HARTCROWSER

Earth and Environmental Technologies

Hart Crowser, Inc.
1910 Fairview Avenue East
Seattle, Washington 98102-3699
Fax 206.328.5581
Tel 206.324.9530
www.hartcrowser.com

J-4978-03

December 9, 1998

Ms. Barbara Hinkle
Health, Safety & Environmental Services
Port of Seattle
17900 International Blvd, Suite 301
Seattle, WA 98188

Re: SeaTac Third Runway - Aquifer Compaction

Dear Ms. Hinkle:

In response to your request, this letter addresses the question of potential compaction of aquifers beneath the proposed Third Runway embankment. We understand that you will use this information in responding to questions raised by U.S. Army Corps of Engineers on potential hydrogeologic impacts related to construction.

SUMMARY

Construction of the Third Runway at SeaTac will involve placement of up to about 160 feet of soil fill to create an embankment to support the new runway on the west side of the current airport. A question has been raised on whether the weight of this fill will compress the underlying aquifers and possibly diminish their resource value. Three aquifers have been identified below the proposed embankment; the Shallow Aquifer which contributes to base flow of Miller Creek, and the underlying Intermediate and Deep Aquifers which provide part of the regional water supply (AGI, 1996).

Hart Crowser's calculations, based on worst-case assumptions, indicate that void ratio within the Shallow, Intermediate, and Deep Aquifers within the area immediately underlying and adjacent to the embankment would be reduced by roughly 1 to 3 percent due to the maximum weight of the embankment. For perspective, this corresponds to about a 4-inch maximum change in thickness for the 50-foot-thick Shallow Aquifer. The magnitude of the change in void ratio would diminish rapidly both laterally and as a function of depth. There would be no effect in the Shallow Aquifer more than 50 feet from the edge of the embankment, and no effect in the Deep Aquifer more than about 500 feet from the edge of the embankment.

Reductions in permeability on the order of 2 to 5 percent corresponding to the change in void ratio are estimated immediately below the embankment, with the effects decreasing with depth. The estimated 2 to 5 percent change is insignificant, given that differences in permeability are usually evaluated in terms of orders of magnitude (powers of 10).

Conceivably effects of the magnitude estimated could be measurable as slight groundwater mounding in the Shallow Aquifer, on the upgradient side of the embankment (i.e., below the existing airport). Base flow to Miller Creek located west of the embankment is not likely to be impacted since the new embankment will increase the area of relatively flat ground surface, resulting in a net increase in infiltration and base flow. No impacts to drinking water resources in the Intermediate and Deep Aquifers are anticipated, since there are no wells within the affected area (maximum about 500 feet from the edge of the embankment).

The degree of aquifer compaction and corresponding reduction in porosity and permeability are a function of the change in *in situ* stresses, and the thickness and compressibility of the aquifer materials. These parameters are discussed in the following sections and used in the calculations summarized in Table 1.

IN SITU STRESS CHANGES

The changes in stress within the aquifers are related to their depth as well as to geometry of the embankment, which varies along its length. For discussion purposes, calculations in this letter used the average increase in stress at the mid-depth of each aquifer, below the maximum height of the embankment. Other parts of the embankment will have a smaller increase in *in situ* stress, corresponding to less weight of fill.

The increased stress due to the weight of the embankment is limited in lateral extent. For instance, where the middle of the Deep Aquifer is about 400 feet below the base of the embankment, the weight of the embankment will only increase stress in the aquifer within a maximum distance of about 200 feet from the outside edge of fill. The extent of this lateral influence is even less for the Shallow and Intermediate Aquifers.

Hart Crowser calculated change in *in situ* stress using an elastic stress distribution below the embankment, typically used in geotechnical calculations; and an average soil unit weight of 135 pounds per cubic foot (pcf) which represents the range in values typical of glacially overridden soils (Terzaghi & Peck, 1967). Depth and thickness of the aquifers used in our calculations are based on published information (Woodward et al., 1995).

AQUIFER COMPRESSIBILITY

Aquifer compaction was calculated as the strain resulting from the increase in stress divided by a deformation modulus which represents compressibility of the aquifer. Considering depth of the aquifers, we used a range of values of 3,000,000 to 7,000,000 pounds per square foot (psf) for the deformation modulus, based on results of local plate load tests and published data (Hart Crowser, 1981; Terzaghi & Peck, 1967). We calculated change in aquifer thickness by dividing the increase in stress by the deformation modulus. The deformation modulus values used are considered to be conservative since the aquifers below the embankment have already been "pre-loaded" by the past weight of glacial ice which created vertical loads of roughly 185,000 psf (Olmsted, 1968) - more than 8 times the maximum load resulting from the weight of the embankment.

