HARTCROWSER

MEMORANDUM

DRAFT

DATE: October 13, 2000

TO: Jim Thomson P.E., HNTB

FROM: Michael Bailey, P.E., and Michael Kenrick, P.E., Hart Crowser

RE: **Effects on Infiltration and Base Flow**
Proposed Third Runway Embankment
J-4978-06

CC: Paul Fendt and Jim Kelley, Parametrix

In response to your request, this memo presents Hart Crowser's most recent analysis of infiltration into the proposed Third Runway embankment and related effect on the shallow water-bearing zone in native soils that provide base flow to Miller Creek and adjacent wetlands. The analysis presented in the attachment to this memo is Appendix C from Hart Crowser's pending geotechnical report on the proposed embankment (Hart Crowser, 2000).

The analysis presented in the attachment is the third and most sophisticated analysis we have accomplished on potential impacts of embankment construction to base flow (see Hart Crowser, 1999 and 1998). The three Hart Crowser analyses are consistent and confirm the independent analysis accomplished by Ecology's consultant Pacific Groundwater Group (PGG, 2000). These analyses indicate that construction of the embankment is expected to reduce overall annual base flow only slightly, and the net effect is a benefit to the environment since percolation through the embankment will experience a hydraulic lag, resulting in increased base flow in the summer months when it is most needed.

The analysis described in the enclosed attachment used a sequence of three models to represent the process of unsaturated flow through the embankment.

- The first part of this approach is a model called Rosetta that uses moisture-conductivity-suction relationships based on gradation of the actual fill materials, to develop parameter sets that control infiltration and unsaturated percolation in the embankment.

- The second part is the EPA developed HELP model that models infiltration and allows the direct simulation of the lateral drainage layer at the base of the embankment.
- The third component is SoilCover, a model that uses real precipitation records and links the subsurface saturated/unsaturated groundwater system and the atmosphere above the soil in a rigorous mathematical algorithm.

These analyses were accomplished with parameters for the type of embankment soils actually being used (Groups 1A through Group 4, using the gradations in the construction specifications). The analyses were also run for the existing native soil conditions to represent the pre-construction condition. The results indicate that groundwater flow rates beneath the proposed embankment will generally be similar to existing conditions but that slight differences are predicted depending on whether annual precipitation is more or less on average, as discussed below.

1. Groundwater flow rates beneath the proposed embankment will generally be similar to or slightly lower than for existing conditions during wet years.
2. Groundwater flow rates beneath the embankment would show a relative increase over existing conditions during dry years.
3. The overall long-term average flows are generally very similar in all years, except for the seasonal lag which produces a net increase in base flow to Miller Creek and adjacent wetlands in the summer and early fall.

The simple layman's explanation for these findings is that although the runway project will produce slightly more runoff (especially in wet years) compared to existing conditions, the longer seepage path through the embankment means more water as base flow in dry years and in the dry part of all years.

As mentioned, the results of the current modeling are consistent with results of PGG's recharge model and Hydrus-2D model results. PGG concluded: "Flows would be lower in the winter than under the current condition, and greater in summer compared to the current condition." PGG also noted that "dependent flows to local wetlands and the creeks will be reduced only in winter when abundant water is typically present anyway."

These results are also consistent with Hart Crowser's previous water balance model (Hart Crowser, 1999) and a previous analysis of potential aquifer compaction (Hart Crowser, 1998), both of which were made available to PGG and the agencies. What these results are not consistent with is the HSPF model that was used to size stormwater management ponds for the Third Runway project. We infer this difference is because 1) the HSPF model is intended to address conditions in the entire drainage basin and is not well-suited to the analysis of unsaturated flow through the embankment; and 2) the HSPF calibration data are from the 1998 fill after the top surface had been smooth rolled to resist erosion, and thus did not represent the condition of the final grassed surface of the permanent embankment adjacent to the airfield pavement.

Please call if you have any questions.

References:

Hart Crowser, 1998. Letter to Ms. Barbara Hinkle, Port of Seattle, re. Sea-Tac Third Runway - Aquifer Compaction, December 9, 1998.

Hart Crowser, 1999. Geotechnical Engineering Report, 404 Permit Support, Third Runway Embankment, Sea-Tac International Airport. July 9. 1999.

Hart Crowser, 2000. Embankment Slope Stability Analyses and Subgrade Improvement Recommendations, Third Runway Project. (DRAFT report in progress, October 2000).

Pacific Groundwater Group, 2000. SeaTac Runway Fill Hydrologic Studies Report, June 19, 2000.

F:\docs\jobs\497806\infiltrationmemo.doc

Attachment:

Appendix C
Embankment Infiltration and Seepage Studies
(From Hart Crowser, 2000)

APPENDIX C
EMBANKMENT INFILTRATION AND SEEPAGE STUDIES

CONTENTS

TABLES

FIGURES

CONTENTS (Continued) Page

FIGURES

APPENDIX C
EMBANKMENT INFILTRATION AND SEEPAGE STUDIES

Introduction

This appendix presents the results of seepage analyses designed to track changes in the infiltration and deep percolation of moisture occurring as a result of constructing the proposed Third Runway embankment. Understanding of these changes is important for a number of reasons:

- Different soil types proposed for the embankment fill will result in different amounts of infiltration and runoff. The surface soil type will also affect rates of evapotranspiration.

- The percolation of moisture through the embankment could potentially create zones of saturation were pore pressures could build up, with consequent risk to the stability of slope faces.

