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7 February 2002

U.S. Army Corps of Engineers
Regulatory Branch
P.O. Box 3755
Seattle, WA 98124
ATTN: Muffy Walker/Gail Terzi

Subject: Comments on Recently Received Documents Pertaining to Seattle Tacoma International Airport Project Third Runway – Low Flow Analysis

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GeoSyntec Consultants (GeoSyntec) has been retained on behalf of the Airport Communities Coalition (ACC) to provide a technical review of investigation, analysis and design relating to geotechnical and hydrogeological elements of the proposed Third Runway Expansion Project at the Seattle Tacoma International Airport. GeoSyntec has previously commented on seismic and geotechnical aspects of the embankment fill and Mechanically Stabilized Earth Wall. In my October 2001 declaration in support of ACC's motion for stay, I raised numerous concerns relating to the Port's Low Flow Analysis. This letter presents an expansion on the issues raised in the declaration based largely on review of the November 27, 2001 report by Pacific Groundwater Group (PGG) titled "Port of Seattle - Sea-Tac Third Runway - Embankment Fill Modeling in Support of Low Streamflow Analysis."

Introduction

The purpose of the low flow analysis is to evaluate the impact that construction of the Third Runway Embankment will have on the rate at which runoff and infiltration recharge the creeks. The impact of the embankment is that it stores infiltrating water and subsequently releases it to recharge the low stream flows at different times than if the embankment were not in place. To mitigate the impact of the embankment, excess water must be stored and released to the creeks to maintain conditions that existed prior to the construction of the embankment. The analysis must be able to predict the magnitude of the impact of the embankment and provide a sound basis for calculating the required storage to maintain flows in the creeks. Like any work of this type, the results of the analyses must consider the reliability of the analytical method and the uncertainty of the parameters input into the analyses. If the analyses are not conservative then other sources of water must be available to make up any shortcomings in the water supply.

In the discussion that follows, several key points and concerns will be made regarding the Low Streamflow analyses presented by the Port. The discussions focus on the following essential findings:

- The Port's analysis fails to consider the substantial additional water requirements during the initial years of operation;
- The Port's analysis on the long term operation of the facility is not reliable and may significantly over estimate the rate at which water will flow through the embankment;
- The Port's analysis includes assumptions which have not been validated as to their reliability and impact on the results; and
- The Port's analytical approach of using a one dimensional version of Hydrus and then converting to the SLICE spreadsheet program appears to be an unnecessary complication that could be introducing additional errors into the analyses.

The Port's consultants have not demonstrated that this project as designed will satisfy the low streamflow requirements of the surrounding creeks. GeoSyntec's review of the Port's analyses, along with results of our own independent analyses, clearly show that following the completion of construction, the amount of water passing through the embankment into the underdrain is likely to be highly erratic and of a substantially lower quantity than the current low flow analysis predicts. The volume requirements of the storage vaults may be substantially under-designed. The under-design is due to the failure to calibrate the computer models being used; failure to evaluate the variability of the embankment soils; and an overestimation of the overall hydraulic conductivity of the soils in the embankment by ignoring the basic flow processes that will be occurring. Based on the Port's current low flow analysis it is impossible to predict whether the current vault sizes will be adequate on a long term basis. During the initial years of operation it is probable that insufficient water will be available from the vaults to mitigate the impacts to low stream flows. The following sections elaborate on the gaps in the analysis, focusing on the above issues.

Comment 1: Flows to the creeks during the first several years after construction have not been accounted for in the analyses, which will likely result in an inability of the Port to provide for the low flow requirements during this time period.

There appears to be no consideration given to the time it will take between the end of construction of the embankment fill and the initial arrival of the predicted flows that have passed through the embankment and into the drainage layer. The low flow analyses presented by the Port apparently encompass a ten-year rainfall record from 1984 to 1994. However, the first six years of the analysis results are not presented and the results after six years apparently represent the post-equilibration period after the early years. During the initial period, water entering the embankment would be absorbed by the fill and relatively little water would be released into the drainage layer for some unknown period of time. This time lag could be several years, and could lead to a requirement for a significantly greater volume of water to be stored than predicted by the current analyses.

The largest storage requirements for water to protect the low flow conditions in the creeks will occur during the initial years following construction when the flow through the embankment is likely to be most erratic. GeoSyntec has performed preliminary analyses using the Hydrus 2D model (presented in more detail in a subsequent section of this letter), which indicate that the initial lag time between completion of the embankment and arrival of water at the creek may be on the order of 1 year or more for a 20 ft high cross-section (shown on Figure 5-3 of the PGG report), 4 years or more for a 110 ft high cross-section (shown on Figure 5-2 of the PGG report) and 6 years or more for a 150 ft high cross-section (shown on Figure 5-1 of the PGG report). These delays would clearly have a severe impact on the creek low flows, yet the Port's current analyses do not appear to consider this critical scenario, even though they are modeling stretches of embankment fill of over 8000 ft in length, with 1600 ft represented by the 150 ft high embankment, 3700 ft represented by the 110 ft high embankment, and 3200 ft represented by the 20 ft high embankment (based on Table 5-7 of the PGG report).

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Comment 2: The analysis relies on a single set of soil parameters to represent the behavior of 20 million cubic yards of fill that will be obtained from numerous different borrow sources. This is a gross oversimplification and will lead to significant discrepancies between the predicted streamflows and those that would actually occur after construction.

The attached Figure 1 presents the range of soil grain sizes allowed by the project specifications and presents the single grain size representation used in the low flow analyses. Fill placement during construction of the embankment will occur in horizontal layers. As a result, there will likely be large areas of fill with fine-grained, low hydraulic conductivity material which will control the rate at which water flows vertically through the embankment. The overall hydraulic conductivity of the actual soil in the embankment could be several orders of magnitude less than that assumed for the current low flow analyses. This difference in hydraulic conductivity will have a substantial effect on the predictions made in the current analyses.