AQUIFER COMPACTION

The amount of aquifer compaction that occurs from the reduction in aquifer thickness is calculated as a change in void ratio or porosity of the aquifer. Because the aquifers are relatively permeable, the increase in stress resulting from the embankment load causes the soil particles to move closer together, with dissipation of excess pore pressures essentially at the same rate the load is applied. We estimated average total porosity of the aquifers was around 30 percent, with corresponding void ratio about 0.43 (Terzaghi & Peck, 1967). We calculated the entire change in aquifer thickness would be reflected in decreased porosity or void ratio, which conservatively assumes the soil particles themselves are incompressible.

CHANGE IN AQUIFER CAPACITY BELOW THE EMBANKMENT

The permeability of an aquifer, or its ability to transmit water, is proportional to the square of the void ratio, since pore size controls the rate at which water can move through an aquifer (Terzaghi & Peck, 1967). We estimated the change in permeability corresponds to the change in the square of void ratio.

The estimated changes in porosity (expressed as void ratio) and permeability have an overall small effect on aquifer capacity, as the groundwater system will tend to compensate by other adjustments. For example, the slight groundwater mounding below the airport would produce a corresponding increase in hydraulic gradient, so that the amount of local groundwater flow would likely remain the same despite the local change in permeability.

The zone of aquifer compaction is limited to that area directly underlying and immediately adjacent to the embankment. Overall aquifer flow rates and groundwater levels vary broadly through the seasons, and from year to year. The changes below the embankment are not anticipated to be distinguishable relative to these natural variations.

Please call if we can provide any additional information.

Sincerely,

HART CROWSER, INC.

Michael A P Kenrick

MICHAEL A.P. KENRICK, PE
Senior Associate Hydrogeologist

Michael Bailey

MICHAEL J. BAILEY, PE
Project Manager

Attachments:
References
Table 1 - Aquifer Compaction Calculations
Vita

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REFERENCES

AGI Technologies, 1996. *Baseline Groundwater Study,* Appendix Q-A, Final Environmental Impact Statement, Proposed Master Plan Update, Sea-Tac International Airport, SeaTac, Washington. Prepared for Shapiro & Associates, January 3, 1996.

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Terzaghi, K. & Peck, R., 1967. *Soil Mechanics in Engineering Practice,* John Wiley & Sons, 2nd Edition.

Woodward, D.G., Packard, F.A., Dion, N.P., & Sumioka, S.S., 1995. *Occurrence and Quality of Ground Water in Southwestern King County, Washington.* Water-Resources Investigation Report 92-4098, US Geological Survey, Tacoma, Washington.

Table 1 - Aquifer Compaction Calculations

1) Pre-Construction Conditions

Aquifer Layer	Top Elevation of Aquifer in feet ASL	Typical Aquifer Thickness in feet	Aquifer Mid Point Depth in feet	*In Situ* Vertical Stress in psf	Modulus of Deformation in psf	Total Porosity in %	Void Ratio	(Void ratio)²
Shallow Aquifer	230	50	25	3,375	3.00E+06	30	0.429	0.184
Intermediate Aquifer	80	100	200	27,000	5.00E+06	30	0.429	0.184
Deep Aquifer	-180	50	435	58,725	7.00E+06	30	0.429	0.184

2) Post-Construction Changes

Aquifer Layer	Average Increase in Stress due to loading in psf	Aquifer Compaction in feet	Post-Construction Porosity in %	Relative Change in Porosity in %	Post-Construction Void Rato	Relative Change in Void Ratio in %	Post-Construction (Void ratio)²	Relative Change in (Void ratio)² in %
Shallow Aquifer	21,073	0.35	29.5	-1.65	0.419	-2.34	0.175	-4.63
Intermediate Aquifer	18,000	0.36	29.7	-0.84	0.423	-1.20	0.179	-2.39
Deep Aquifer	15,052	0.11	29.8	-0.50	0.425	-0.72	0.181	-1.43

Assumptions 1) Unit weight of fill = 135 pcf
2) Maximum thickness of fill = 160 ft
3) Average width of embankment = 1000 ft

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Vita

Michael Bailey, P.E., is a registered Professional Engineer in the States of Washington and Alaska. He received his Master of Science Degree in Civil Engineering in 1976 from Purdue University, and his Bachelor of Science Degree in Civil Engineering, with Honors, in 1974 from Michigan Technological University. Mr. Bailey is a Principal in the Seattle-based geotechnical and environmental engineering firm Hart Crowser, Inc. where he has worked as a geotechnical engineer since 1980.

Michael Kenrick, P.E., is a registered Civil Engineer in the State of Washington. He received a Bachelor of Science degree in Civil Engineering, with Honors, at the University of Manchester, England (1973) with senior-year emphasis on soil mechanics, hydrology, and structural engineering. In 1977, he received a Master of Science degree in Hydrogeology at the University of Birmingham, England. He has over 12 years of experience in engineering project work in the Puget Sound area, and currently holds the position of Senior Associate Hydrogeologist in the Seattle-based geotechnical and environmental engineering firm Hart Crowser, Inc.