between different portions of the fill.

Groundwater inflows and outflows were calculated based on effective transmissivities and gradients between adjacent cells. Transmissivity was calculated for each cell by summing the product of the saturated thickness and hydraulic conductivity of each soil layer. The transmissivity of a given cell was used to calculate the groundwater outlow from that cell. Gradient was defined as the head difference divided by the spacing between cells. More detailed explanation of calculation of groundwater flow is provided in Section 5 of this appendix. No groundwater inflow was assumed into the eastern edge of the model.

Outflow via downward seepage through underlying till was based on the till hydraulic conductivity and variable heads below and above the till. Head at the top of the till was equal to the value calculated for each model cell. Head at the bottom of the till was assumed equal to bottom elevation of the till layer in the eastern upland portion of the model (cells 1-24) and the mid-point of the till layer in the middle of the model slice (cells 25-33). These assignments lead to vertical hydraulic gradients of about 1.0 and 0.5, respectively, with the saturated thickness of each model cell effecting the vertical gradient through the till. Instead of assigning a vertical gradient of zero in the wetland, the hydraulic conductivity was set equal to zero.

Surface flow was calculated in the current condition simulation to accommodate the portion of accumulated recharge that the groundwater system could not conduct. Each model cell has a maximum flow capacity, based on its maximum hydraulic gradient (i.e. the gradient of the land surface) and its maximum transmissivity. When the cell is fully saturated (i.e. to the land surface) conditions may occur where the combined recharge and groundwater inflow estimated for that cell cannot be accommodated or passed on to the next cell within the subsurface. In this case, the model routes the excess portion of inflow to a surficial flow term and passes it on to the next downgradient cell as surface outflow. If the downgradient cell can accommodate the surface flow along with recharge and groundwater inflows, then the surface flow is allowed to infiltrate. The surface inflow for a particular time-step is limited by either the volume of surface flow available from the upgradient cell, the excess storage capacity of the downgradient cell, or the infiltration capacity of that cell (as defined by the permeability of the surficial soil). If a portion of upgradient surface flow does not infiltrate to a cell, it is passed on to the next downgradient cell. In this manner, surface flow can accumulate over the length of the model.

5 Modeling Approach

The explicit formulation of the transient finite difference equation for groundwater flow calculates the various inflows and outflows for a model cell at a given time-step (t) based on conditions defined in the prior time-step (t-1). The explicit finite difference equation can be viewed as a mass balance, where inflows minus outflows equal the change in storage for the model cell. The following mass balance represents the terms included in the finite difference equation:

$$Rech + GW_{in} + SW_{in} - Till - GW_{out} - SW_{out} = \Delta S \qquad (1)$$

Recharge input (Rech) is calculated for each model cell by multiplying the recharge rate (applicable to the time of year) by the length of the time-step and top area of the cell. Lookup tables, presented in **Tables E-3** and **E-6**, were used to determine recharge rates for each time-step. The top area of the cell is the product of its length (25 feet) and the width of the slice model (1foot). By multiplying the recharge rate by a time interval and area, a volume is calculated for the time-step in question.

Groundwater inflows and outflows (GW_{in} and GW_{out}) were calculated using the same approach. Inflow and outflow volumes were calculated by multiplying the length of the time-step by the rate of groundwater flow between adjacent cells. Groundwater outflow was calculated by multiplying the cell's transmissivity by the hydraulic gradient between the cell and its downgradient neighbor. For each cell, transmissivity is calculated by summing products of saturated thickness and hydraulic conductivity for each of the soil layers included. Saturated thickness is determined from the head values calculated in the previous time-step (t-1). Groundwater inflow is defined as the outlfow from the cell's upgradient neighbor.

The volume of downward seepage through the till layer (Till) is equal to the product of the time-step interval, the top area of the model cell, and the calculated flow rate through the till. This flow rate is the product of the hydraulic conductivity of the till and the hydraulic gradient across the till, where the hydraulic gradient defined as:

$$(h_{cell} - h_{tb})/b \qquad (2)$$

where: h_{cell} = the head value of the model cell from the previous time-step
h_{tb} = the head value of the bottom of the till (assumed constant)
b = the thickness of the till (10 feet).

The mass balance, defined above in equation 1, is performed for every cell for every time-step of the model simulation. For each time-step, mass balance proceeds in consecutive order from upgradient to downgradient cells. In certain instances, when recharge and/or available storage are low, adjustments were required to the till outflow term for the groundwater flow system to ensure that predicted outflows did not exceed available inflows and storage. When such instances occurred, till seepage was scaled back so as not to exceed available volumes.

For the current condition simulation, surface inflows and outflows were defined based on the following set-up rules:

1. Surface flow is accumulated from cell to cell in a downgradient direction. Losses and gains to surface flow calculated for a given cell are applied to the accumulated flow volume from the adjacent, upgradient cell.
2. Surface inflow to a cell (SW_{in}) can only occur when cumulative surface flow exists from upgradient, and when storage capacity still exists in the cell after all groundwater system inflows (Rech and GW_{in}) and outflows (Till and GW_{out}) are applied.
3. The portion of the cumulative surface-flow volume allowed to infiltrate from upgradient is equal to the minimum value among the cumulative surface-flow volume, the maximum infiltration volume allowable over the time-step, and the available cell storage after all the groundwater inflows and outflows are accounted for. The maximum allowable infiltration volume is equal to the product of the top area of the cell, the length of the time-step, and the hydraulic conductivity of the surficial soils.
4. Surface outflow from a cell (SW_{out}) can only occur when there is no surface inflow, and the groundwater terms in the mass balance (inflows minus outflows) exceed the available storage of the cell.
5. Surface outflow is calculated as the groundwater system inflows minus the groundwater system outflows minus the change in storage (ΔS) required to bring the model cell to full-thickness saturation.

6 Time Steps, Initial Conditions, and Length of Simulation

Time stepping within the model was designed to maintain numerical stability of the explicit finite difference formulation, in accordance with recommendations by Anderson and Woesner, 1982). A critical (maximum) time-step can be estimated based on the following formula:

$$dt = 0.5*S*a^2/T \qquad (3)$$

where:
dt = critical time-step length
S = storage coefficient
a = length of model cell (25 ft)
T = transmissivity

For the current condition, the critical time-step was estimated to be 1.7 days, and a value of 1 day was used. For the built simulation, the critical time-step was estimated to be 0.4 days; however a value of 0.1 day was required for stability. In the built case, it was necessary to rigorously define a plausible initial condition before the time-step value of 0.1 day provided stable results. This was performed by running the model over a long time period with a fixed recharge input and a time-step of 0.1 days.

The model was run for a single year, over and over again, until a repeating cyclic pattern was achieved. Repetition was confirmed by comparing the results of one year with the results of the following year. Model simulations were initiated on the first day of February. This date was chosen because it follows the three months of highest shallow recharge (December through January). For the current condition, a fully saturated initial condition was estimated at the onset of model simulation and several years were required to achieve a repeating cyclic pattern. For the built condition, zero saturation was assumed at the onset of simulation, using a time-step of 0.1 and recharge rates for February. The stable head distribution calculated for February recharge was used as an initial condition for the annual simulations. A minimum of three years was required to achieve a repeating cyclic pattern for the built condition.

7 References

Hart Crowser Inc., 1999, Geotechnical Engineering Report, 404 Permit Supprt, Third Runway Embankment, Sea-Tac International Airport

McDonald , M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-differences groundwater flow model; U.S. Geological Survey Techniques of Water Resources Investigations, Book 6, Chapter A1

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

Table E-1
Model Parameters for the Current Condition Simulation

<u>Model Parameters for Cells Types</u>

	Cell Type 1	Cell Type 2	Cell Type 3	Cell Type 4	Cell Type 5
Surficial Soil	Alderwood	Everett	Everett	Everett	peaty
Aquifer Materials	till derived soil	outwash stringers	outwash stringers	outwash stringers	peat & outwash
Land Cover	forest	forest	impermeable	grass	grass/forest
Wetland/Upland	upland	upland	upland	upland	wetland
Bottom Layer Hydraulic Conductivity (ft/d)	4	6	6	6	2.7
Top of Bottom Layer (ft above till)	2.5	7.5	7.5	7.5	7.5
Middle Layer Hydraulic Conductivity (ft/d)		4	4	4	1
Top of Middle Layer (ft above till)		10	10	10	10
Upper Layer Hydraulic Conductivity (ft/d)					
Top of Upper Layer (ft above till)					
Maximum Saturated Thickness (ft)	2.5	10	10	10	10
Gradient of Top of Till (ft/ft)	18.8%	18.8%	18.8%	18.8%	3.6%
Full Thickness Hydraulic Conductivity (ft/d)	4	5.5	5.5	5.5	2.2
Maximum Subsurface Flow (cfd)	1.9	10.3	10.3	10.3	0.8
Maximum Downgradient Flow (cfd)	10.3	10.3	10.3	0.8	0.0
Cell Length (ft)	25	25	25	25	25
Specific Yield	30%	30%	30%	30%	30%
Maximum Storage (cubic ft)	18.75	75	75	75	75

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

<u>Model Constants</u>	
Till Thickness (ft)	10
Till Permeability Beneath Uplands (ft/d)	0.004
Till Permeability Beneath Wetlands (ft/d)	0
Outwash Permeability (ft/d)	6
Peat Permeability (ft/d)	1
Percent Outwash in Peaty Aquifer	33%
Peaty Aquifer Permeability (ft/d)	2.65
Drain Material Permeability (ft/d)	
Till Derived Soil Permeability (ft/d)	4
Outwash Derived Soil Permeability (ft/d)	4
Wetland Surficial Soil Permeability (ft/d)	1

<u>Time Stepping</u>	
"delta X" (ft)	25
maximum transmissivity (ft^2/d)	55
minimum storage coefficient	30%
maximum time step (d)*	1.70
user defined model timestep (d)	1.00