- The rate and timing of recharge to groundwater beneath the embankment could change, affecting the groundwater level beneath the fill. This could affect the extent of areas susceptible to liquefaction during earthquake events, and/or affect base flow to wetlands and Miller Creek.

The analyses presented in this appendix are designed to address:

- The relative quantities of moisture percolating downward through the embankment and into the underlying drainage layer;
- The proportion of moisture that flows along the drainage layer and discharges at the embankment toe;
- The proportion and timing of groundwater recharge occurring as downward seepage from the drainage layer into the native soils beneath the embankment; and
- The water table elevation maintained in the existing subgrade soils after embankment construction.

Approach

The movement of moisture into and through the Third Runway embankment represents a complex interplay of hydrologic processes occurring at and beneath the soil surface, which are listed and defined below. Figure C-1 shows a representative cross section through the embankment and illustrates the water balance components used in the model.

- **Precipitation (P).** The occurrence of rainfall is the main driver for the infiltration process.
- **Evaporation (E).** A portion of the precipitation evaporates without infiltrating or running off, this includes interception storage on leaves and in shallow surface ponds.
- **Runoff (R_o).** The occurrence of runoff from the surface of the embankment (excluding the effect of impervious surfaces) depends on a number of factors, including:
  - The intensity and duration of each precipitation event;
  - The prevailing moisture content of the surface soil, as influenced by antecedent conditions;
  - The type and density of vegetation;
  - Surface slope; and
  - The hydraulic conductivity of the surface soil, as influenced by grain size, soil fabric, macro-porosity, and degree of compaction.
- **Infiltration (I).** The amount of water infiltrating into the soil surface is complimentary to the runoff, and is largely dependent on the same factors.
- **Transpiration (T).** A portion of the moisture in the upper soil layer(s) is taken up by the vegetation and lost back into the atmosphere.
- **Percolation (P).** Excess moisture in the upper soil zone(s) is available to move downward under the influence of gravity and the pressure gradient created by soil moisture tension in the unsaturated vadose zone within the body of the embankment. The moisture content in the vadose zone continually adjusts to the rate of percolation to achieve a dynamic balance with the unsaturated hydraulic conductivity.
- **Seepage (S).** Locally saturated conditions can occur within or beneath the embankment where deep percolation encounters lower-permeability layers (e.g., silty or clayey soils or very dense soils such as glacial till), potentially creating zones of saturation in which water can perch and move laterally.
- **Drain Flow (DF).** Seepage within the underdrain is identified as drain flow. There is both a horizontal and vertical component of drain flow.
- **Groundwater Flow (GW).** Seepage into the native soils below the underdrain becomes groundwater flow (horizontal or base flow component).
- **Deep Percolation (DP).** Deep percolation is the vertical component of groundwater flow that goes down into the ground below the surficial water-bearing zone to recharge deeper regional aquifers.

The approach taken to analyzing embankment infiltration and seepage uses a sequence of three models to represent these processes, recognizing that unsaturated flow conditions likely predominate within the embankment.

Rosetta. The USDA has developed a "neural network" database model to generate soil moisture and hydraulic conductivity characteristic curves from grain size and soil density information (Schaap and Bouten, 1996). These curves define the fundamental moisture-conductivity-suction relationships that control infiltration and unsaturated percolation in the embankment, and are needed as input to simulation models, such as SoilCover and SEEP/W.

HELP. The EPA has developed a program for studying runoff, infiltration, and evapotranspiration as an aid to the design of landfill covers (Schroeder et al., 1994). The program, called HELP (Hydrologic Evaluation of Landfill Performance) has since been widely used to calculate groundwater recharge. It is applicable to the Third Runway embankment design in that it allows the direct simulation of lateral drainage layers within the embankment.

SoilCover. SoilCover is a soil-atmosphere flux model that links the subsurface saturated/unsaturated groundwater system and the atmosphere above the soil in a rigorous mathematical algorithm that represents the physical processes that occur between the soil and the atmosphere. These include: precipitation, infiltration, runoff, transpiration, and evaporation. The model calculates moisture fluxes within an unsaturated soil profile, as driven by day-to-day variations in atmospheric conditions, including precipitation, temperature, humidity, and solar radiation.

Soil Properties

Infiltration and seepage of moisture into the proposed embankment are controlled primarily by atmospheric conditions and soil properties. The soil properties of interest are those that govern the physical processes occurring at the soil surface, namely runoff, infiltration, and evapotranspiration. These processes are controlled primarily by the relative hydraulic conductivity of the soil layer, where the hydraulic conductivity of the unsaturated soil varies with the moisture content of the soil. The relative hydraulic conductivity is some fraction of the saturated hydraulic conductivity of the soil.

In recent years, numerous attempts have been made to define the unsaturated characteristics of soils using mathematical relationships among the three key parameters: moisture content, matric suction, and hydraulic conductivity. The computer program Rosetta was used to determine unsaturated hydraulic parameters from the grain-size distributions of the proposed fill materials (van Genuchten, 1980). Once the parameters were obtained, relationships (also known as soil characteristic curves) between matric potential (also known as soil suction or tension) and volumetric water content were constructed using the van Genuchten method, and between matric potential and unsaturated hydraulic conductivity using the Mualem (1976) method. Rosetta input requires percentages of sand, silt, and clay along with the bulk density for the soil(s) of interest. The program uses a limiting maximum bulk density value of 2.0 g/cm^3 (128 pcf).