Regarding the reliability of the unsaturated flow model used by the Port, the developers of the Rosetta model the Port uses in developing their unsaturated flow parameters for use in Hydrus, have stated: "Bootstrap analyses showed that the uncertainty in predicted unsaturated hydraulic conductivity was about one order of magnitude near saturation and larger at lower water contents."[1] This indicates that even if the material to be used was well defined (i.e. if there was only one source of material and it was of uniform characteristics) the uncertainties in the model would be greater than one order of magnitude for these analyses.

The current low flow analyses should not be accepted without a proper parametric evaluation of the influence of soil parameters on flow paths and travel times. A comparison of the soil parameters used for the low flow analyses and the range of soil types allowed for construction indicate that the flow rates through the embankment will be significantly more variable than the current analyses would indicate. That variability will likely increase the vault storage volumes required to protect low flow conditions in the creeks.

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[1] Schaap, M.G. and Leij, F.J. (2000) "Improved Prediction of Unsaturated Hydraulic Conductivity with the Mualem-van Genuchten Model," Soil Science Society of America Journal, Vol. 64, 843-851.

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In Hart Crowser's "Embankment Infiltration and Seepage Studies" report[2], they presented unsaturated flow parameters and corresponding unsaturated behavior curves for three of the fill types proposed for the embankment (Group 1B, Group 3, and Group 4). Figures 2a and 2b present the representative curves developed by Hart Crowser for the three fill types, along with the single set of curves being used presently by PGG in their Hydrus modeling (labeled "Port Properties"). While Hart Crowser's modeling with the HELP program was overly simplistic and their method of accounting for gravel content was not well validated, their performance of parametric studies on the fill types was a step in the right direction compared to the single fill type currently being modeled in Hydrus. The Hart Crowser properties show that the hydraulic conductivity (which controls the rate at which water will pass through the fill) can range over several orders of magnitude for soils likely to be placed in the embankment. The figures clearly show that the single curve being used by the Port is not representative of the potential range of behavior.

In order to demonstrate the influence of the variability of soil properties on the lag time between embankment construction and first arrival of water at the drain, several simple cases were analyzed. 1-Dimensional columns of varying fill thickness (25 ft, 50 ft, 100 ft, and 150 ft) were modeled using Hydrus for three different sets of fill properties (Hart Crowser Group 1B, Hart Crowser Group 3, and the Port Properties). The 1-Dimensional columns were modeled in a fashion similar to the Port's analyses, where all infiltration was assumed to travel vertically through the fill, without an allowance for horizontal flow. Figure 3 shows the results of these analyses. A curve is shown for each set of properties, immediately revealing the potential for variability in the results. Each point on the curves represents the time between the beginning of the analysis (Day 0) when the precipitation record begins, and the time when the first water reaches the drain at the base of the column. As the height of the 1-Dimensional column is increased (i.e. as the embankment fill thickness increases) the time lag increases relative to the properties for each fill type. For example, for a 50 ft fill thickness, the range of time lags shown is 250 to 500 days (approximately 0.7 to 1.4 years), and for a 150 ft fill thickness, the range is 850 to 2250 days (approximately 2.3 to 6.2 years). It will be shown later that ignoring the horizontal flow component in the fill (i.e. performing a 1-Dimensional analysis) results in an overestimation of the rate at which water flows through the fill, and thus the predicted lag times will actually be even longer than these values. In any case, the differences clearly demonstrate the potential variability in results which the port is ignoring in their analyses. Incorporation of this type of

[2] Appendix C of the Hart Crowser "Geotechnical Engineering Analyses and Recommendations – Third Runway Embankment," prepared for HNTB, dated December 4, 2000, draft.

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parametric study in the Port's analysis will likely have a significant impact on the design of the Port's low flow mitigation scheme and is absolutely necessary for proper representation of the possible impacts of the embankment fill.

Comment 3: The Port's selected method of ignoring the gravel content of the fill (which is assumed equal to more than half of the total mass) and adjusting the water inflows and outflows to compensate for this action is not a validated technique and may have significant impacts on the predicted versus actual flow paths and travel times.

The Port's selected "representative" embankment fill material consists of 55% gravel, and 45% sand and silt. In order to model this material in Hydrus, they have made the following assumptions:

1. No flow will travel through the 55% gravel;
2. The entire embankment can be represented by a uniformly distributed material with properties corresponding to the remaining sand and silt matrix;
3. In order to mimic the corresponding rate of flow through the sand and silt, the amount of water entering the embankment can be increased by an amount that is proportional to the gravel content of the fill (i.e. multiplied by 2.22 = 1/0.45) and the amount of water exiting the embankment at the end of the analysis can be reduced by this same amount.

This approach is highly questionable as it in essence completely ignores the effect of the gravel on the unsaturated flow properties of the fill.

A review of available literature on the subject provides a more representative approach for modeling the fill that takes into account the influence of the gravel rather than ignoring it. In this approach, the Rosetta model is used with the sand and silt matrix to develop initial parameters. The residual and saturated moisture contents are then adjusted to account for gravel following the approach described and tested by Khaleel and Relyea (1997)[3], and the estimated saturated hydraulic conductivity is then adjusted following the approach described and tested by Brakensiek et al. (1986)[4]. By incorporating the influence of the gravel within the model parameters, there is no longer

[3] Khaleel, R. and Relyea, J.F. (1997) "Correcting laboratory-measured moisture retention data for gravels," Water Resources Research, Vol. 33, No. 8, 1875-1878, August 1997.
[4] Brakensiek, D.L., Rawls, W.J., and Stephenson, G.R. (1986) "Determining the saturated hydraulic conductivity of a soil containing rock fragments," Soil Science Society of America Journal, Vol. 50, 834-851.

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any need for artificial adjustment to the input precipitation values to Hydrus or to the predicted output discharges.

While this approach presents a significant improvement over the simplified method used by the Port, it must also be taken in the context of the potential for variability among the parameters and the predictive capability of the model. The uncertainties of over an order of magnitude are still present. Therefore, this proposed approach should be calibrated by means of laboratory testing of representative samples of the embankment fill, and the analysis and subsequent design should not be based on a single set of parameters, but rather a representative range sufficient to bracket the likely behaviors of the embankment fill.