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

Table E-2
Model Parameters for Individual Cells in the Current Condition Simulation

Cell ID	Distance from Outlet	Top of Till Elevation	Cell Length (ft)	Cell Type	Recharge Class	Head at Bottom of Till	Maximum Subsurface Outflow (cfd)	Maximum Runoff Infiltration (cfd)	Specific Yield	Maximum Storage (cf)	Land Surface Elevation
1	1137.5	385.0	25	1	A	375.0	1.9	100	30%	18.8	387.5
2	1112.5	380.4	25	1	A	370.4	1.9	100	30%	18.8	382.9
3	1087.5	375.7	25	1	A	365.7	1.9	100	30%	18.8	378.2
4	1062.5	371.0	25	1	A	361.0	1.9	100	30%	18.8	373.5
5	1037.5	366.3	25	1	A	356.3	1.9	100	30%	18.8	368.8
6	1012.5	361.6	25	1	A	351.6	1.9	100	30%	18.8	364.1
7	987.5	356.9	25	1	A	346.9	1.9	100	30%	18.8	359.4
8	962.5	352.2	25	1	A	342.2	1.9	100	30%	18.8	354.7
9	937.5	347.5	25	1	A	337.5	1.9	100	30%	18.8	350.0
10	912.5	342.9	25	1	A	332.9	1.9	100	30%	18.8	345.4
11	887.5	338.2	25	1	A	328.2	1.9	100	30%	18.8	340.7
12	862.5	333.5	25	1	A	323.5	1.9	100	30%	18.8	336.0
13	837.5	328.8	25	1	A	318.8	1.9	100	30%	18.8	331.3
14	812.5	324.1	25	1	A	314.1	1.9	100	30%	18.8	326.6
15	787.5	319.4	25	1	A	309.4	10.3	100	30%	18.8	321.9
16	762.5	314.7	25	2	B	304.7	10.3	100	30%	75.0	324.7
17	737.5	310.0	25	2	B	300.0	10.3	100	30%	75.0	320.0
18	712.5	305.4	25	2	B	295.4	10.3	100	30%	75.0	315.4
19	687.5	300.7	25	2	B	290.7	10.3	100	30%	75.0	310.7
20	662.5	296.0	25	2	B	286.0	10.3	100	30%	75.0	306.0
21	637.5	291.3	25	2	B	281.3	10.3	100	30%	75.0	301.3
22	612.5	286.6	25	2	B	276.6	10.3	100	30%	75.0	296.6
23	587.5	281.9	25	2	B	271.9	10.3	100	30%	75.0	291.9
24	562.5	277.2	25	2	B	267.2	10.3	100	30%	75.0	287.2
25	537.5	272.5	25	2	B	267.5	10.3	100	30%	75.0	282.5
26	512.5	267.9	25	2	B	262.9	10.3	100	30%	75.0	277.9
27	487.5	263.2	25	2	B	258.2	10.3	100	30%	75.0	273.2
28	462.5	258.5	25	2	B	253.5	10.3	100	30%	75.0	268.5
29	437.5	253.8	25	2	B	248.8	10.3	100	30%	75.0	263.8
30	412.5	249.1	25	3	Z	244.1	10.3	100	30%	75.0	259.1
31	387.5	244.4	25	4	C	239.4	10.3	100	30%	75.0	254.4
32	362.5	239.7	25	4	C	234.7	10.3	100	30%	75.0	249.7
33	337.5	235.0	25	4	C	230.0	0.8	100	30%	75.0	245.0
34	312.5	232.3	25	5	D	222.3	0.8	25	30%	75.0	242.3
35	287.5	231.4	25	5	D	221.4	0.8	25	30%	75.0	241.4
36	262.5	230.5	25	5	D	220.5	0.8	25	30%	75.0	240.5
37	237.5	229.6	25	5	D	219.6	0.8	25	30%	75.0	239.6
38	212.5	228.7	25	5	D	218.7	0.8	25	30%	75.0	238.7
39	187.5	227.8	25	5	D	217.8	0.8	25	30%	75.0	237.8
40	162.5	226.9	25	5	D	216.9	0.8	25	30%	75.0	236.9
41	137.5	226.0	25	5	D	216.0	0.8	25	30%	75.0	236.0
42	112.5	225.1	25	5	D	215.1	0.8	25	30%	75.0	235.1
43	87.5	224.2	25	5	D	214.2	0.8	25	30%	75.0	234.2
44	62.5	223.3	25	5	D	213.3	0.8	25	30%	75.0	233.3
45	37.5	222.4	25	5	D	212.4	0.8	25	30%	75.0	232.4
46	12.5	221.5	25	5	D	211.5	99999.0	25	30%	75.0	231.5

Table E-3
Specified Rates of Recharge for Different Recharge Classes in the Current Condition Simulation

Daily Recharge Rates (ft/d)

Month	Days	Cum Days	forest-till A	forest-outwash B	grass outwash C	mixed wetland D	road impermeable Z
Feb-1	28	0	0.010	0.011	0.010	0.011	0.000
Mar-1	31	28	0.007	0.007	0.007	0.007	0.000
Apr-1	30	59	0.002	0.002	0.001	0.002	0.000
May-1	31	89	-0.002	0.000	0.000	-0.003	0.000
Jun-1	30	120	0.000	0.000	0.000	-0.006	0.000
Jul-1	31	150	0.000	0.000	0.000	-0.010	0.000
Aug-1	31	181	0.000	0.000	0.000	-0.007	0.000
Sep-1	30	212	0.000	0.000	0.000	-0.002	0.000
Oct-1	31	242	0.003	0.003	0.002	0.005	0.000
Nov-1	30	273	0.014	0.014	0.014	0.014	0.000
Dec-1	31	303	0.015	0.015	0.014	0.015	0.000
Jan-1	31	334	0.014	0.014	0.014	0.014	0.000

Monthly Recharge Volumes (Inches)

Month	forest-till A	forest-outwash B	grass outwash C	mixed wetland D	road impermeable Z
Feb-1	3.40	3.58	3.49	3.55	0
Mar-1	2.60	2.62	2.44	2.55	0
Apr-1	0.78	0.78	0.52	0.68	0
May-1	-0.58	0.00	0.00	-1.14	0
Jun-1	-0.02	0.00	0.00	-2.19	0
Jul-1	0.00	0.00	0.00	-3.56	0
Aug-1	0.00	0.00	0.00	-2.67	0
Sep-1	0.00	0.00	0.00	-0.55	0
Oct-1	0.97	1.29	0.63	1.95	0
Nov-1	5.20	5.20	4.95	5.15	0
Dec-1	5.46	5.46	5.30	5.42	0
Jan-1	5.26	5.26	5.17	5.23	0
TOTAL	23.04	24.19	22.50	14.43	0.00

Table E-4
Model Parameters for the Built Simulation

Model Parameters for Cells Types

	Cell Type 1	Cell Type 2	Cell Type 5
Surficial Soil	removed	removed	removed
Aquifer Materials	fill	outwash stringers	peat & outwash
Land Cover	embankment	embankment	embankment
Wetland/Upland	upland	upland	wetland
Bottom Layer Hydraulic Conductivity (ft/d)	300	6	2.65
Top of Bottom Layer (ft above till)	4	7.5	7.5
Middle Layer Hydraulic Conductivity (ft/d)		300	300
Top of Middle Layer (ft above till)		11.5	11.5
Upper Layer Hydraulic Conductivity (ft/d)			
Top of Upper Layer (ft above till)			
Maximum Saturated Thickness (ft)	4	11.5	11.5
Gradient of Top of Till (ft/ft)	18.8%	18.8%	3.6%
Full Thickness Hydraulic Conductivity (ft/d)	300	108.2608696	106.076087
Maximum Subsurface Flow (cfd)	225.0	233.4	43.9
Maximum Downgradient Flow (cfd)	233.4	43.9	124.2
Cell Length (ft)	25	25	25
Specific Yield	30%	30%	30%
Maximum Storage (cubic ft)	30	86.25	86.25
Bottom Layer Storage (cubic ft)	30	56.25	56.25

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

Model Constants

Till Thickness (ft)	10
Till Permeability Beneath Uplands (ft/d)	0.004
Till Permeability Beneath Wetlands (ft/d)	0
Outwash Permeability (ft/d)	6
Peat Permeability (ft/d)	1
Percent Outwash in Peaty Aquifer	33%
Peaty Aquifer Permeability (ft/d)	2.65
Drain Material Permeability (ft/d)	300
Till Derived Soil Permeability (ft/d)	4
Outwash Derived Soil Permeability (ft/d)	4
Wetland Surficial Soil Permeability (ft/d)	1

Time Stepping

"delta X" (ft)	25
maximum transmissivity (ft^2/d)	236
minimum storage coefficient	30%
maximum time step (d)*	0.40
user defined model timestep (d)	0.10