Existing Soils

Hart Crowser reviewed the results of more than 50 test pits and borings in the proposed embankment foot print area, and identified two soil types that are representative of the overall embankment subgrade. The existing embankment subgrade soils of interest for the infiltration and seepage study are as follows:

- **Outwash Sand and Silty Sand.** Outwash sand and silty sand are the predominant surficial soil type within the embankment footprint. A representative sample of this soil type was chosen for use as input to the analyses based on a review of grain-size analyses. Sample S-2 from a depth of 8 feet in boring HC00-B115 was chosen. Gradation for this sample was comprised of 74 percent sand and 26 percent silt, with an estimated bulk density of 106 pcf (1.7 g/cm^3). These parameters were run through the Rosetta model to develop the characteristic unsaturated moisture content/matric potential/hydraulic conductivity curves shown on Figure C-2.

- **Dense Glacial Till.** Surficial soils at the embankment site are underlain at relatively shallow depth (5 to 20 feet) by glacially overridden advance outwash and glacial till soils, generally consisting of silty sand and sandy silt. For the HELP runs, the "glacial till" was represented using a default soil type available within the HELP program (Material 24 - a sand-silt-clay loam mixture with a saturated hydraulic conductivity of 2.7×10^{-6} cm/sec.). This material is considered representative of the conductivity expected for glacial tills and silty advance deposits of the type observed at the embankment site. The moisture/conductivity characteristic curves for this soil generated within SoilCover, using field capacity and wilting point data from HELP, are shown on Figure C-3.

Fill Materials

Four generalized soil groups are proposed for the Third Runway embankment construction, with Group 1 soils split into two subgroups (see Hart Crowser, 2000):

- **Group 1A.** This is a free-draining sand and gravel with less than 5 percent fines (i.e., passing the US No. 200 sieve) conforming to the grain size envelope presented on Figure C-4. Group 1A soils are required to be used for the embankment drainage layer.

- **Group 1B.** This is a sand and gravel with less than 8 percent fines conforming to the grain size envelope presented on Figure C-5.

  Soils from Groups 1A and 1B will be used as select fill in the reinforced zone for the West MSE wall, may be used in the reinforced zone for the South MSE and NSA walls, and as wet weather fill for the embankment.

- **Group 2.** This is a sand and gravel with up to 12 percent fines conforming to the grain size envelope presented on Figure C-6. Group 2 soils may be used in the reinforced zones for the NSA and South MSE walls, and will be used as common embankment fill except during wet weather.

- **Group 3.** This is a silt, sand, and gravel with up to 35 percent fines conforming to the grain size envelope presented on Figure C-7. Group 3 soils are intended for use as common embankment fill, except during wet weather.

- **Group 4.** This is a clay, silt, sand, and gravel with up to 50 percent fines conforming to the grain size envelope presented on Figure C-8. Group 4 soils may be used as common embankment fill, except during wet weather.

For each of these soil groups, a median grain size distribution was selected to be representative of the respective group (as shown on the figures listed above). This median grain size distribution was extrapolated into the fines region and used to define the proportions of gravel, sand, silt, and clay for each soil group. These proportions are listed in Table C-1. The Rosetta model was then used to generate the unsaturated moisture content/matric potential/hydraulic conductivity characteristic curves for each representative median soil type. Curves for soil Groups 1B, 3, and 4 are shown on Figures C-9 through C-11.

The soils proposed as fill material for the Third Runway embankment have significant percentages of gravel (up to 80 percent in Group 1A), which is ignored in the inputs to the Rosetta program. Rosetta deals only with the sand-silt-clay fractions, so the percentages listed in Table 1 were normalized to discount the presence of gravel before being input to Rosetta. As a result, the Rosetta model tends to slightly underpredict the unsaturated hydraulic parameters to a degree that is proportional to the gravel content.

A method was devised to account for the effect of gravel content on the hydraulic properties calculated by the Rosetta model. The parameter that can be manipulated in Rosetta without affecting the grain size distribution of the soil is the bulk density. A correction factor for the percentage of gravel contained in the soil was therefore applied to the saturated hydraulic conductivity value calculated initially by Rosetta, after the method of Brakensiek et al. (1974). This correction factor was determined by:

Correction Factor = 1 + (% gravel) / 100

As needed, the bulk density value for each soil group was then reduced to below limiting value of 2.0 g/cm³ and Rosetta was rerun to produce a new parameter set with a saturated hydraulic conductivity equal to the corrected value. The reduction in bulk density represents in part the reduced degree of compaction achieved among the sand-silt-clay fraction in soils with increasing gravel content.

Note that hydraulic conductivity of the glacial till was not analyzed with the Rosetta model because we used a default conductivity value from the HELP model for the till. This is acceptable because the unsaturated hydraulic properties of the glacial till would not be affected by the presence of the embankment. The Rosetta model was used for the embankment fill materials and the native surficial soil (outwash) so that the HELP model output would accurately represent conditions following embankment construction.

Weather Data

Precipitation, temperature, humidity, and solar radiation are the main atmospheric drivers controlling the surficial soil moisture. Data collected at SeaTac for the most recent 11 years (1987 through 1997) and published by NCDC (1998 and 1999) were used to the extent possible. Data are incomplete for the years 1998 and 1999; however, the total precipitation in those years was similar to 1995 and 1991, respectively. We therefore reused data from 1995 and 1991 to extend the data record to the end of 1999.

Simulations

The HELP model was used to simulate infiltration and seepage under existing conditions at the site of the proposed embankment, and to study changes in infiltration and seepage that will occur following construction of the embankment. HELP works by routing the products of precipitation, apportioning them between runoff, evapotranspiration, and percolation. In the model, precipitation is applied as inches of rainfall and is thus independent of the surface area under consideration. To maintain consistency in the model, all other fluxes are measured in inches of water per unit time.