Comment 4: The Port's method of modeling of flow through the fill as a 1-Dimensional phenomenon using Hydrus is an oversimplification of a truly 3-Dimensional process, and will result in an overprediction of the rate at which water travels through the embankment.

In addition to the Port's ignoring the gravel content of the embankment fill, their analysis consists of a series of 1-Dimensional columns of soil of varying thickness which force the infiltrating water to travel downward unimpeded without any lateral migration. Figure 4a shows a schematic of the system the port is actually modeling. Each column theoretically consists of 55% gravel and 45% sand and silt. However, water falling on any given column of soil is forced through the sand and silt matrix (achieved through artificial adjustment of precipitation and discharge quantities), bypassing the gravel completely. It should also be noted that water falling on the sloping face of the embankment is assumed not to infiltrate at all, and because the water can only travel vertically, this region never sees any water at all.

Figure 4b shows a schematic (which is still a simplification) of the type of layering that will exist in the embankment fill as a result of the construction process. 20,000,000 cubic yards of fill will be imported from numerous borrow sources and placed in horizontal layers at the then current elevation. The soil layers with the lowest hydraulic conductivity will control the vertical rate of flow of water traveling through the embankment. It will be impossible for the Port to control the fill sufficiently that an assumption of uniform flow behavior can be assumed realistically. The Port has failed to consider the very real variability of the soils that will be placed in the embankment. As a result of the fill layering, the flow path will be significantly more complex than represented by the Port (e.g. Figure 4a), and the time for water to travel through the embankment will be much slower than predicted.

Comment 5: The modeling transition from Hydrus to SLICE and then to HSPF adds undesirable complexity and potential for error in the analysis.

The multiple transitions between programs add significant potential for human error as the data must be manipulated on several occasions as it is fed from one program to the next. This was seen previously in the Port's admitted error where flows were off by a factor of 24. The Port's consultants have not explained the rationales for this unnecessary complexity. GeoSyntec has performed preliminary analyses using the Hydrus 2D model in which the use of the SLICE model has been successfully eliminated from the analysis, as Hydrus is fully capable of modeling the flow into and through the drainage layer, as well as the flow into the underlying till.

Preliminary Results of GeoSyntec Analysis

GeoSyntec is currently performing a detailed review of the Port's analysis, using the HYDRUS program to examine the sensitivity of the results to changes in input parameters. While the analyses are only preliminary at this time, and the models will be subjected to further refinement, several important trends have been noted already.

Figure 5a presents a schematic of the Hydrus model cross-section being used by GeoSyntec, which is based on PGG's section 2, with an embankment fill height of up to 110 ft. The embankment fill, the drainage layer, the outwash layer, and the underlying till are all being modeled within Hydrus. The model is being run using approximately four years of daily precipitation data (January 1990 through February 1995) from the SeaTac airport. No runoff or evapotranspiration calculation has been made, so all precipitation is assumed to enter the embankment.

Figures 5a through 5e present preliminary results using the Hart Crowser Group 3 fill properties described in Comment 2. The lighter colored front that progresses downward over time represents the propagation of the infiltrating precipitation. It is clear that the water infiltrating near the face of the slope, which has a shorter travel path to the drainage layer has already begun to reach the drain and then the creek by approximately 1 year after the modeling begins (Figure 5b). However, the flow under the thick majority of the embankment is only beginning to reach the drainage layer between 3 and 4 years (Figures

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5d and 5e). With the uniform soil profile assumption relied upon by the Port, there is only slight evidence of horizontal flow of water, although Figures 5b through 5e show a gradual narrowing of the dark colored band of dry soil beneath the runway, indicating that moisture is gradually working its way laterally. This effect can also be seen in the flow of water between the filter strips on the right side of the model. The significance of this lateral flow component is that water will travel within the embankment fill for longer periods of time prior to reaching the drain and the creeks than with analyses limited to vertical flow only. The Port, using their simplified analyses, has reported none of these trends.

To demonstrate the impact of horizontal flow on the travel time of water flowing through the embankment, two sets of analyses were performed using the Port's soil properties as shown on Figure 6. Two 25 ft thick fill columns were modeled in Hydrus. In the 1-Dimensional (1D) column, water infiltrating at the top of the column travels downward vertically, without an opportunity for any horizontal flow (same analysis as described in Comment 2). In the 2-Dimensional (2D) column, water was applied over the middle 2/5[ths] of the column only, but once the water entered the soil column, it was allowed to travel both vertically and horizontally. This 2-Dimensional scenario is representative of precipitation adjacent to the runway or filter strips (as seen on Figure 5), where water landing directly on the fill surface can pass directly into the embankment, but water landing on the impermeable runway or filter strips cannot.

Comparison of the 1D and 2D columns on Figure 6 makes the impact of horizontal flow immediately apparent. After 30 days, while flow in the 1D column has had nowhere to go but downwards (represented by the advancing dark colored wetting front), flow in the 2D column has traveled downwards and laterally (represented by the dark colored center and lighter colored bands spreading outwards both in front and on the sides of the wetting front). By 60 days, the wetting front in the 1D column has traveled approximately two thirds of the distance to the drain, while the 2D column wetting front has only progressed a quarter of the distance to the drain. This trend continues throughout the analysis, as the 1D column can only send water downwards, while the 2D column continues to allow water to fill in underneath the impermeable regions on either side of the entry point. Clearly, without incorporating this effect into their analysis, the Port is overpredicting the rate at which water flows through the fill, and therefore their estimates of the time at which flows will arrive at the creek will not be representative.

While these results are preliminary, GeoSyntec believes that the trends described are valid and will remain throughout the refined calculations presently under way. The implication

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of these results (i.e. the large lag time prior to initial arrival of water at the creek, the demonstrated influence of horizontal flow on travel times, and the influence of variability in the soil properties on travel times) is that the Port has underestimated the need for water to mitigate the low flow impacts to the Creeks, in particular in the first several years.