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

Table E-5
Model Parameters for Individual Cells in the Built Simulation

Cell ID	Distance from Outlet	Top of Till Elevation	Cell Length (ft)	Cell Type	Till Permeability	Head at Bottom of Till	Maximum Subsurface Outflow (cfd)	Specific Yield	Maximum Storage (cf)	Fill Material	Actual Embankment Thickness (ft)	Modeled Embankment Thickness for Recharge(ft)
1	1137.5	385.0	25	1	0.004	375.0	225.00	30%	30.0	Type 2	3	0
2	1112.5	380.4	25	1	0.004	370.4	225.00	30%	30.0	Type 2	7	0
3	1087.5	375.7	25	1	0.004	365.7	225.00	30%	30.0	Type 2	11	0
4	1062.5	371.0	25	1	0.004	361.0	225.00	30%	30.0	Type 2	14	0
5	1037.5	366.3	25	1	0.004	356.3	225.00	30%	30.0	Type 2	19	0
6	1012.5	361.6	25	1	0.004	351.6	225.00	30%	30.0	Type 2	24	30
7	987.5	356.9	25	1	0.004	346.9	225.00	30%	30.0	Type 2	27	30
8	962.5	352.2	25	1	0.004	342.2	225.00	30%	30.0	Type 2	32	30
9	937.5	347.5	25	1	0.004	337.5	225.00	30%	30.0	Type 2	35	30
10	912.5	342.9	25	1	0.004	332.9	225.00	30%	30.0	Type 2	40	30
11	887.5	338.2	25	1	0.004	328.2	225.00	30%	30.0	Type 2	44	50
12	862.5	333.5	25	1	0.004	323.5	225.00	30%	30.0	Type 2	49	50
13	837.5	328.8	25	1	0.004	318.8	225.00	30%	30.0	Type 2	54	50
14	812.5	324.1	25	1	0.004	314.1	225.00	30%	30.0	Type 2	57	50
15	787.5	319.4	25	1	0.004	309.4	225.00	30%	30.0	Type 2	60	50
16	762.5	314.7	25	2	0.004	304.7	233.44	30%	86.3	Type 2	64	70
17	737.5	310.0	25	2	0.004	300.0	233.44	30%	86.3	Type 2	69	70
18	712.5	305.4	25	2	0.004	295.4	233.44	30%	86.3	Type 2	74	70
19	687.5	300.7	25	2	0.004	290.7	233.44	30%	86.3	Type 2	78	70
20	662.5	296.0	25	2	0.004	286.0	233.44	30%	86.3	Type 2	84	90
21	637.5	291.3	25	2	0.004	281.3	233.44	30%	86.3	Type 2	90	90
22	612.5	286.6	25	2	0.004	276.6	233.44	30%	86.3	Type 2	96	90
23	587.5	281.9	25	2	0.004	271.9	233.44	30%	86.3	Type 2	101	110
24	562.5	277.2	25	2	0.004	267.2	233.44	30%	86.3	Type 2	105	110
25	537.5	272.5	25	2	0.004	257.5	233.44	30%	86.3	Type 2	111	110
26	512.5	267.8	25	2	0.004	262.9	233.44	30%	86.3	Type 2	116	no recharge
27	487.5	263.2	25	2	0.004	258.2	233.44	30%	86.3	Type 2	120	no recharge
28	462.5	258.5	25	2	0.004	253.5	233.44	30%	86.3	Type 2	125	no recharge
29	437.5	253.8	25	2	0.004	248.8	233.44	30%	86.3	Type 2	128	no recharge
30	412.5	249.1	25	2	0.004	244.1	233.44	30%	86.3	Type 2	132	no recharge
31	387.5	244.4	25	2	0.004	239.4	233.44	30%	86.3	Type 2	138	no recharge
32	362.5	239.7	25	2	0.004	234.7	233.44	30%	86.3	Type 2	142	no recharge
33	337.5	235.0	25	2	0.004	230.0	43.92	30%	86.3	Type 2	147	no recharge
34	312.5	232.3	25	5	0	222.3	43.92	30%	86.3	Type 2	148	no recharge
35	287.5	231.4	25	5	0	221.4	43.92	30%	86.3	Type 2	148	150
36	262.5	230.5	25	5	0	220.5	43.92	30%	86.3	Type 2	148	150
37	237.5	229.6	25	5	0	219.6	43.92	30%	86.3	Type 2	148	150
38	212.5	228.7	25	5	0	218.7	43.92	30%	86.3	Type 2	148	150
39	187.5	227.8	25	5	0	217.8	43.92	30%	86.3	Type 2	148	150
40	162.5	226.9	25	5	0	216.9	43.92	30%	86.3	Type 1	148	0
41	137.5	226.0	25	5	0	216.0	43.92	30%	86.3	Type 1	146	0
42	112.5	225.1	25	5	0	215.1	43.92	30%	86.3	Type 1	145	0
43	87.5	224.2	25	5	0	214.2	43.92	30%	86.3	Type 1	115	0
44	62.5	223.3	25	5	0	213.3	43.92	30%	86.3	Type 1	35	0
45	37.5	222.4	25	5	0	212.4	43.92	30%	86.3	Type 1	7	0
46	12.5	221.5	25	5	0	211.5	9999.00	30%	86.3	Type 1	0	0

Table E-6
Specified Rates of Recharge for Different Embankment Thicknesses in the Built Simulation

Daily Recharge Rates (ft/d)

Month	Days	Cum Days	150 ft	130 ft	110 ft	90 ft	70 ft	50 ft	30 ft	0 ft
Feb-1	28	0	0.004	0.003	0.003	0.002	0.005	0.014	0.013	0.010
Mar-1	31	28	0.003	0.003	0.003	0.006	0.012	0.011	0.010	0.007
Apr-1	30	59	0.003	0.003	0.006	0.011	0.010	0.008	0.007	0.001
May-1	31	89	0.003	0.007	0.010	0.009	0.007	0.006	0.005	0.000
Jun-1	30	120	0.007	0.009	0.008	0.007	0.006	0.005	0.003	0.000
Jul-1	31	150	0.008	0.007	0.007	0.006	0.005	0.004	0.002	0.000
Aug-1	31	181	0.007	0.007	0.006	0.005	0.004	0.003	0.002	0.000
Sep-1	30	212	0.006	0.006	0.005	0.004	0.003	0.002	0.002	0.000
Oct-1	31	242	0.006	0.005	0.004	0.004	0.003	0.002	0.001	0.002
Nov-1	30	273	0.005	0.004	0.004	0.003	0.002	0.002	0.001	0.014
Dec-1	31	303	0.004	0.004	0.003	0.003	0.002	0.002	0.003	0.014
Jan-1	31	334	0.004	0.004	0.003	0.002	0.002	0.004	0.014	0.014

Monthly Recharge Rates (cm/d)

Month	150 ft	130 ft	110 ft	90 ft	70 ft	50 ft	30 ft
Feb-1	0.113	0.098	0.084	0.069	0.146	0.416	0.393
Mar-1	0.105	0.091	0.077	0.178	0.356	0.322	0.292
Apr-1	0.095	0.083	0.196	0.321	0.300	0.254	0.206
May-1	0.090	0.210	0.296	0.262	0.222	0.195	0.150
Jun-1	0.224	0.273	0.240	0.213	0.193	0.154	0.097
Jul-1	0.249	0.221	0.203	0.184	0.153	0.113	0.070
Aug-1	0.210	0.201	0.182	0.153	0.122	0.088	0.055
Sep-1	0.196	0.177	0.154	0.130	0.103	0.074	0.046
Oct-1	0.178	0.156	0.134	0.111	0.087	0.063	0.039
Nov-1	0.156	0.136	0.116	0.096	0.076	0.055	0.034
Dec-1	0.137	0.121	0.103	0.085	0.066	0.049	0.093
Jan-1	0.125	0.109	0.092	0.076	0.060	0.118	0.423

NOTE: Values for 0 feet embankness thickness taken directly from estimates for recharge to grass on outwash (see Table E-3).
All other values taken from Hydrus model (grass-outwash input).

AR 022084

APPENDIX F

Analytical Resources, Incorporated
Analytical Chemists and Consultants

November 10, 1999

Inger Jackson
Pacific Groundwater Group
2377 Eastlake Ave. East, Suite 200
Seattle, WA 98102

RE: Project No. JE9907
ARI Job No. AX18

Dear Leslie:

Please find enclosed original Chain of Custody (COC) and analytical results for the above-referenced project. Analytical Resources, Inc. (ARI) accepted four water samples in good condition on October 25, 1999.

The samples were analyzed for total metals and hardness by EPA methods 6010/200.8, total suspended solids by EPA method 160.2, ammonia by EPA method 350.1, nitrate plus nitrite by EPA method 353.2, total phosphorus and ortho-phosphorus by EPA method 365.2, biological oxygen demand by EPA method 405.1, and total oil and grease by EPA method 413.1 as requested on the COC. Quality control analysis results are included for your review.

Lead was detected in the total metals method blank at .002 mg/L. Lead was undetected in three of the samples and detected at .001 mg/L in the fourth. Lead is a common contaminant at this low level and no corrective action was taken.

No other analytical complications were encountered. A copy of this report and all associated raw data will remain on file with ARI. If you have any questions or require additional information, please contact me at your convenience.

Sincerely,

ANALYTICAL RESOURCES, INC.

Mary Lou Fox

Mary Lou Fox
Project Manager
206-389-6155

MLF/mlf
Enclosure

AR 022086

333 Ninth Avenue North • Seattle WA 98109-5187 • 206-621-6490 • 206-621-7523 fax

Chain of Custody Record & Laboratory Analysis Request

Date: 10/25/99
Page 1 of 1
Number of coolers: 2
Cooler Temp:

Analytical Resources, Incorporated
Analytical Chemist and Consultants
400 Ninth Avenue North
Seattle, WA 98109-4708
(206) 621-6490
(206) 621-7523 (Fax)

ARI Client: Pacific Groundwater Group Phone#: 329-0141
Client Contact: Inger Jackson
Client Project ID: JE9907
Samplers: IRJ/CTE

Notes/Comments: 99-16119 / 99-16122 / ~~A~~ 18

	Sample ID	Date	Time	Matx	No Cont	Lab ID	FOG	BOD	TSS	SRP	Total P, NO2+NO3, NH3, Hardness	Total Metals: As, Cd, Pb, Cu, Zn			Notes/Comments
1	Miller Creek at Kiwanis	10/22/99	17:20	W	6		X	X	X	X	X	X			
2	Miller Creek at 3156th	10/22/99	15:30	W	6		X	X	X	X	X	X			
3	Des Moines Cr at South 18th	10/23/99	12:00	W	6		X	X	X	X	X	X			
4	Des Moines at Tyee	10/23/99	12:40	W	6		X	X	X	X	X	X			
5															
6															
7															

ARI Project No:
T.A.T. Requested:
Comments/Special Instructions: Do not perform metals analyses until contacted by PGG.