Existing Conditions (Baseline)

The infiltration and seepage analysis was applied to existing subgrade soils in the embankment area to establish a baseline for post-construction comparisons. Natural vegetation conditions at the embankment site were approximated in HELP with a leaf area index (of 4.5 for Western Washington forested lands) and an evaporative zone depth of 20 inches. Net infiltration from the surface water balance currently sustains the shallow groundwater table typically found in the outwash sands and silts, perched on the underlying till layer, as noted in observation wells.

Existing hydrogeologic conditions in the proposed embankment area are characterized as follows:

- Moderately sloping ground surface, dropping down from the airfield elevation (~400 feet) to the toe of the west slope of the proposed embankment (between 280 and 320 feet elevation).
- Vegetation cover is generally deciduous forest with a moderate understory
- Shallow soils are typically outwash sands and silts, 5 to 20 feet thick, overlying dense glacial till that is 5 to 15 feet thick

The following soil profile was simulated in HELP:

- **Layer 1.** 5 feet of outwash sand and silt - vertical percolation layer;
- **Layer 2.** 10 feet of outwash sand and silt - lateral drainage layer that transmits base flow in the existing condition; and
- **Layer 3.** 5 feet of glacial till - generally an aquitard or barrier soil layer with only limited ability to transmit deeper percolation vertically.

The model was configured to allow ponding and lateral flow of water in Layer 2, as representative of the perched groundwater conditions observed overlying the glacial till. In calibration runs, the hydraulic conductivity of the glacial till had to be reduced to 5×10^{-7} cm/sec to develop the typical range in saturated thickness (listed in Table C-2 as Head on top of Layer 3) that was comparable to field observations in monitoring wells (i.e., 1 to 10 feet).

Constructed Conditions

The infiltration and seepage analysis was also applied to anticipated soil conditions to assess changes that would occur as a result of embankment construction. The following generalized soil profile was simulated in HELP:

- **Layer 1.** 100 feet of embankment fill - vertical percolation layer;

- **Layer 2.** 3 feet of sand and gravel - lateral drainage layer;
- **Layer 3.** 5 feet of outwash sand and silt - native surficial soil layer that might act as a nominal barrier layer, depending on its conductivity relative to the overlying embankment soils;
- **Layer 4.** 10 feet of outwash sand and silt - existing soils that act as a lateral drainage layer (transmitting base flow to Miller Creek); and
- **Layer 5.** 5 feet of glacial till - existing barrier soil layer.

Three different types of embankment fill material were simulated, representing median conditions and probable extremes in terms of grain size distribution for the bulk of the fill material:

- Group 1B represents the coarsest material likely to be used within the main body of the embankment;
- Group 3 represents the median soil type that may be expected to predominate in embankment construction (based on 1998 (Phase I) and 1999 (Phase II) construction records); and
- Group 4 represents the finest gradation material likely to be used within the embankment.

A long-term vegetated surface condition was modeled for each soil group with a leaf area index of 2.0 (representing a fair stand of grass) with an evaporative zone depth of 20 inches.

Layer 2 immediately beneath the fill represents the drainage layer, comprised of Group 1A material.

The lower layers (3, 4, and 5) in the post-construction model represent the same soils as in the existing conditions (see previous section). A limitation of the HELP model requires that a barrier soil layer must underlie any lateral drainage layer. This does not affect the soil properties, except that HELP considers a barrier soil to be permanently at 100 percent saturation.

We elected not to model the Group 2 soil material because it is very similar in grain size distribution to the Group 1B material, and because quantities used in embankment construction to date have been relatively minor.

Model Results

The models were used to simulate hydrologic conditions as they affect the existing water table beneath the embankment. Predicted model flux rates calculated in HELP are markedly affected by the initially assumed moisture content distribution in the unsaturated soil profile at the start of the simulations;

this effect lasted for between 1 and 3 years into the simulation period, depending on soil type. Our comparison of results, therefore, focuses on the last 10 years of the simulation period (1990 through 1999).

Existing Conditions

The lateral drainage rate from Layer 2 of the HELP model for the existing conditions is equated to groundwater base flow or discharge in the shallow water table aquifer. The predicted rate ranges between 3.8 and 20.0 inches per year as shown highlighted in Table C-2. This forms the baseline we used for comparison with possible changes that are predicted due to the placement of various embankment fill configurations in the constructed condition.

Embankment Conditions

The lateral drainage rate from Layer 4 of the HELP model for the constructed conditions is equated to groundwater base flow or discharge in the shallow water table aquifer beneath the embankment. The abbreviated annual output from HELP for each year of the simulation period is listed in Tables C-3, C-4, and C-5 for the respective embankment soil groups. The predicted discharge rates are highlighted in each table, ranging between 5.1 to 21.3 inches per year, and groundwater of 5.4 to 18.3 inches per year, for the different fill soils modeled.

Group 1B

The embankment profile composed of Group 1B material exhibits minimal runoff and slightly lower evapotranspiration than the other fill materials. The lower evapotranspiration is attributed to higher porosity and steeper soil moisture characteristic curves (see Figure C-9), which limit soil moisture utilization in the active near-surface soil zone. As a result, the amount of deep percolation remaining that can move downward through the embankment is higher than for the finer-grained Group 3 material.

Group 3

The embankment profile composed of Group 3 material exhibits a minor amount of runoff and slightly more evapotranspiration than for the Group 1B soil. As a result, the amount of deep percolation remaining that can move downward through the embankment is lower than for the coarser-grained Group 1B material.