Conclusions

During the initial years following the completion of construction, the amount of water passing through the embankment into the underdrain is likely to be highly erratic and of a substantially lower quantity than the current low flow analysis predicts. The volume requirements of the storage vaults may be substantially under-designed. The under-design is due to the failure to calibrate the computer models being used; failure to evaluate the variability of the embankment soils; and an over estimation of the overall hydraulic conductivity of the soils in the embankment by ignoring the basic flow processes that will be occurring. Based on the current low flow analysis it is impossible to predict whether the current vault sizes will be adequate on a long term basis. During the initial years of operation it is probable that insufficient water will be available from the vaults to mitigate the impacts to low stream flows.

Through a series of previous letters as well as this one, GeoSyntec has identified persistent gaps in the analyses carried out by the Port of Seattle's consultants in their efforts to design this project. We have raised numerous substantive questions, not only about the Low Streamflow Analysis, but also relating to the soundness of the design (particularly seismic) of the embankment and Mechanically Stabilized Earth wall. To date, the Port's consultants have not satisfactorily answered these questions.

Sincerely,

Patrick C. Lucia, Ph.D., P.E.
Principal

cc: Peter Eglick, Helsell Fetterman LLP
Kelly Evans, Airport Communities Coalition

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Figure 1 - SeaTac Embankment Fill Grain Size Analysis

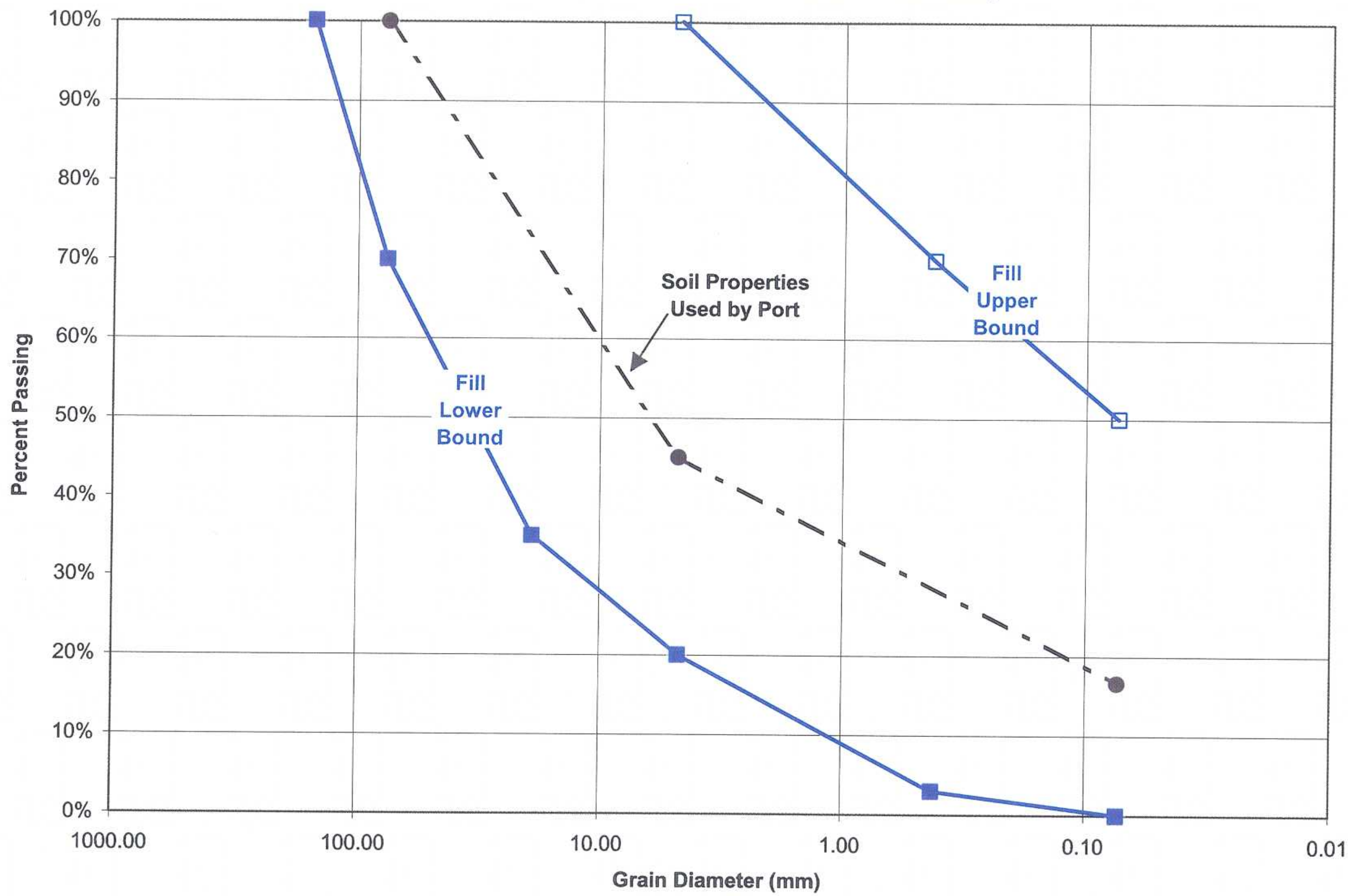

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Figure 2a: Van Genuchten Parameter Variability