Relinquished by: (Signature) Inger Jackson	Relinquished by: (Signature)	Relinquished by: (Signature)
Printed Name: Inger Jackson	Printed Name:	Printed Name:
Company: PGG	Company:	Company:
Date: 10/25/99 Time: 11:53	Date: Time:	Date: Time:
Received by: (Signature) Mary Lou Fox	Received by: (Signature)	Received by: (Signature)
Printed Name: Mary Lou Fox	Printed Name:	Printed Name:
Company: ARI	Company:	Company:
Date: 10/25/99 Time: 1153	Date: Time:	Date: Time:

ANALYTICAL RESOURCES INCORPORATED

Final Report
Laboratory Analysis of Conventional Parameters

Sample No: Miller At Kiwanis

Lab Sample ID: BF85A
LIMS ID: 00-876
Matrix: Water

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907

Date Sampled: 01/27/00
Date Received: 01/28/00

Data Release Authorized:
Reported: 02/10/00 Dr. M.A. Perkins

Analyte	Analysis Date & Batch	Method	RL	Units	Result
Total Suspended Solids	01/28/00 01280#1	EPA 160.2	1.1	mg/L	4.1
N-Ammonia	01/31/00 01310#3	EPA 350.1	0.010	mg-N/L	0.013
Nitrate + Nitrite (NO2+NO3)	01/28/00 01280#2	EPA 353.2	0.10	mg-N/L	1.3
Total Phosphorous	01/31/00 01310#1	EPA 365.2	0.016	mg-P/L	0.060
Ortho-Phosphorous	01/28/00 01280#1	EPA 365.2	0.004	mg-P/L	0.029
Biological Oxygen Demand	01/28/00 01280#1	EPA 405.1	2	mg/L	< 2 U
Total Oil & Grease	02/03/00 02030#1	EPA 413.1	0.9	mg/L	1.8

RL Analytical reporting limit
U Undetected at reported detection limit

Report for BF85 received 01/28/00

ANALYTICAL RESOURCES INCORPORATED

Final Report
Laboratory Analysis of Conventional Parameters

Sample No: Des Moines at S 18th

Lab Sample ID: BF85B
LIMS ID: 00-877
Matrix: Water

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907

Date Sampled: 01/27/00
Date Received: 01/28/00

Data Release Authorized: MB
Reported: 02/10/00 Dr. M.A. Perkins

Analyte	Analysis Date & Batch	Method	RL	Units	Result
Total Suspended Solids	01/28/00 01280#1	EPA 160.2	1.1	mg/L	1.7
N-Ammonia	01/31/00 01310#3	EPA 350.1	0.010	mg-N/L	< 0.010 U
Nitrate + Nitrite (NO2+NO3)	01/28/00 01280#1	EPA 353.2	0.010	mg-N/L	0.54
Total Phosphorous	01/31/00 01310#1	EPA 365.2	0.016	mg-P/L	0.051
Ortho-Phosphorous	01/28/00 01280#1	EPA 365.2	0.004	mg-P/L	0.013
Biological Oxygen Demand	01/28/00 01280#1	EPA 405.1	2	mg/L	2
Total Oil & Grease	02/03/00 02030#1	EPA 413.1	0.9	mg/L	1.5

RL Analytical reporting limit
U Undetected at reported detection limit

Report for BF85 received 01/28/00

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

ANALYTICAL RESOURCES INCORPORATED

Lab Sample ID: BF85LCS
LIMS ID: 00-877
Matrix: Water

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907

Data Release Authorized:
Reported: 02/08/00

BLANK SPIKE QUALITY CONTROL REPORT

Analyte	Spike mg/L	Spike Added	% Recovery	Q
Arsenic	2.47	2.50	98.8%	
Cadmium	0.0232	0.0250	92.8%	
Calcium	10.3	10.0	103%	
Copper	0.102	0.100	102%	
Lead	0.024	0.025	96.0%	
Magnesium	10.0	10.0	100%	
Zinc	0.486	0.500	97.2%	

'Q' codes: N = control limit not met

Control Limits: 80-120%

FORM-VII

ANALYTICAL RESOURCES INCORPORATED

QA Report - Method Blank Analysis

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907
Date Received: NA

Matrix: Water

Data Release Authorized: MP
Reported: 02/10/00 Dr. M.A. Perkins

METHOD BLANK RESULTS
CONVENTIONALS

Analysis Date & Batch	Constituent	Units	Result	
01/28/00 01280#1	Total Suspended Solids	mg/L	< 1.0	U
01/28/00 01280#2	Nitrate + Nitrite (NO2+NO3)	mg-N/L	< 0.010	U
01/31/00 01310#1	Total Phosphorous	mg-P/L	< 0.008	U
01/28/00 01280#1	Ortho-Phosphorous	mg-P/L	< 0.004	U
02/03/00 02030#1	Total Oil & Grease	mg/L	< 1.0	U
01/28/00 01280#1	Biological Oxygen Demand	mg/L	< 1	U
01/31/00 01310#3	N-Ammonia	mg-N/L	< 0.010	U

ANALYTICAL RESOURCES INCORPORATED

Final Report
Laboratory Analysis of Conventional Parameters

Sample No: Miller at S 156th

Lab Sample ID: BF85C
LIMS ID: 00-878
Matrix: Water

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907

Date Sampled: 01/27/00
Date Received: 01/28/00

Data Release Authorized: MP
Reported: 02/10/00 Dr. M.A. Perkins

Analyte	Analysis Date & Batch	Method	RL	Units	Result
Total Suspended Solids	01/28/00 01280#1	EPA 160.2	1.8	mg/L	17
N-Ammonia	01/31/00 01310#3	EPA 350.1	0.010	mg-N/L	0.066
Nitrate + Nitrite (NO2+NO3)	01/28/00 01280#2	EPA 353.2	0.10	mg-N/L	1.3
Total Phosphorous	01/31/00 01310#1	EPA 365.2	0.016	mg-P/L	0.098
Ortho-Phosphorous	01/28/00 01280#1	EPA 365.2	0.004	mg-P/L	0.026
Biological Oxygen Demand	01/28/00 01280#1	EPA 405.1	2	mg/L	2
Total Oil & Grease	02/03/00 02030#1	EPA 413.1	1.0	mg/L	1.6

RL Analytical reporting limit
U Undetected at reported detection limit

Report for BF85 received 01/28/00

ANALYTICAL RESOURCES INCORPORATED

Final Report
Laboratory Analysis of Conventional Parameters

Sample No: Des Moines at Tyee

Lab Sample ID: BF85D
LIMS ID: 00-879
Matrix: Water

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907

Date Sampled: 01/27/00
Date Received: 01/28/00

Data Release Authorized: MP
Reported: 02/10/00 Dr. M.A. Perkins

Analyte	Analysis Date & Batch	Method	RL	Units		Result
Total Suspended Solids	01/28/00 01280#1	EPA 160.2	2.0	mg/L		3.8
N-Ammonia	01/31/00 01310#3	EPA 350.1	0.010	mg-N/L	<	0.010 U
Nitrate + Nitrite (NO2+NO3)	01/28/00 01280#2	EPA 353.2	0.010	mg-N/L		0.56
Total Phosphorous	01/31/00 01310#1	EPA 365.2	0.016	mg-P/L		0.060
Ortho-Phosphorous	01/28/00 01280#1	EPA 365.2	0.004	mg-P/L		0.005
Biological Oxygen Demand	01/28/00 01280#1	EPA 405.1	2	mg/L		2
Total Oil & Grease	02/03/00 02030#1	EPA 413.1	0.9	mg/L		1.4

RL Analytical reporting limit
U Undetected at reported detection limit

Report for BF85 received 01/28/00

ANALYTICAL RESOURCES INCORPORATED

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

Sample No: Method Blank

Lab Sample ID: AX18MB
LIMS ID: 99-16119
Matrix: Water

QC Report No: AX18-Pacific Groundwater Group
Project: JE9907

Date Sampled: NA
Date Received: NA

Data Release Authorized:
Reported: 11/08/99

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	RL	mg/L
3010	10/26/99	6010	11/04/99	7440-38-2	Arsenic	0.05	0.05 U
200.8	10/27/99	200.8	11/01/99	7440-43-9	Cadmium	0.0002	0.0002 U
3010	10/26/99	6010	11/04/99	7440-70-2	Calcium	0.05	0.05 U
3010	10/26/99	6010	11/04/99	7440-50-8	Copper	0.002	0.002 U
200.8	10/27/99	200.8	11/01/99	7439-92-1	Lead	0.001	0.002
3010	10/26/99	6010	11/04/99	7439-95-4	Magnesium	0.02	0.02 U
3010	10/26/99	6010	11/04/99	7440-66-6	Zinc	0.006	0.006 U

U Analyte undetected at given RL

RL Reporting Limit

FORM-I

ANALYTICAL RESOURCES INCORPORATED

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

Sample No: Miller Creek at Kiwanis

Lab Sample ID: AX18A
LIMS ID: 99-16119
Matrix: Water

QC Report No: AX18-Pacific Groundwater Group
Project: JE9907

Date Sampled: 10/22/99
Date Received: 10/25/99

Data Release Authorized:
Reported: 11/08/99

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	RL	mg/L
3010	10/26/99	6010	11/04/99	7440-38-2	Arsenic	0.05	0.05 U
200.8	10/27/99	200.8	11/01/99	7440-43-9	Cadmium	0.0002	0.0002 U
3010	10/26/99	6010	11/04/99	7440-70-2	Calcium	0.05	24.8
3010	10/26/99	6010	11/04/99	7440-50-8	Copper	0.002	0.002 U
200.8	10/27/99	200.8	11/01/99	7439-92-1	Lead	0.001	0.001 U
3010	10/26/99	6010	11/04/99	7439-95-4	Magnesium	0.02	15.6
3010	10/26/99	6010	11/04/99	7440-66-6	Zinc	0.006	0.007