Group 4

The embankment profile composed of Group 4 material exhibits substantial runoff and moderate to low evapotranspiration. Plant growth in Group 4 material is least able to extract moisture from the active surface layer because unit changes in matric suction yield the smallest volume of moisture, due to the relative flatness of the soil moisture characteristic curve (See Figure C-11). Taking into account the water lost as runoff, the amount of deep percolation remaining that can then move downward into the passive mass of the embankment is less than for the Group 3 material. but more than the Group 1B material.

For all fill soils, the seasonality of the groundwater recharge/flow component from the embankment (also called the hydroperiod) is strongly impacted, with reduced peaks and troughs that are shifted by 3 to 6 months relative to the existing conditions (see Figures C-12, C-13, and C-14). These changes reflect the delay and buffering effect created by time for percolation through and storage within the full thickness of the embankment.

Conclusions

The results of the model show groundwater base flow rates for existing and post-construction conditions, indicating substantial differences on a month-by-month basis, but the overall long-term average amounts are generally very similar. The differences are the seasonal lag which produces a net benefit of more base flow to Miller Creek in the summer and early fall. The overall long-term similarity is best illustrated by cumulative plots of groundwater discharge for each fill type for a 10-year simulation period, as plotted on Figure C-15.

Implications for Underlying Water Table Conditions

Close examination of the cumulative plots (Figure C-15) indicates the groundwater flowrates beneath the proposed embankment will generally be similar to existing conditions but that slight differences are predicted depending on whether annual precipitation is more or less on average, as discussed below.

Years with More than Average Precipitation (Wet Years)

Groundwater flowrates beneath the proposed embankment will generally be similar to or slightly lower than for existing conditions during wet years (1990; 1995-99). This implies that groundwater water levels beneath the toe of the embankment would be similar to or slightly lower than those observed in monitored wells over the past 12+ months (a relatively wet period in the precipitation record).

Years with Less than Average Precipitation (Dry Years)

The cumulative plots indicate that groundwater flowrates beneath the embankment would show a relative increase over existing conditions during dry years (1991-94). While this would result in higher water levels compared to existing conditions (i.e., a wet year), it should be noted that the absolute water levels during dry years would be lower than the levels recently observed in monitored wells over the past 12+ months.

It is, therefore, concluded that groundwater levels beneath the constructed embankment should become no higher than the peak levels observed over the last 12 moths or so, which means no increase in the area(s) susceptible to liquefaction is anticipated. Similarly, the effect of the embankment on hydraulic lag in precipitation becoming base flow will be most pronounced in dry years, when the increased water is most beneficial to the environment.

Effect of Different Fill Materials

Although the grain size and consequently the saturated hydraulic conductivity of the fill materials vary widely, there is a much narrower envelope of variation bounding their respective hydrologic behaviors under constructed conditions in the embankment.

Group 1B materials allow more recharge than would occur under existing conditions, but it is unlikely that a large portion of the embankment would be constructed of Group 1B materials.

Group 3 materials allow approximately the same recharge than would occur under existing conditions, and this is likely the most representative of the bulk materials that will be used in the embankment.

Group 4 materials result in less recharge than would occur under existing conditions, but use of Group 4 fill will not be allowed in wet weather conditions (i.e., when the less silty Group 1A or 1B materials must be used), which will limit the overall quantities of Group 4 soils that will be placed.

The reasons for the broad similarity in recharge response (compare Figures C-12 through C-14) relates to the mechanisms of unsaturated flow by which infiltrated water percolates through the embankment.

Deep percolation in the embankment is driven by the net flux leaving the surficial soil layer once the processes of runoff, evaporation, infiltration, and transpiration have been satisfied. This net flux is relatively insensitive to soil type, as long as the infiltration capacity is not too low. The net surface flux that moves downward into the body of the embankment causes the moisture content of the fill material to adjust under the physical constraints of unsaturated flow. This requires that the unsaturated hydraulic conductivity of the soil mass be approximately equal to the net surface flux. The moisture content and matric potential of the soil mass thus adjust in concert with the hydraulic conductivity, as governed by the soil characteristic functions (Figures C-9 through C-11). The result is differing soil moisture and matric suction distributions for the three soil types studied, but very similar unsaturated hydraulic conductivities, because the net flux rates are essentially similar.

This balance should not be significantly affected by layering of different fill materials as the embankment is constructed, as long as each layer is capable of passing the net flux entering from above. The limiting value for the saturated hydraulic conductivity of any discrete layer within the embankment should be no less than the net flux rate for deep percolation in the embankment. This rate is estimated using Soil Cover to be around 4.6 x 10^{-6} cm/sec, which is well below the value expected for any of the proposed embankment soils. In the event less permeable soils do become part of the fill (for instance, due to variability within an approved fill material source), the result would be creation of a local perched zone of limited extent within the embankment, with no loss in overall infiltration capacity. The frequent gradation checks accomplished as part of the embankment construction process prevent such an effect from extending over any significant area.

Effect of Different Fill Thicknesses

The simulation results presented above were for a nominal 100-foot-thick embankment fill. In reality, the embankment thickness will vary from zero to 160 feet. We made some additional runs of the HELP model using rainfall records for the year 1997, with Group 3 material in fill thickness of 150, 100, 60, 30, and 15 feet to see if there was a trend in seepage behavior, or a point at which the seepage behavior changed significantly.

Flux rates in the simulations of different fill thickness showed little variation (on the order of 2 to 5 percent) from the nominal 100-foot base case (see Table C-6). The results show a trend of increasing groundwater recharge rates with decreasing fill thickness, down to thicknesses of about 30 feet. Reduced thicknesses of fill in general, have less moisture storage capacity and so yield less water during a period of declining precipitation.