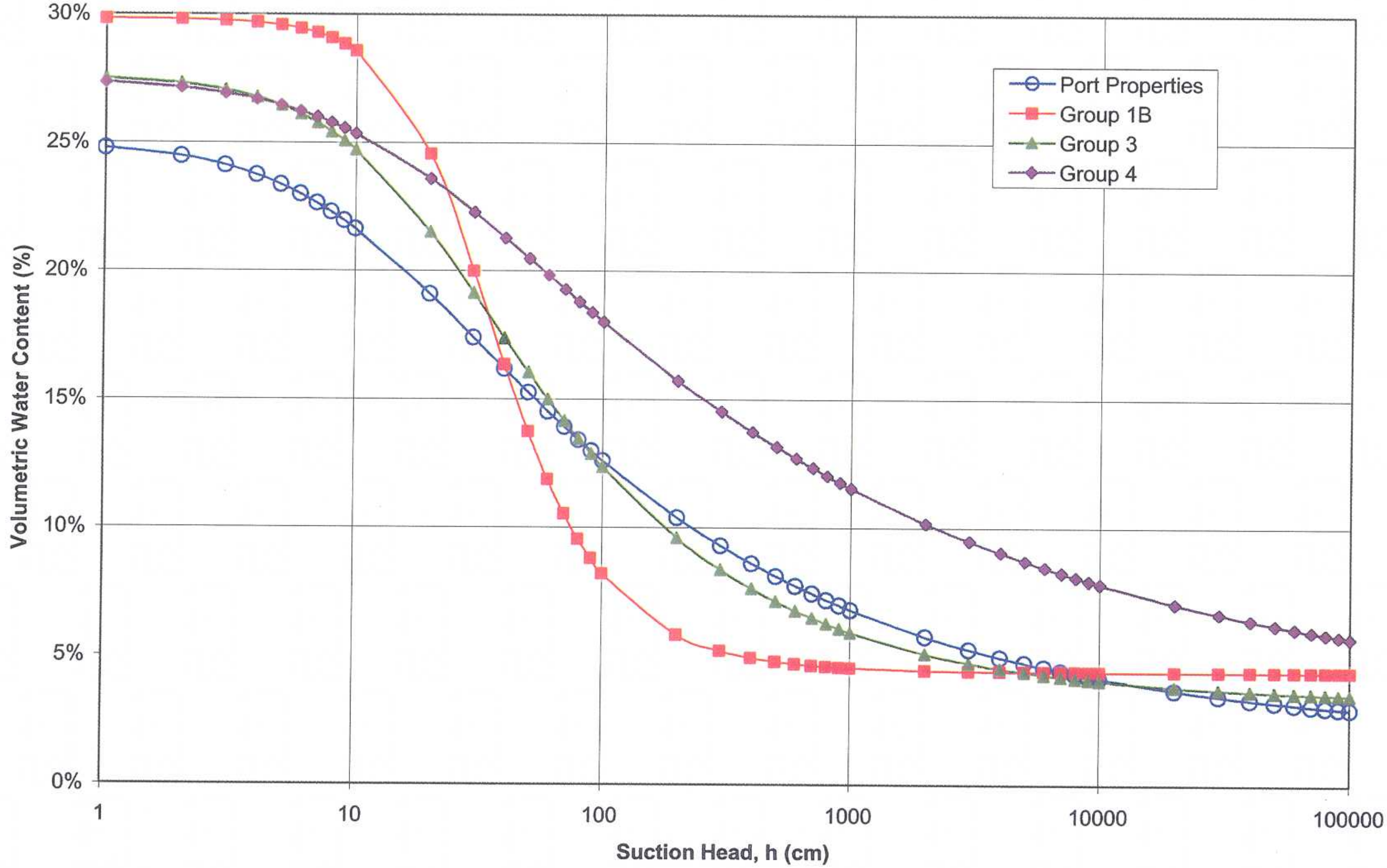

Figure 2b: Mualem Hydraulic Conductivity

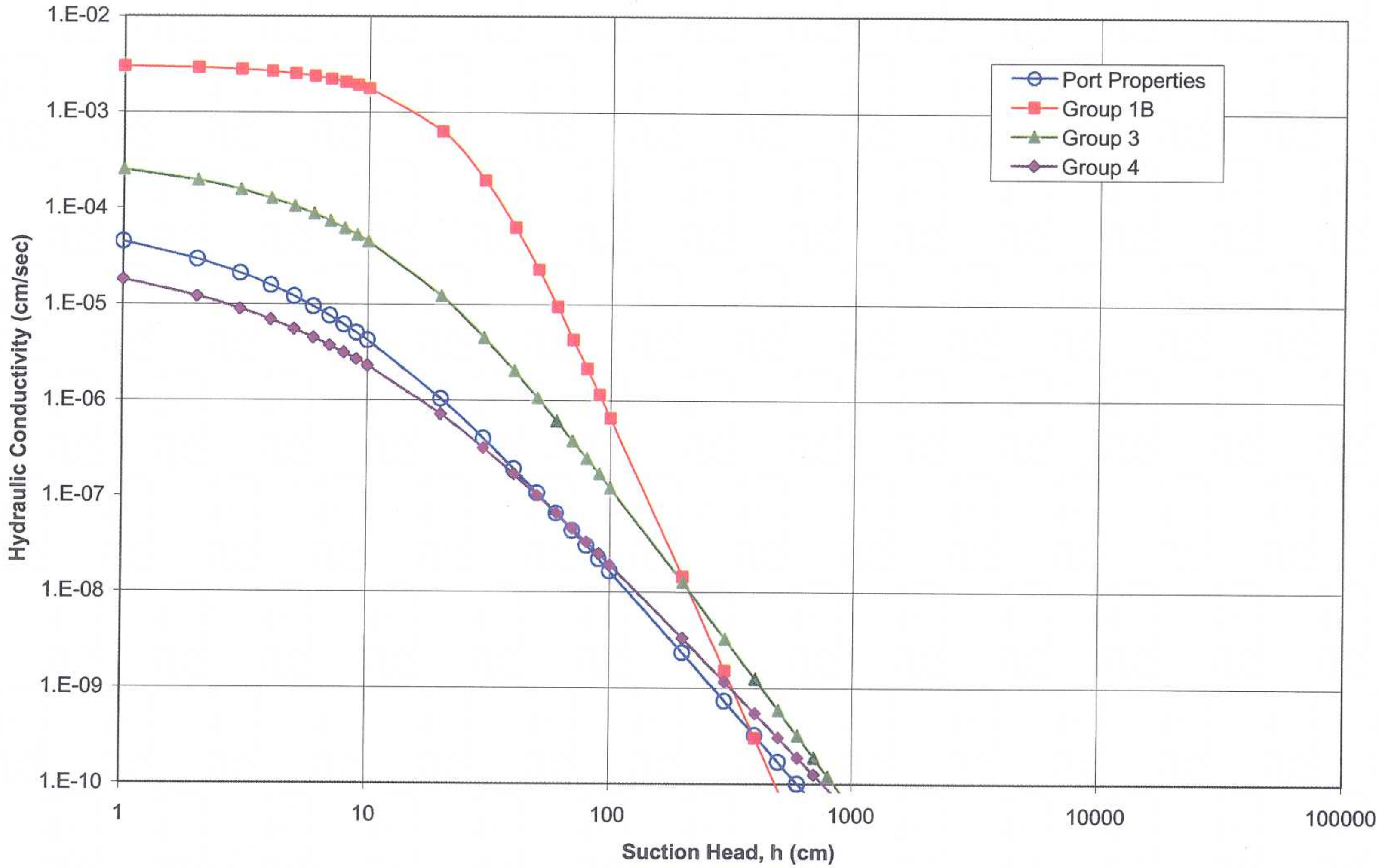

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