Calculated Hardness (mg-CaCO3/L): 130

U Analyte undetected at given RL

RL Reporting Limit

FORM-I

ANALYTICAL RESOURCES INCORPORATED

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

Sample No: Miller Creek at S 156th

Lab Sample ID: AX18B
LIMS ID: 99-16120
Matrix: Water

QC Report No: AX18-Pacific Groundwater Group
Project: JE9907

Date Sampled: 10/22/99
Date Received: 10/25/99

Data Release Authorized:
Reported: 11/08/99

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	RL	mg/L
3010	10/26/99	6010	11/04/99	7440-38-2	Arsenic	0.05	0.05 U
200.8	10/27/99	200.8	11/01/99	7440-43-9	Cadmium	0.0002	0.0002 U
3010	10/26/99	6010	11/04/99	7440-70-2	Calcium	0.05	27.8
3010	10/26/99	6010	11/04/99	7440-50-8	Copper	0.002	0.002 U
200.8	10/27/99	200.8	11/01/99	7439-92-1	Lead	0.001	0.001
3010	10/26/99	6010	11/04/99	7439-95-4	Magnesium	0.02	18.6
3010	10/26/99	6010	11/04/99	7440-66-6	Zinc	0.006	0.008

Calculated Hardness (mg-CaCO3/L): 150

U Analyte undetected at given RL

RL Reporting Limit

FORM-I

ANALYTICAL RESOURCES INCORPORATED

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

Sample No: Des Moines at Tyee

Lab Sample ID: AX18D
LIMS ID: 99-16122
Matrix: Water

QC Report No: AX18-Pacific Groundwater Group
Project: JE9907

Date Sampled: 10/23/99
Date Received: 10/25/99

Data Release Authorized:
Reported: 11/08/99

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	RL	mg/L
3010	10/26/99	6010	11/04/99	7440-38-2	Arsenic	0.05	0.05 U
200.8	10/27/99	200.8	11/01/99	7440-43-9	Cadmium	0.0002	0.0002 U
3010	10/26/99	6010	11/04/99	7440-70-2	Calcium	0.05	21.8
3010	10/26/99	6010	11/04/99	7440-50-8	Copper	0.002	0.004
200.8	10/27/99	200.8	11/01/99	7439-92-1	Lead	0.001	0.001 U
3010	10/26/99	6010	11/04/99	7439-95-4	Magnesium	0.02	12.2
3010	10/26/99	6010	11/04/99	7440-66-6	Zinc	0.006	0.010

Calculated Hardness (mg-CaCO3/L): 100

U Analyte undetected at given RL

RL Reporting Limit

FORM-I

ANALYTICAL RESOURCES INCORPORATED

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

Sample No: Des Moines Cr at S 18th

Lab Sample ID: AX18C
LIMS ID: 99-16121
Matrix: Water

QC Report No: AX18-Pacific Groundwater Group
Project: JE9907

Date Sampled: 10/22/99
Date Received: 10/25/99

Data Release Authorized:
Reported: 11/08/99

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	RL	mg/L
3010	10/26/99	6010	11/04/99	7440-38-2	Arsenic	0.05	0.05 U
200.8	10/27/99	200.8	11/01/99	7440-43-9	Cadmium	0.0002	0.0002 U
3010	10/26/99	6010	11/04/99	7440-70-2	Calcium	0.05	20.7
3010	10/26/99	6010	11/04/99	7440-50-8	Copper	0.002	0.003
200.8	10/27/99	200.8	11/01/99	7439-92-1	Lead	0.001	0.001 U
3010	10/26/99	6010	11/04/99	7439-95-4	Magnesium	0.02	11.7
3010	10/26/99	6010	11/04/99	7440-66-6	Zinc	0.006	0.010

Calculated Hardness (mg-CaCO3/L): 100

U Analyte undetected at given RL

RL Reporting Limit

FORM-I

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

ANALYTICAL RESOURCES INCORPORATED

Lab Sample ID: AX18LCS
LIMS ID: 99-16119
Matrix: Water

QC Report No: AX18-Pacific Groundwater Group
Project: JE9907

Data Release Authorized:
Reported: 11/08/99

BLANK SPIKE QUALITY CONTROL REPORT

Analyte	Spike mg/L	Spike Added	% Recovery	Q
Arsenic	2.60	2.50	104%	
Cadmium	0.0241	0.0250	96.4%	
Calcium	10.5	10.0	105%	
Copper	0.106	0.100	106%	
Lead	0.025	0.025	100%	
Magnesium	10.4	10.0	104%	
Zinc	0.515	0.500	103%	

'Q' codes: N = control limit not met

Control Limits: 80-120%

FORM-VII

ANALYTICAL RESOURCES INCORPORATED

QA Report - Method Blank Analysis

QC Report No: AX18-Pacific Groundwater Group
Project: JE9907
Date Received: NA

Matrix: Water

Data Release Authorized: [signature]
Reported: 11/09/99 Dr. M.A. Perkins

METHOD BLANK RESULTS
CONVENTIONALS

Analysis Date & Batch	Constituent	Units	Result	
10/27/99 102799#1	Total Suspended Solids	mg/L	< 1.0	U
11/02/99 110299#1	N-Ammonia	mg-N/L	< 0.010	U
11/02/99 110299#1	Total Phosphorous	mg-P/L	< 0.008	U
10/25/99 102599#1	Ortho-Phosphorous	mg-P/L	< 0.004	U
11/03/99 110399#1	Total Oil & Grease	mg/L	< 1.0	U
10/29/99 102999#2	Nitrate + Nitrite (NO2+NO3)	mg-N/L	< 0.010	U
10/25/99 102599#1	Biological Oxygen Demand	mg/L	< 1	U

ANALYTICAL RESOURCES INCORPORATED

Final Report
Laboratory Analysis of Conventional Parameters

Sample No: Miller Creek at Kiwanis

Lab Sample ID: AX18A
LIMS ID: 99-16119
Matrix: Water

QC Report No: AX18-Pacific Groundwater Group
Project: JB9907

Date Sampled: 10/22/99
Date Received: 10/25/99

Data Release Authorized: MP
Reported: 11/09/99 Dr. M.A. Perkins

Analyte	Analysis Date & Batch	Method	RL	Units	Result
Total Suspended Solids	10/27/99 102799#1	EPA 160.2	1.8	mg/L	< 1.8 U
N-Ammonia	11/02/99 110299#1	EPA 350.1	0.010	mg-N/L	0.013
Nitrate + Nitrite (NO2+NO3)	10/29/99 102999#2	EPA 353.2	0.020	mg-N/L	1.3
Total Phosphorous	11/02/99 110299#1	EPA 365.2	0.016	mg-P/L	0.071
Ortho-Phosphorous	10/25/99 102599#1	EPA 365.2	0.004	mg-P/L	0.038
Biological Oxygen Demand	10/25/99 102599#1	EPA 405.1	3	mg/L	< 3 U
Total Oil & Grease	11/03/99 110399#1	EPA 413.1	1.0	mg/L	1.2

RL Analytical reporting limit
U Undetected at reported detection limit

Report for AX18 received 10/25/99

ANALYTICAL RESOURCES INCORPORATED

Final Report
Laboratory Analysis of Conventional Parameters

Sample No: Miller Creek at S 156th

Lab Sample ID: AX18B
LIMS ID: 99-16120
Matrix: Water

QC Report No: AX18-Pacific Groundwater Group
Project: JE9907

Date Sampled: 10/22/99
Date Received: 10/25/99

Data Release Authorized: MP
Reported: 11/09/99 Dr. M.A. Perkins

Analyte	Analysis Date & Batch	Method	RL	Units	Result
Total Suspended Solids	10/27/99 102799#1	EPA 160.2	1.1	mg/L	5.0
N-Ammonia	11/02/99 110299#1	EPA 350.1	0.010	mg-N/L	0.058
Nitrate + Nitrite (NO2+NO3)	10/29/99 102999#2	EPA 353.2	0.020	mg-N/L	1.3
Total Phosphorous	11/02/99 110299#1	EPA 365.2	0.016	mg-P/L	0.080
Ortho-Phosphorous	10/25/99 102599#1	EPA 365.2	0.004	mg-P/L	0.033
Biological Oxygen Demand	10/25/99 102599#1	EPA 405.1	2	mg/L	2
Total Oil & Grease	11/03/99 110399#1	EPA 413.1	0.9	mg/L	< 1.0 U

RL Analytical reporting limit
U Undetected at reported detection limit

Report for AX18 received 10/25/99

AR 022102

ANALYTICAL RESOURCES INCORPORATED

Final Report
Laboratory Analysis of Conventional Parameters

Sample No: Des Moines Cr at S 18th

Lab Sample ID: AX18C
LIMS ID: 99-16121
Matrix: Water

QC Report No: AX18-Pacific Groundwater Group
Project: JE9907

Date Sampled: 10/22/99
Date Received: 10/25/99

Data Release Authorized
Reported: 11/09/99 Dr. M.K. Perkins

Analyte	Analysis Date & Batch	Method	RL	Units		Result
Total Suspended Solids	10/27/99 102799#1	EPA 160.2	1.1	mg/L		1.2
N-Ammonia	11/02/99 110299#1	EPA 350.1	0.010	mg-N/L	<	0.010 U
Nitrate + Nitrite (NO2+NO3)	10/29/99 102999#2	EPA 353.2	0.010	mg-N/L		0.69
Total Phosphorous	11/02/99 110299#1	EPA 365.2	0.016	mg-P/L		0.043
Ortho-Phosphorous	10/25/99 102599#1	EPA 365.2	0.004	mg-P/L		0.025
Biological Oxygen Demand	10/25/99 102599#1	EPA 405.1	2	mg/L	<	2 U
Total Oil & Grease	11/03/99 110399#1	EPA 413.1	1.0	mg/L	<	1.0 U