References for Appendix C

Brakensiek, D.L., W.J. Rawls, and G.R. Stephenson, 1974. A Note on Determining Soil Properties for Soils Containing Rock Fragments. J. Range Manage., Vol. 39, No. 5, pp. 408 - 409.

Hart Crowser, 2000. Geotechnical Input to MSE Wall and Reinforced Slope Design, Third Runway Embankment. Memorandum from J. Beaver, M Bailey, and B. Chen to J. Thompson of HNTB, May 12, 2000.

Mualem, Y., 1976. A new model predicting the hydraulic conductivity of unsaturated porous media. Water Resour. Res. 12:513-522.

NCDC, 1997. National Climatic Data Center, Weather Data Set 1987-1997 (CD ROM).

Schaap, M.G. and W. Bouten, 1996. Modeling water retention curves of sandy soils using neural networks. Water Resour. Res. 32:3033-3040.

Schroeder, P.R., C.M Lloyd, P.A. Zappi, and N.M. Aziz, 1994. Hydrologic Evaluation of Landfill Performance (HELP) Model. User's Guide for Version 3. Army Engineer Waterways Experiment Station, Vicksburg, MS. and Clemson Univ., SC. Dept. of Civil Engineering. 103p.

van Genuchten, M.Th., 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Am. J. 44:892-898.

F:\docs\jobs\497806\infiltrationappendix.doc

Table C-1 - Soil Properties Used for Developing Input to Rosetta Model

	Size Fractions in %					
Material	Gravel	Sand	Silt	Clay	Bulk Density in gm/cm^3	Gravel Correction Factor
Group 1A	74	22	3	1	1.77	1.74
Group 1B	69	26	4	1	1.81	1.69
Group 2	62	31	5	2	1.85	1.62
Group 3	35	57	6	2	1.9	1.35
Group 4	37	38	20	5	1.91	1.37
Outwash	8	68	24	0	1.7	1.08

Notes: Bulk density value is based on the relative compaction of the sand - silt - clay fraction, adjusted by using the Gravel Correction Factor after Brakensiek et al. (1974), (see text).

497806/infiltrationtables - Table 1

Table C-2 - HELP Output Summary for Existing Conditions (Baseline)

	1987 INCHES	1988 INCHES	1989 INCHES	1990 INCHES	1991 INCHES	1992 INCHES	1993 INCHES	1994 INCHES	1995 INCHES	1996 INCHES	1997 INCHES	1998 INCHES	1999 INCHES
PRECIPITATION	29.9	33.0	34.7	44.8	35.4	32.8	28.8	34.8	42.6	50.3	43.3	44.8	42.6
RUNOFF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EVAPOTRANSPIRATION	14.3	18.4	16.5	17.8	16.2	17.1	19.5	15.8	18.1	16.8	21.1	17.9	17.8
DRAINAGE COLLECTED FROM LAYER 2	34.0	7.6	9.7	13.3	16.0	8.0	5.6	3.8	13.1	19.8	20.0	13.7	14.1
PERC./LEAKAGE THROUGH LAYER 3	13.6	7.9	8.3	9.1	9.7	8.0	6.8	6.6	9.1	10.5	10.5	9.2	9.3
AVG. HEAD ON TOP OF LAYER 3	71.6	16.0	20.4	28.0	33.5	16.9	11.8	8.0	27.6	41.5	42.0	28.9	29.6
CHANGE IN WATER STORAGE	-31.9	-1.0	0.2	4.6	-6.4	-0.3	-3.1	8.6	2.3	3.2	-8.4	4.0	1.4
SOIL WATER AT START OF YEAR	86.7	54.8	53.8	54.0	58.6	52.2	51.9	48.9	57.5	59.8	63.0	54.7	58.6
SOIL WATER AT END OF YEAR	54.8	53.8	54.0	58.6	52.2	51.9	48.9	57.5	59.8	63.0	54.7	58.6	60.0
SNOW WATER AT START OF YEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SNOW WATER AT END OF YEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL WATER BUDGET BALANCE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Highlight = Contribution of precipitation that becomes groundwater base flow. Note first 3 years of model results reflect "initial saturation" and are not representative of long-term conditions.

497806/infiltrationtables.xls - Table 2

Table C-3 - HELP Output Summary for Group 1B Embankment Fill

	1987 INCHES	1988 INCHES	1989 INCHES	1990 INCHES	1991 INCHES	1992 INCHES	1993 INCHES	1994 INCHES	1995 INCHES	1996 INCHES	1997 INCHES	1998 INCHES	1999 INCHES
PRECIPITATION	29.9	33.0	34.7	44.8	35.4	32.8	28.8	34.8	42.6	50.3	43.3	44.8	42.6
RUNOFF	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.0
EVAPOTRANSPIRATION	12.7	16.4	14.5	15.7	14.5	14.5	18.0	13.0	16.5	14.4	18.5	16.4	16.1
DRAINAGE COLLECTED FROM LAYER 2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERC./LEAKAGE THROUGH LAYER 3	124.3	16.6	18.3	23.7	28.2	18.3	16.7	11.6	22.1	32.3	32.2	25.4	24.6
AVG. HEAD ON TOP OF LAYER 3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DRAINAGE COLLECTED FROM LAYER 4	57.3	54.6	20.4	14.5	17.4	12.4	8.7	5.1	11.2	19.0	21.3	17.1	15.6
PERC./LEAKAGE THROUGH LAYER 5	18.6	18.0	10.6	9.4	10.0	8.9	8.1	7.3	8.6	10.3	10.8	9.9	9.6
AVG. HEAD ON TOP OF LAYER 5	119.9	114.0	42.9	30.4	36.4	25.9	18.3	10.7	23.4	39.6	44.5	35.8	32.7
CHANGE IN WATER STORAGE	-58.8	-56.1	-10.8	4.9	-6.7	-3.1	-6.0	9.4	6.3	6.4	-7.3	1.1	1.3
SOIL WATER AT START OF YEAR	416.7	357.9	301.8	290.9	295.9	289.2	286.1	280.1	289.5	295.8	302.2	294.9	296.0
SOIL WATER AT END OF YEAR	357.9	301.8	290.9	295.9	289.2	286.1	280.1	289.5	295.8	302.2	294.9	296.0	297.3
SNOW WATER AT START OF YEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SNOW WATER AT END OF YEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL WATER BUDGET BALANCE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes: Fill Height = 98 ft
Runoff Curve Number = 49