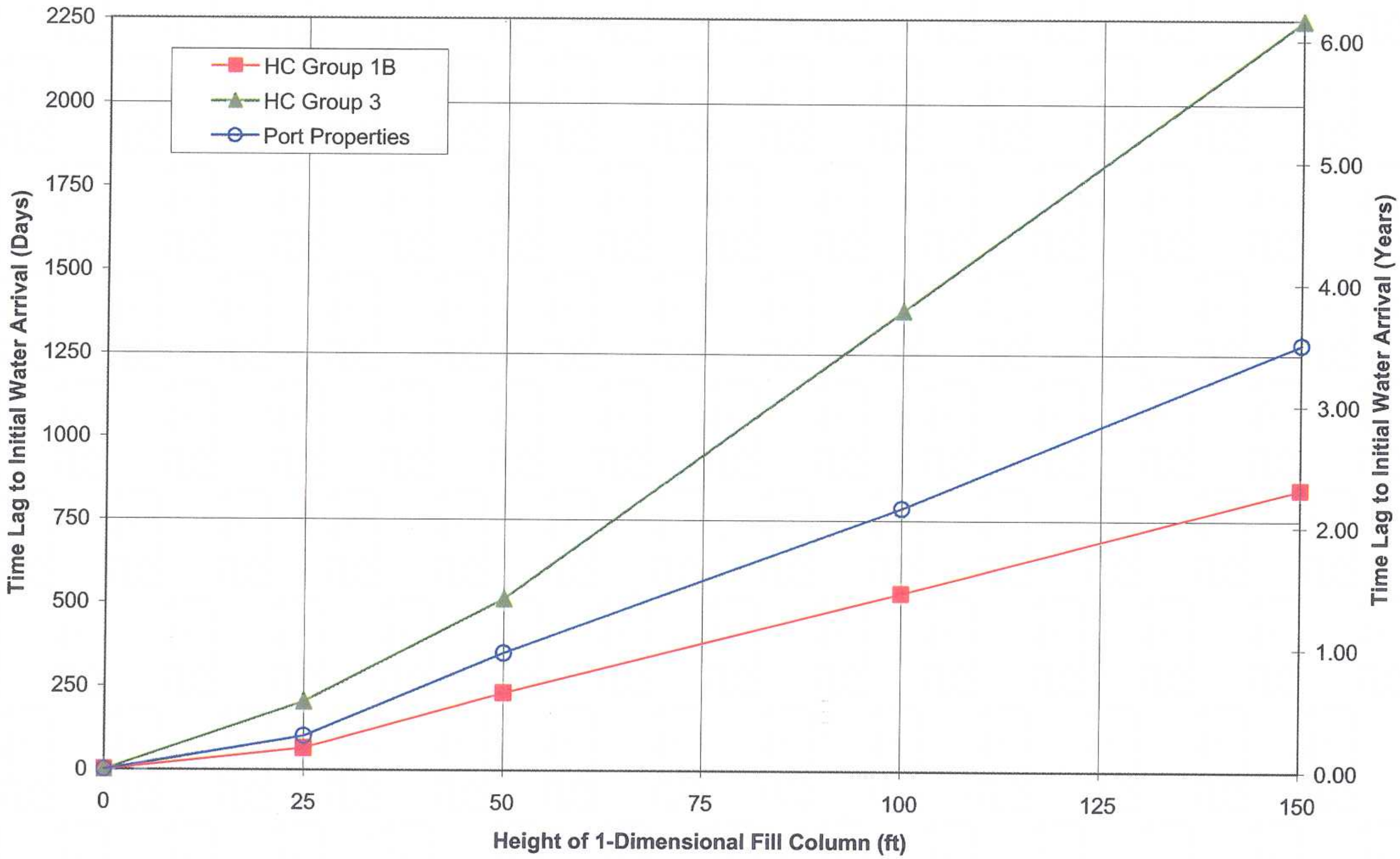
Figure 3: 1-Dimensional Column Initial Lag Times for Infiltration to Reach Drainage Layer under Varying Soil Properties and Column Heights