RL Analytical reporting limit
U Undetected at reported detection limit

Report for AX18 received 10/25/99

AR 022103

ANALYTICAL RESOURCES INCORPORATED

Final Report
Laboratory Analysis of Conventional Parameters

Sample No: Des Moines at Tyee

Lab Sample ID: AX18D
LIMS ID: 99-16122
Matrix: Water

QC Report No: AX18-Pacific Groundwater Group
Project: JE9907

Date Sampled: 10/23/99
Date Received: 10/25/99

Data Release Authorized: [signature]
Reported: 11/09/99 Dr. M.A. Perkins

Analyte	Analysis Date & Batch	Method	RL	Units	Result
Total Suspended Solids	10/27/99 102799#1	EPA 160.2	1.1	mg/L	< 1.1 U
N-Ammonia	11/02/99 110299#1	EPA 350.1	0.010	mg-N/L	0.017
Nitrate + Nitrite (NO2+NO3)	10/29/99 102999#2	EPA 353.2	0.010	mg-N/L	0.86
Total Phosphorous	11/02/99 110299#1	EPA 365.2	0.016	mg-P/L	0.040
Ortho-Phosphorous	10/25/99 102599#1	EPA 365.2	0.004	mg-P/L	0.017
Biological Oxygen Demand	10/25/99 102599#1	EPA 405.1	2	mg/L	2
Total Oil & Grease	11/03/99 110399#1	EPA 413.1	1.0	mg/L	< 1.0 U

RL Analytical reporting limit
U Undetected at reported detection limit

Report for AX18 received 10/25/99

ANALYTICAL RESOURCES INCORPORATED

QA Report - Laboratory Control Samples

QC Report No: AX18-Pacific Groundwater Group
Project: JE9907
Date Received: NA

Data Release Authorized:
Reported: 11/09/99 Dr. M.A. Perkins

LABORATORY CONTROL SAMPLES
CONVENTIONALS

Constituent	Units	Measured Value	True Value	Recovery
Laboratory Control Sample Total Oil & Grease Date analyzed: 11/03/99 Batch ID: 110399#1	mg/L	45.2	57.0	79.3%
Laboratory Control Sample Biological Oxygen Demand Date analyzed: 10/25/99 Batch ID: 102599#1	mg/L	178	200	89.0%

ANALYTICAL RESOURCES INCORPORATED

QA Report - Standard Reference Material Analysis

QC Report No: AX18-Pacific Groundwater Group
Project: JB9907
Date Received: NA

Data Release Authorized:
Reported: 11/09/99 Dr. M.A. Perkins

STANDARD REFERENCE MATERIAL ANALYSIS
CONVENTIONALS

Constituent	Units	Value	True Value	Recovery
IV #1035 N-Ammonia Date analyzed: 11/02/99 Batch ID: 110299#1	mg-N/L	0.815	0.800	102%
SPEX #6-26 Total Phosphorous Date analyzed: 11/02/99 Batch ID: 110299#1	mg-P/L	5.14	5.00	103%
IV #1032 Ortho-Phosphorous Date analyzed: 10/25/99 Batch ID: 102599#1	mg-P/L	0.132	0.129	102%
IV #1084 Nitrate + Nitrite (NO2+NO3) Date analyzed: 10/29/99 Batch ID: 102999#2	mg-N/L	0.407	0.400	102%

ANALYTICAL RESOURCES INCORPORATED

QA Report - Replicate Analysis

QC Report No: AX18-Pacific Groundwater Group
Project: JE9907
Date Received: 10/25/99

Matrix: Water

Data Release Authorized:
Reported: 11/09/99 Dr. M.A. Perkins

DUPLICATE ANALYSIS RESULTS
CONVENTIONALS

Constituent	Units	Sample Value	Duplicate Value	RPD
ARI ID: 99-16119, AX18 A	Client Sample ID: Miller Creek at Kiwanis			
N-Ammonia	mg-N/L	0.013	0.014	7.4%
Total Phosphorous	mg-P/L	0.071	0.068	4.3%
Ortho-Phosphorous	mg-P/L	0.038	0.038	0.0%
ARI ID: 99-16122, AX18 D	Client Sample ID: Des Moines at Tyee			
Nitrate + Nitrite (NO2+NO3)	mg-N/L	0.86	0.89	3.4%
Biological Oxygen Demand	mg/L	2	2	0.0%

ANALYTICAL RESOURCES INCORPORATED

QA Report - Matrix Spike/Matrix Spike Duplicate Analysis

QC Report No: AX18-Pacific Groundwater Group
Project: JE9907
Date Received: 10/25/99

Matrix: Water

Data Release Authorized
Reported: 11/09/99 Dr. M.A. Perkins

MATRIX SPIKE QA/QC REPORT
CONVENTIONALS

Constituent	Units	Sample Value	Spike Value	Spike Added	Recovery
ARI ID: 99-16119, AX18 A Client Sample ID: Miller Creek at Kiwanis					
N-Ammonia	mg-N/L	0.013	0.447	0.400	108%
Total Phosphorous	mg-P/L	0.071	0.469	0.400	99.5%
Ortho-Phosphorous	mg-P/L	0.038	0.138	0.100	100%
ARI ID: 99-16122, AX18 D Client Sample ID: Des Moines at Tyee					
Nitrate + Nitrite (NO2+NO3)	mg-N/L	0.857	1.23	0.400	93.2%

MS/MSD Recovery Limits: 75 - 125 %

Analytical Resources, Incorporated
Analytical Chemists and Consultants

February 14, 2000

Inger Jackson
Pacific Groundwater Group
2377 Eastlake Ave. East, Suite 200
Seattle, WA 98102

RE: Project No. JE9907
ARI Job No. BF85

Dear Inger:

Please find enclosed original Chain of Custody (COC) and analytical results for the above-referenced project. Analytical Resources, Inc. (ARI) accepted four water samples in good condition on January 28, 2000.

The samples were analyzed for total metals and hardness by EPA methods 6010/200.8, total suspended solids by EPA method 160.2, ammonia by EPA method 350.1, nitrate plus nitrite by EPA method 353.2, total phosphorus and ortho-phosphorus by EPA method 365.2, biological oxygen demand by EPA method 405.1, and total oil and grease by EPA method 413.1 as requested on the COC. Quality control analysis results are included for your review.

Magnesium was detected in the total metals method blank at .03 mg/L. Magnesium was detected in all of the samples at levels greater than ten times the level in the method blank and no corrective action was taken.

No further analytical complications were encountered. A copy of this report and all associated raw data will remain on file with ARI. If you have any questions or require additional information, please contact me at your convenience.

Sincerely,

ANALYTICAL RESOURCES, INC.

Mary Lou Fox

Mary Lou Fox
Project Manager
206-389-6155
marylou@arilabs.com

AR 022109

MLF/mlf
Enclosure

333 Ninth Avenue North • Seattle WA 98109-5187 • 206-621-6490 • 206-621-7523 fax

Chain of Custody Record & Laboratory Analysis Request

Analytical Resources, Incorporated
Analytical Chemist and Consultants
400 Ninth Avenue North
Seattle, WA 98109-4708
(206) 621-6490
(206) 621-7523 (Fax)

Date: 1/27/00
Page 1 of 1
Number of coolers: 2
Cooler Temp: 3.5 5.5

ARI Client: PGG   Phone#: 329-0141
Client Contact: Inger Jackson/Charles Ellingson
Client Project ID: JE9907
Samplers: IRJ/LAM.

	Sample ID	Date	Time	Matx	No Cont	Lab ID	BOD	FOG	SRP + (NO_2 + NO_3)	TSS	Total Metals: As, Cd, Cu, Pb, Zn	NH_3, Total-P, Hardness		Notes/Comments
1	Miller at Kiwanis	1/27/00	13:45	W	6		1	1	1	1	1	1		BF85 00-976 879
2	Des Moines at S18th	1/27/00	15:30	W	6		1	1	1	1	1	1		
3	Miller at S156th	1/27/00	1045	W	6		1	1	1	1	1	1		
4	Des Moines at Tyee	1/27/00	16:50.	W	6		1	1	1	1	1	1		
5														
6														
7														

ARI Project No:
T.A.T. Requested:
Comments/Special Instructions:
Refer to Mary Lou Fox (ARI) or Inger Jackson (PGG) for Metals Method.

Relinquished by:	Relinquished by:	Relinquished by:
(Signature) Inger Jackson	(Signature)	(Signature)
Printed Name: Inger R Jackson	Printed Name:	Printed Name:
Company: PGG	Company:	Company:
Date: 1/27/00 Time: 18:40	Date: Time:	Date: Time:

Received by:	Received by:	Received by:
(Signature) [signature]	(Signature)	(Signature)
Printed Name: Zach Simmons	Printed Name:	Printed Name:
Company: ARI	Company:	Company:
Date: 1/28/00 Time: 7:30	Date: Time:	Date: Time:

ANALYTICAL RESOURCES INCORPORATED

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

Sample No: Method Blank

Lab Sample ID: BF85MB
LIMS ID: 00-877
Matrix: Water

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907

Date Sampled: NA
Date Received: NA

Data Release Authorized:
Reported: 02/08/00

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	RL	mg/L
3010	01/31/00	6010	02/03/00	7440-38-2	Arsenic	0.05	0.05 U
200.8	01/31/00	200.8	02/04/00	7440-43-9	Cadmium	0.0002	0.0002 U
3010	01/31/00	6010	02/03/00	7440-70-2	Calcium	0.05	0.05 U
3010	01/31/00	6010	02/03/00	7440-50-8	Copper	0.002	0.002 U
200.8	01/31/00	200.8	02/04/00	7439-92-1	Lead	0.001	0.001 U
3010	01/31/00	6010	02/03/00	7439-95-4	Magnesium	0.02	0.03
3010	01/31/00	6010	02/03/00	7440-66-6	Zinc	0.006	0.006 U