Highlight = Contribution of precipitation that becomes groundwater base flow. Note first 3 years of model results reflect "initial saturation" and are not representative of long-term conditions.

497806/infiltrationtables xls - Table 3

AR 046186

Table C-4 - HELP Output Summary for Group 3 Embankment Fill

	1987 INCHES	1988 INCHES	1989 INCHES	1990 INCHES	1991 INCHES	1992 INCHES	1993 INCHES	1994 INCHES	1995 INCHES	1996 INCHES	1997 INCHES	1998 INCHES	1999 INCHES
PRECIPITATION	29.9	33.0	34.7	44.8	35.4	32.8	28.8	34.8	42.6	50.3	43.3	44.8	42.6
RUNOFF	0.1	0.0	0.0	1.0	0.5	0.0	0.0	0.0	0.1	0.6	0.1	1.0	0.1
EVAPOTRANSPIRATION	13.3	17.2	15.8	16.8	15.5	16.1	18.8	14.8	17.4	15.5	20.0	17.1	17.2
DRAINAGE COLLECTED FROM LAYER 2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERC./LEAKAGE THROUGH LAYER 3	137.1	19.6	17.7	21.0	26.7	19.1	15.8	11.5	17.9	28.7	30.2	24.6	23.8
AVG. HEAD ON TOP OF LAYER 3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DRAINAGE COLLECTED FROM LAYER 4	57.3	57.5	29.2	14.2	15.0	12.7	8.4	5.4	8.5	15.7	19.4	16.6	14.8
PERC./LEAKAGE THROUGH LAYER 5	18.6	18.7	12.5	9.3	9.4	9.0	8.0	7.4	8.1	9.6	10.4	9.8	9.4
AVG. HEAD ON TOP OF LAYER 5	119.9	120.0	61.2	29.7	31.2	26.6	17.5	11.3	17.8	32.7	40.6	34.7	30.9
CHANGE IN WATER STORAGE	-59.4	-60.4	-22.9	3.5	-5.0	-5.1	-6.4	7.2	8.5	8.9	-6.7	0.3	1.1
SOIL WATER AT START OF YEAR	393.3	333.9	273.4	250.6	254.1	249.1	244.1	237.7	244.9	253.3	262.2	255.6	255.8
SOIL WATER AT END OF YEAR	333.9	273.4	250.6	254.1	249.1	244.1	237.7	244.9	253.3	262.2	255.6	255.8	257.0
SNOW WATER AT START OF YEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SNOW WATER AT END OF YEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL WATER BUDGET BALANCE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes: Fill Height = 98 ft
Runoff Curve Number = 69

Highlight = Contribution of precipitation that becomes groundwater base flow. Note first 3 years of model results reflect "initial saturation" and are not representative of long-term conditions.

497806/infiltrationtables xls - Table 4

AR 046187

Table C-5 - HELP Output Summary for Group 4 Embankment Fill

	1987 INCHES	1988 INCHES	1989 INCHES	1990 INCHES	1991 INCHES	1992 INCHES	1993 INCHES	1994 INCHES	1995 INCHES	1996 INCHES	1997 INCHES	1998 INCHES	1999 INCHES
PRECIPITATION	29.9	33.0	34.7	44.8	35.4	32.8	28.8	34.8	42.6	50.3	43.3	44.8	42.6
RUNOFF	0.6	0.2	0.3	2.6	1.2	0.2	0.1	0.5	1.0	2.2	0.8	2.6	1.0
EVAPOTRANSPIRATION	13.4	17.5	15.8	17.2	15.6	15.9	18.5	14.6	17.4	15.9	20.5	17.4	17.3
DRAINAGE COLLECTED FROM LAYER 2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERC./LEAKAGE THROUGH LAYER 3	87.4	18.2	17.3	20.7	24.6	18.2	15.9	11.5	17.5	27.9	28.9	23.5	21.9
AVG. HEAD ON TOP OF LAYER 3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DRAINAGE COLLECTED FROM LAYER 4	57.3	35.1	11.7	11.8	13.6	11.8	8.1	5.4	8.4	15.2	18.3	15.6	13.4
PERC./LEAKAGE THROUGH LAYER 5	18.6	13.8	8.8	8.8	9.2	8.8	8.0	7.4	8.0	9.5	10.2	9.6	9.1
AVG. HEAD ON TOP OF LAYER 5	119.9	73.4	24.6	24.7	28.4	24.7	17.0	11.3	17.5	31.6	38.3	32.6	28.1
CHANGE IN WATER STORAGE	-60.0	-33.6	-1.9	4.4	-4.1	-3.9	-5.9	7.0	7.8	7.6	-6.5	-0.4	1.7
SOIL WATER AT START OF YEAR	381.5	321.5	287.9	286.0	290.4	286.2	282.3	276.5	283.5	291.3	298.9	292.4	292.0
SOIL WATER AT END OF YEAR	321.5	287.9	286.0	290.4	286.2	282.3	276.5	283.5	291.3	298.9	292.4	292.0	293.8
SNOW WATER AT START OF YEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SNOW WATER AT END OF YEAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL WATER BUDGET BALANCE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes: Fill Height = 98 ft
Runoff Curve Number = 79

Highlight = Contribution of precipitation that becomes groundwater base flow. Note first 3 years of model results reflect "initial saturation" and are not representative of long-term conditions.