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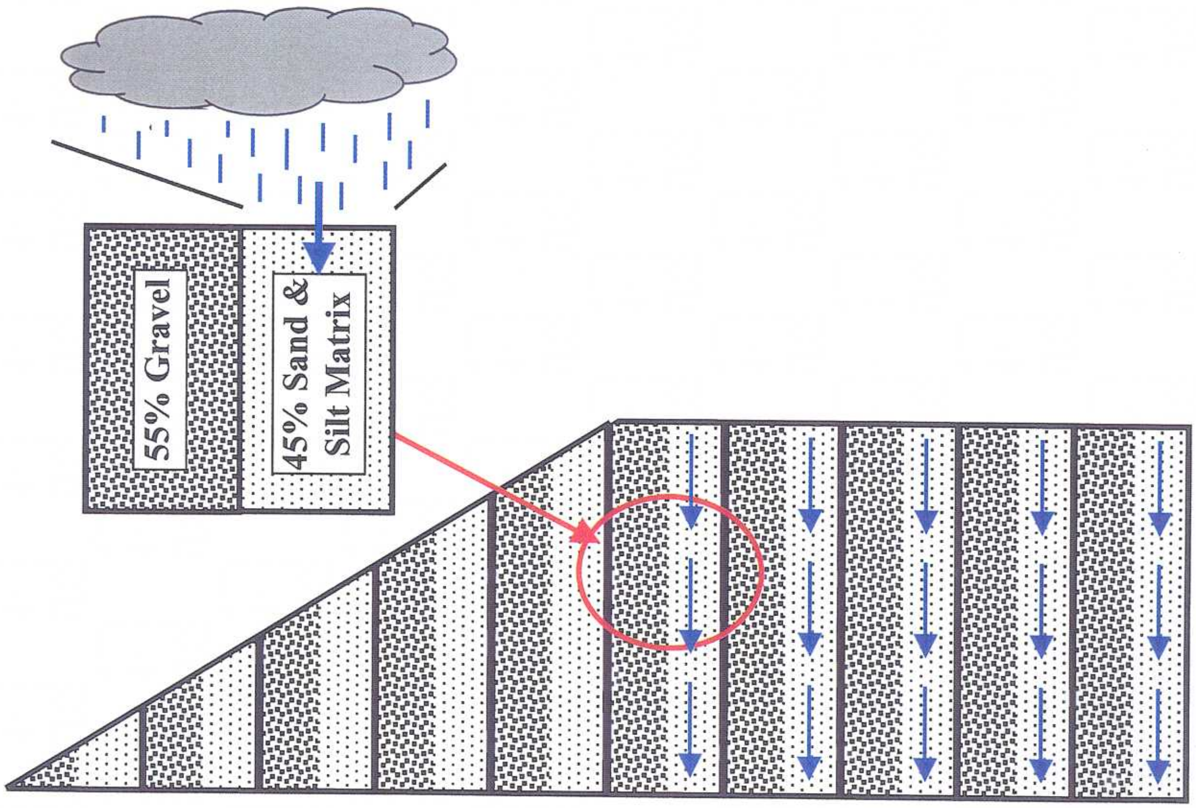

Figure 4a: Current Model System, all flow travels vertically through sand & silt matrix

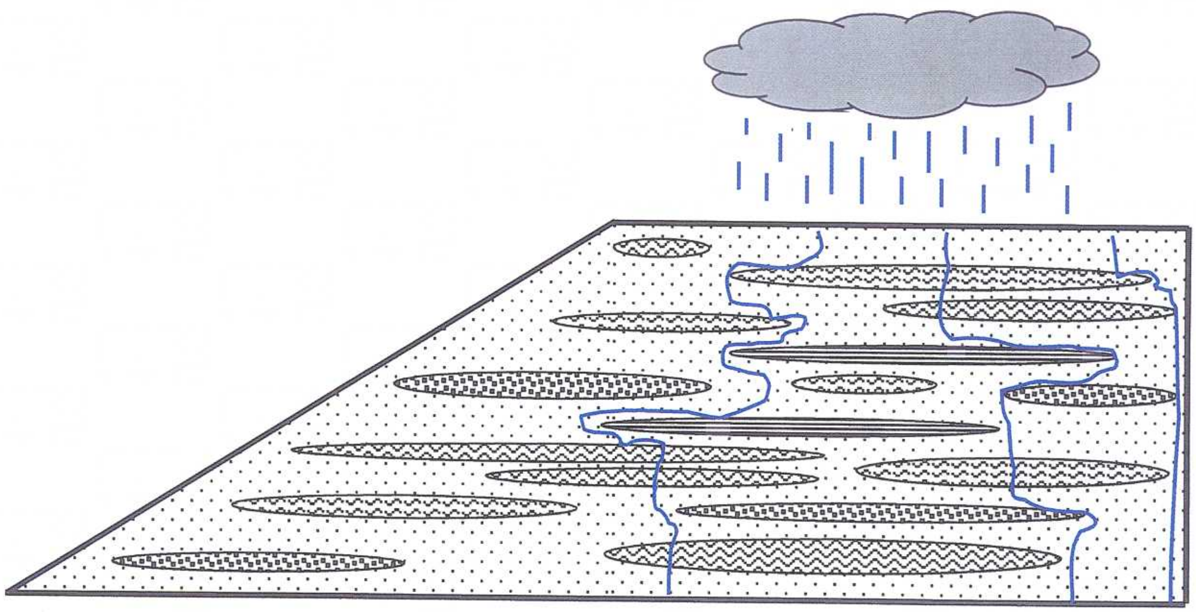

Figure 4b: More realistic scenario, flow paths change continuously throughout profile