U Analyte undetected at given RL

RL Reporting Limit

FORM-I

ANALYTICAL RESOURCES INCORPORATED

QA Report - Replicate Analysis

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907
Date Received: 01/28/00

Matrix: Water

Data Release Authorized: MP
Reported: 02/10/00 Dr. M.A. Perkins

DUPLICATE ANALYSIS RESULTS
CONVENTIONALS

Constituent	Units	Sample Value	Duplicate Value	RPD
ARI ID: 00-876, BF85 A Client Sample ID: Miller At Kiwanis				
Nitrate + Nitrite (NO2+NO3)	mg-N/L	1.3	1.3	0.0%
Total Phosphorous	mg-P/L	0.060	0.060	0.0%
Ortho-Phosphorous	mg-P/L	0.029	0.029	0.0%
ARI ID: 00-877, BF85 B Client Sample ID: Des Moines at S 18th				
Biological Oxygen Demand	mg/L	2	2	0.0%
ARI ID: 00-879, BF85 D Client Sample ID: Des Moines at Tyee				
N-Ammonia	mg-N/L	< 0.010 U	< 0.010 U	NA

ANALYTICAL RESOURCES INCORPORATED

QA Report - Matrix Spike/Matrix Spike Duplicate Analysis

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907
Date Received: 01/28/00

Matrix: Water

Data Release Authorized:
Reported: 02/10/00 Dr. M.A. Perkins

MATRIX SPIKE QA/QC REPORT
CONVENTIONALS

Constituent	Units	Sample Value	Spike Value	Spike Added	Recovery
ARI ID: 00-876, BF85 A Client Sample ID: Miller At Kiwanis					
Nitrate + Nitrite (NO2+NO3)	mg-N/L	1.31	5.10	4.00	94.8%
Total Phosphorous	mg-P/L	0.060	0.461	0.400	100%
Ortho-Phosphorous	mg-P/L	0.029	0.128	0.100	99.0%
ARI ID: 00-879, BF85 D Client Sample ID: Des Moines at Tyee					
N-Ammonia	mg-N/L	< 0.010	0.383	0.400	95.8%

MS/MSD Recovery Limits: 75 - 125 %

ANALYTICAL RESOURCES INCORPORATED

QA Report - Laboratory Control Samples

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907
Date Received: NA

Data Release Authorized: [signature]
Reported: 02/10/00 Dr. M.A. Perkins

LABORATORY CONTROL SAMPLES
CONVENTIONALS

Constituent	Units	Measured Value	True Value	Recovery
Laboratory Control Sample Total Oil & Grease Date analyzed: 02/03/00 Batch ID: 02030#1	mg/L	51.6	66.7	77.4%
Laboratory Control Sample Biological Oxygen Demand Date analyzed: 01/28/00 Batch ID: 01280#1	mg/L	163	200	81.5%

ANALYTICAL RESOURCES INCORPORATED

QA Report - Standard Reference Material Analysis

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907
Date Received: NA

Data Release Authorized: MB
Reported: 02/10/00 Dr. M.A. Perkins

STANDARD REFERENCE MATERIAL ANALYSIS
CONVENTIONALS

Constituent	Units	Value	True Value	Recovery
SPEX #15-121				
Nitrate + Nitrite (NO2+NO3)	mg-N/L	0.429	0.400	107%
Date analyzed: 01/28/00	Batch ID: 01280#2			
SPEX #6-26				
Total Phosphorous	mg-P/L	5.17	5.00	103%
Date analyzed: 01/31/00	Batch ID: 01310#1			
SPEX #17-17				
Ortho-Phosphorous	mg-P/L	0.122	0.120	102%
Date analyzed: 01/28/00	Batch ID: 01280#1			
SPEX #16-50				
N-Ammonia	mg-N/L	0.794	0.800	99.2%
Date analyzed: 01/31/00	Batch ID: 01310#3			

ANALYTICAL RESOURCES INCORPORATED

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

Sample No: Miller At Kiwanis

Lab Sample ID: BF85A
LIMS ID: 00-876
Matrix: Water

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907

Date Sampled: 01/27/00
Date Received: 01/28/00

Data Release Authorized:
Reported: 02/08/00

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	RL	mg/L
3010	01/31/00	6010	02/03/00	7440-38-2	Arsenic	0.05	0.05 U
200.8	01/31/00	200.8	02/04/00	7440-43-9	Cadmium	0.0002	0.0002 U
3010	01/31/00	6010	02/03/00	7440-70-2	Calcium	0.05	21.0
3010	01/31/00	6010	02/03/00	7440-50-8	Copper	0.002	0.004
200.8	01/31/00	200.8	02/04/00	7439-92-1	Lead	0.001	0.001
3010	01/31/00	6010	02/03/00	7439-95-4	Magnesium	0.02	10.4
3010	01/31/00	6010	02/03/00	7440-66-6	Zinc	0.006	0.014

Calculated Hardness (mg-CaCO3/L): 95

U Analyte undetected at given RL

RL Reporting Limit

FORM-I

ANALYTICAL RESOURCES INCORPORATED

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

Sample No: Miller At Kiwanis
QC Report No: BF85-Pacific Groundwater Group
Project: JE9907

Lab Sample ID: BF85A
LIMS ID: 00-876
Matrix: Water

Date Received: 01/28/00

Data Release Authorized:
Reported: 02/08/00

MATRIX SPIKE QUALITY CONTROL REPORT

Analyte	Sample mg/L	Spike mg/L	Spike Added	% Recovery	Q
Arsenic	0.05 U	2.49	2.50	99.6%	
Cadmium	0.0002 U	0.0244	0.0250	97.6%	
Calcium	21.0	30.8	10.0	98.0%	
Copper	0.004	0.104	0.100	100%	
Lead	0.001	0.027	0.025	104%	
Magnesium	10.4	20.2	10.0	98.0%	
Zinc	0.014	0.504	0.500	98.0%	

'Q' codes:
- N = control limit not met
- H = %R not applicable, sample concentration too high
- * = RPD control limit not met
- NA = Not applicable - analyte not spiked

Control Limits:
- Percent Recovery: 75-125%
- RPD: +/-20%

FORM-V

ANALYTICAL RESOURCES INCORPORATED

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

Sample No: Des Moines at S 18th

Lab Sample ID: BF85B
LIMS ID: 00-877
Matrix: Water

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907

Date Sampled: 01/27/00
Date Received: 01/28/00

Data Release Authorized:
Reported: 02/08/00

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	RL	mg/L
3010	01/31/00	6010	02/03/00	7440-38-2	Arsenic	0.05	0.05 U
200.8	01/31/00	200.8	02/04/00	7440-43-9	Cadmium	0.0002	0.0002 U
3010	01/31/00	6010	02/03/00	7440-70-2	Calcium	0.05	19.1
3010	01/31/00	6010	02/03/00	7440-50-8	Copper	0.002	0.005
200.8	01/31/00	200.8	02/04/00	7439-92-1	Lead	0.001	0.001 U
3010	01/31/00	6010	02/03/00	7439-95-4	Magnesium	0.02	8.75
3010	01/31/00	6010	02/03/00	7440-66-6	Zinc	0.006	0.012

Calculated Hardness (mg-CaCO3/L): 84

U Analyte undetected at given RL

RL Reporting Limit

FORM-I

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

ANALYTICAL RESOURCES INCORPORATED

Sample No: Des Moines at S 18th
QC Report No: BF85-Pacific Groundwater Group
Project: JE9907

Lab Sample ID: BF85B
LIMS ID: 00-877
Matrix: Water

Date Received: 01/28/00

Data Release Authorized:
Reported: 02/08/00

MATRIX DUPLICATE QUALITY CONTROL REPORT

Analyte	Sample mg/L	Duplicate mg/L	RPD	Control Limit	Q
Arsenic	0.05 U	0.05 U	0.0%	+/- 0.05	L
Cadmium	0.0002 U	0.0002 U	0.0%	+/- 0.0002	L
Calcium	19.1	19.1	0.0%	+/- 20 %	
Copper	0.005	0.005	0.0%	+/- 0.002	L
Lead	0.001 U	0.001 U	0.0%	+/- 0.001	L
Magnesium	8.75	8.71	0.5%	+/- 20 %	
Zinc	0.012	0.012	0.0%	+/- 0.006	L

'Q' codes:
* = control limit not met
L = RPD not valid, alternate limit = detection limit

ANALYTICAL RESOURCES INCORPORATED

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

Sample No: Miller at S 156th

Lab Sample ID: BF85C
LIMS ID: 00-878
Matrix: Water

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907

Date Sampled: 01/27/00
Date Received: 01/28/00

Data Release Authorized:
Reported: 02/08/00

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	RL	mg/L
3010	01/31/00	6010	02/03/00	7440-38-2	Arsenic	0.05	0.05 U
200.8	01/31/00	200.8	02/04/00	7440-43-9	Cadmium	0.0002	0.0002 U
3010	01/31/00	6010	02/03/00	7440-70-2	Calcium	0.05	21.0
3010	01/31/00	6010	02/03/00	7440-50-8	Copper	0.002	0.005
200.8	01/31/00	200.8	02/04/00	7439-92-1	Lead	0.001	0.004
3010	01/31/00	6010	02/03/00	7439-95-4	Magnesium	0.02	10.2
3010	01/31/00	6010	02/03/00	7440-66-6	Zinc	0.006	0.022

Calculated Hardness (mg-CaCO3/L): 95

U Analyte undetected at given RL

RL Reporting Limit

FORM-I

ANALYTICAL RESOURCES INCORPORATED

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

Sample No: Des Moines at Tyee

Lab Sample ID: BF85D
LIMS ID: 00-879
Matrix: Water

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907

Date Sampled: 01/27/00
Date Received: 01/28/00

Data Release Authorized:
Reported: 02/08/00

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	RL	mg/L
3010	01/31/00	6010	02/03/00	7440-38-2	Arsenic	0.05	0.05 U
200.8	01/31/00	200.8	02/04/00	7440-43-9	Cadmium	0.0002	0.0002 U
3010	01/31/00	6010	02/03/00	7440-70-2	Calcium	0.05	19.3
3010	01/31/00	6010	02/03/00	7440-50-8	Copper	0.002	0.007
200.8	01/31/00	200.8	02/04/00	7439-92-1	Lead	0.001	0.001 U
3010	01/31/00	6010	02/03/00	7439-95-4	Magnesium	0.02	8.54
3010	01/31/00	6010	02/03/00	7440-66-6	Zinc	0.006	0.014

Calculated Hardness (mg-CaCO3/L): 83

U Analyte undetected at given RL

RL Reporting Limit

FORM-I

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS

ANALYTICAL RESOURCES INCORPORATED

Lab Sample ID: BF85LCS
LIMS ID: 00-877
Matrix: Water

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907

Data Release Authorized
Reported: 02/08/00

BLANK SPIKE QUALITY CONTROL REPORT

Analyte	Spike mg/L	Spike Added	% Recovery	Q
Arsenic	2.47	2.50	98.8%	
Cadmium	0.0232	0.0250	92.8%	
Calcium	10.3	10.0	103%	
Copper	0.102	0.100	102%	
Lead	0.024	0.025	96.0%	
Magnesium	10.0	10.0	100%	
Zinc	0.486	0.500	97.2%	

'Q' codes: N = control limit not met

Control Limits: 80-120%

FORM-VII

ANALYTICAL RESOURCES INCORPORATED

QA Report - Method Blank Analysis

QC Report No: BF85-Pacific Groundwater Group
Project: JE9907
Date Received: NA

Matrix: Water

Data Release Authorized: MAP
Reported: 02/10/00 Dr. M.A. Perkins

METHOD BLANK RESULTS
CONVENTIONALS

Analysis Date & Batch	Constituent	Units	Result	
01/28/00 01280#1	Total Suspended Solids	mg/L	< 1.0	U
01/28/00 01280#2	Nitrate + Nitrite (NO2+NO3)	mg-N/L	< 0.010	U
01/31/00 01310#1	Total Phosphorous	mg-P/L	< 0.008	U
01/28/00 01280#1	Ortho-Phosphorous	mg-P/L	< 0.004	U
02/03/00 02030#1	Total Oil & Grease	mg/L	< 1.0	U
01/28/00 01280#1	Biological Oxygen Demand	mg/L	< 1	U
01/31/00 01310#3	N-Ammonia	mg-N/L	< 0.010	U

APPENDIX G

Appendix G
Ecological Evaluation of Maury Island Soil as Potential Fill

Gravel from a mine on Maury Island is being considered as fill for the proposed runway expansion. The top eighteen inches of gravel at Maury Island contain high levels of arsenic, cadmium, and lead originating from the former ASARCO smelter in Tacoma. The top 18 inches of soil at Maury Island are proposed to be contained at the island mine prior to aggregate extraction. Ecology must have assurance that the fill used for the airport project will not result in exceedances of state water quality criteria. The Port and Ecology are working to determine what screening methods and contingencies are necessary to ensure that water quality criteria are met.

This project analyzed the potential effects to ecological receptors, such as the benthic community and wildlife-consuming benthic organisms, if contaminants in the Maury Island fill were to migrate from soils to nearby sediments. Surface and subsurface soil data of the potential Maury Island fill were compared to ecological benchmarks to assess whether unacceptable ecological risks may occur.

For screening purposes, concentrations of arsenic, cadmium, and lead in soil were compared directly to Ecology's proposed Lowest Adverse Effects Thresholds (LAETs) for sediment (Cubbage, 1997). Sediment concentrations would be expected to be much lower than soil concentrations since contamination would need to leach or migrate from soil to sediment. Therefore, this comparison represents a conservative initial screening step, and exceedence of benchmarks does not imply that unacceptable ecological risks would occur.

A summary of the benchmarks used for comparison is presented in **Table G-1**. In addition to the LAETs, background concentrations for Washington State and MTCA Method A, industrial and residential concentrations are included for comparison. In each case, the ecological benchmarks are lower than the industrial human health MTCA levels and above background concentrations. The ecological benchmarks are similar to the residential human health MTCA Level A values.

Surface and subsurface soil data are presented in **Tables G-2 and G-3**, respectively. For the purpose of this evaluation, surface soil was defined as samples collected less than 2 feet below ground surface (BGS); subsurface soil was defined as samples collected from 2 or more feet BGS. These data are as presented in *Draft Environmental Impact Statement for Lone Star Maury Island Mining Operation, Final Sampling Results NW Aggregates Maury Island Gravel Mine, and the Technical Memorandum on Environmental Soil Sampling, Arsenic, Cadmium, and Lead, Lone Star Maury Island Site, King County, Washington.*

As shown in **Table G-2**, surface soil samples frequently exceed ecological benchmarks, particularly for arsenic and lead. Concentrations of these contaminants are highest in the more shallow soils; although many samples from nine inches BGS exceeded the LAET screening level for arsenic and a few samples from 18 inches BGS also marginally exceeded the LAET screening level for arsenic.

Contamination in surface soils could pose an unacceptable risk if this contamination migrates to sediments. If surface soils are to be used as fill, more comprehensive modeling of contamination leaching and migration should be performed to estimate potential sediment concentrations.

Table G-3 presents the available subsurface soil data. As indicated in this table, all subsurface soil results are below ecological screening levels for all three analytes. Cadmium and lead generally were not detected in subsurface soil, and arsenic concentrations were generally an order of magnitude below the LAET screening level and the MTCA Level A Residential level.

Based on the above analysis, use of subsurface soils as fill should not pose an unacceptable risk to ecological receptors.

Table G-1
Summary of Benchmarks and Screening Levels

	Ecology LAETs	Background Concentrations	MTCA Method A Industrial	MTCA Method A Residential
Arsenic	40	7	200	20
Cadmium	7.6	1	10	2
Lead	260	24	1000	250

All values expressed in mg/kg.

Table G-2
Comparison of Surface Soil Samples to Ecotoxicological Benchmarks

Sample Number	Surface Arsenic	Surface Cadmium	Surface Lead	9-Inch Depth Arsenic	9-Inch Depth Cadmium	9-Inch Depth Lead	18-Inch Depth Arsenic	18-Inch Depth Cadmium	18-Inch Depth Lead
1	**330**	2	**830**	37	0.84	27	**43**	0.66	19
2	**120**	2.3	**390**	25	1.2	10	8.7	0.56 U	5.6 U
3	**150**	0.79 U	**280**	**110**	0.91	81	10	0.62	8.6
4	**160**	1.5	**450**	19	0.72	25	4.2	0.53 U	5.3 U
5	**47**	0.92	54	**47**	0.84	59	**43**	0.63 U	51
6	**100**	**9.3**	**470**	**270**	2.9	120	**64**	1.1	30
7	17	0.58 U	13	19	0.56 U	18	13	0.53 U	11
8	**190**	3	**550**	**67**	0.94	41	10	0.58 U	7.6
9	**98**	1.6	**510**	**110**	0.95	30	9.2	0.77	7.1
10	4.3	0.53 U	5.3 U	1.6 U	0.53 U	5.3 U	1.6 U	0.52 U	5.2 U
11	1.9	0.53 U	5.3 U	1.6 U	0.55 U	5.3 U	1.6 U	0.53 U	5.3 U
12	6.1	0.54 U	5.8	6.2	0.54 U	5.4 U	5.7	0.55 U	6
13	**220**	1.2 U	**470**	**130**	0.82	45	8.2	1.5	8.3
14	18	0.91	70	**130**	1.2	37	2.0 U	0.92	36
15	1.6 U	0.53 U	5.3 U	1.6 U	0.53 U	5.3 U	1.6 U	0.53 U	5.3 U
16	**280**	1.6	**730**	39	0.84	17	40	0.89	23
17	**61**	6	240	**260**	1.2	35	11	0.52 U	5.2 U
18	11	0.59 U	7.1	8.2	0.57 U	5.7 U	5.9	0.57 U	6.1
19	**100**	6	**470**	**270**	1.4	67	3.8	0.59 U	5.9 U
20	**140**	5.4	**710**	11	0.59 U	11	7.6	0.59	6.6

Values expressed in mg/kg.
U = undetected
Bold values exceed proposed Ecology LAETs for freshwater sediment.

Table G-3
Comparison of Subsurface Soil Samples to Ecotoxicological Benchmarks

Depth (bgs)	Arsenic	Cadmium	Lead
9	4.3	0.58 U	5.8 U
10	4.6	0.54 U	5.4 U
8.5	2.7	0.61 U	6.1 U
10	2.4	0.53 U	5.3 U
10	3.9	0.54 U	5.4 U
10	2.4	0.54 U	5.4 U
10	3.5	0.54 U	5.4 U
10	3.1	0.54 U	5.4 U
10	4.6	0.54 U	5.4 U
10	6.9	0.58 U	5.8 U
10	3.1	0.54 U	5.4 U
10	3.3	0.54 U	5.4 U
10	4	0.56 U	5.6 U
10	2.2	0.52 U	5.2 U
NL	1.6 U	0.53 U	5.3 U
NL	2.2	0.53 U	5.3 U
NL	1.6	0.53 U	5.3 U
NL	1.8	0.54 U	5.4 U
95	1.9 U	0.63 U	6.3 U
270	2.4	0.67 U	6.7 U
55	3 U	NA	7.7
190	1.7 U	NA	6
140	3 U	NA	8.9
220	3 U	NA	5.3
2	8 U	1 U	10 U
2	8 U	1 U	10 U
2	8 U	1 U	10 U
2	8 U	1 U	10 U

Values expressed in mg/kg
U = Undetected
NA = Not analyzed.
NL = Not listed.
All samples are below proposed Ecology LAETs for freshwater sediment and background concentrations.