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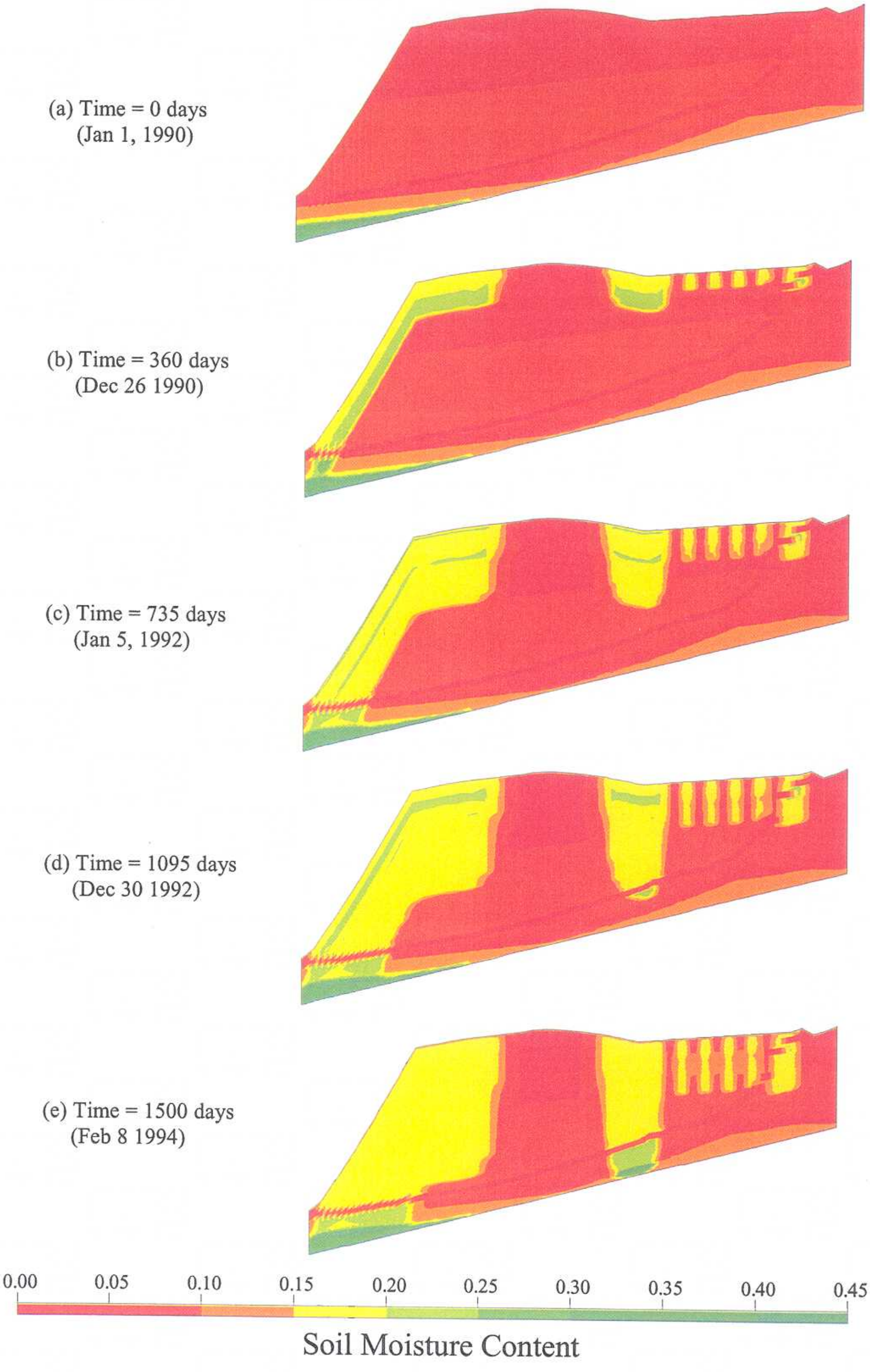

Figure 5: Moisture Content Variation Over Time for Cross Section 2
Using Hart Crowser Group 3 Embankment Fill Properties

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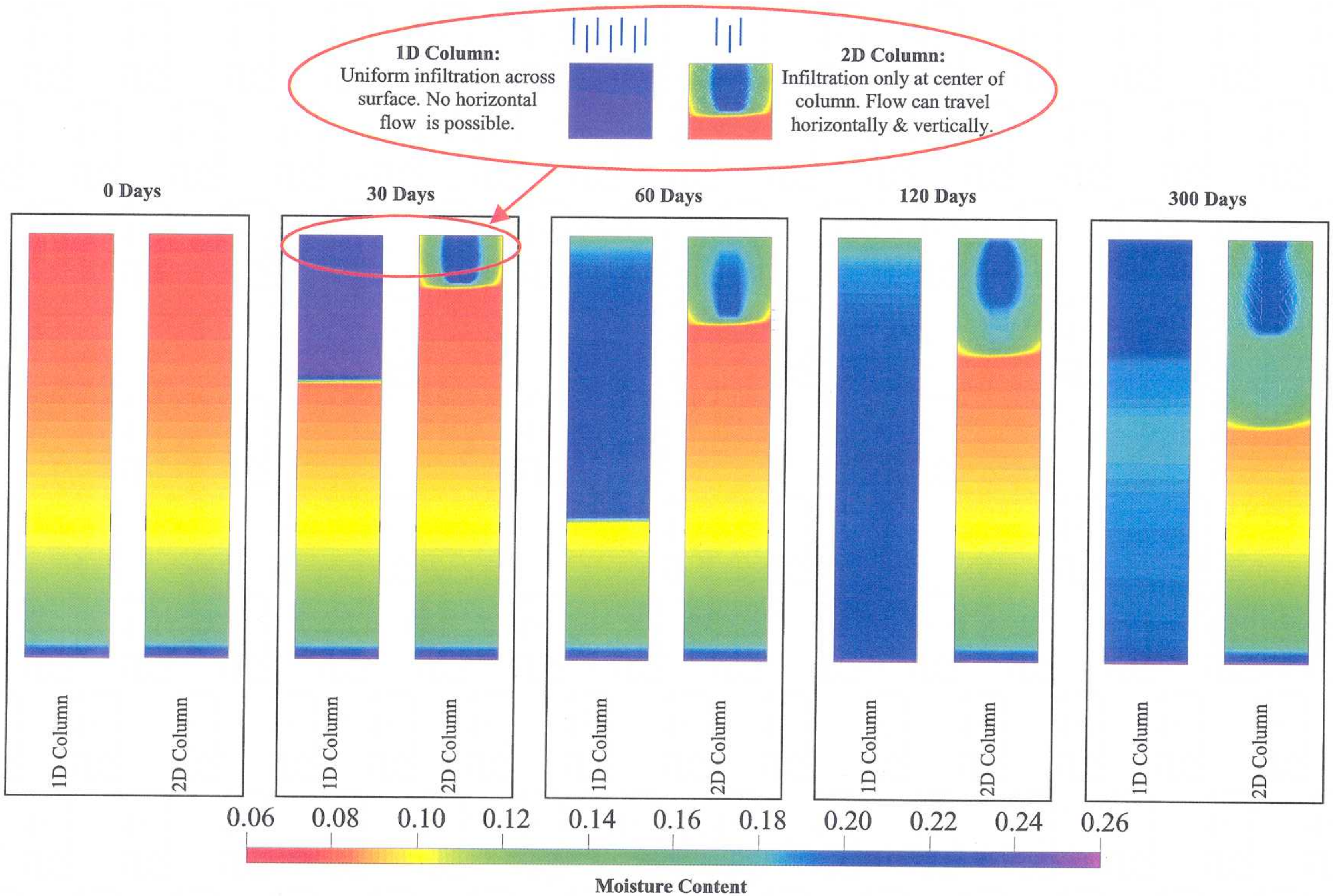

Figure 6: Comparison of 1-Dimensional versus 2-Dimensional Flow in Uniform Fill Columns (25 ft thick) with Port Properties