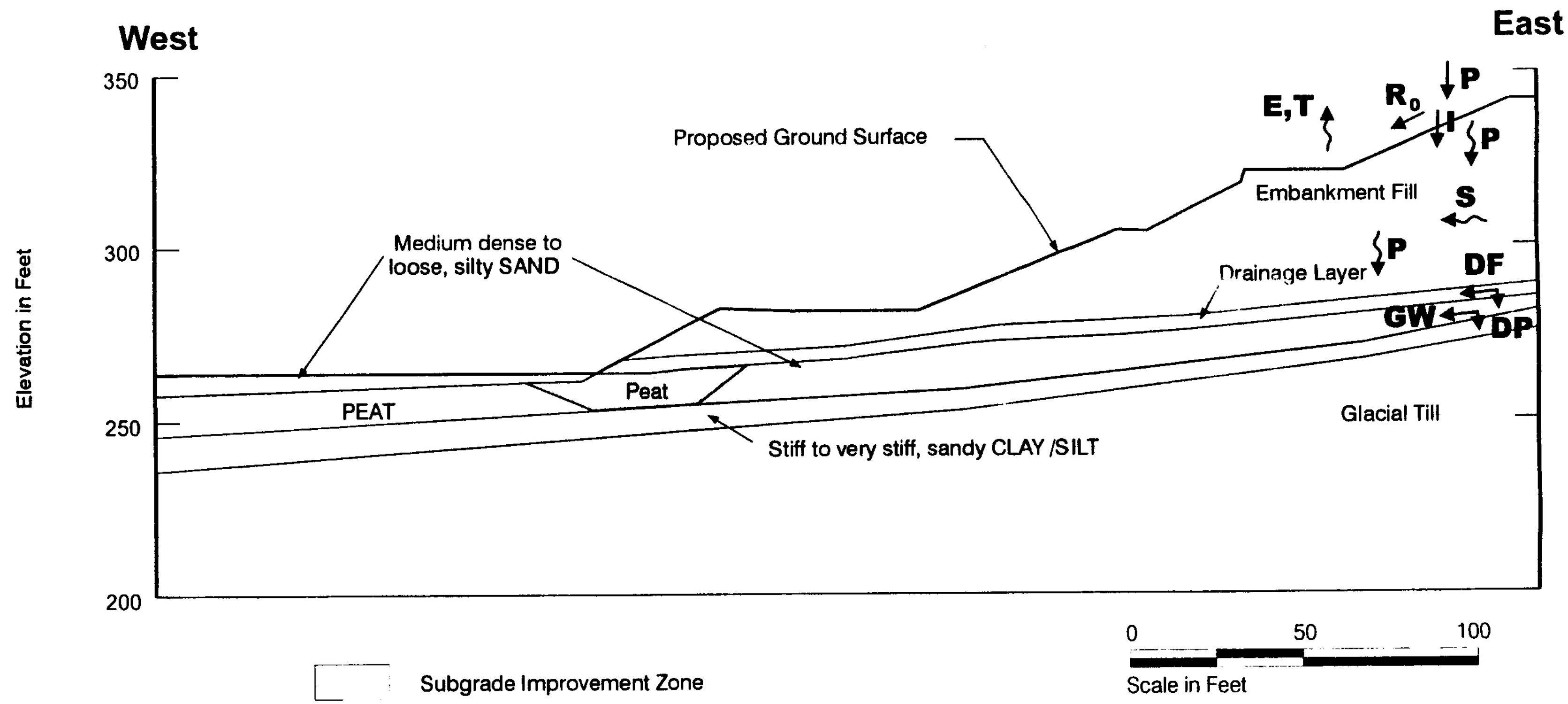
Table C-6 - HELP Output Summary for Various Embankment Heights

	Embankment Height in Feet				
	150	100	60	30	15
			Inches of H_2O		
PRECIPITATION	43.3	43.3	43.3	43.3	43.3
RUNOFF	0.0	0.0	0.0	0.0	0.0
EVAPOTRANSPIRATION	20.0	20.0	20.0	20.0	20.0
DRAINAGE COLLECTED FROM LAYER 2	0.0	0.0	0.0	0.0	0.0
PERC./LEAKAGE THROUGH LAYER 3	28.9	30.5	31.0	30.4	28.0
AVG. HEAD ON TOP OF LAYER 3	0.0	0.0	0.0	0.0	0.0
DRAINAGE COLLECTED FROM LAYER 4	17.9	19.6	20.6	21.0	20.9
PERC./LEAKAGE THROUGH LAYER 5	10.1	10.5	10.7	10.8	10.7
AVG. HEAD ON TOP OF LAYER 5	37.3	41.1	43.1	44.0	43.9
CHANGE IN WATER STORAGE	-4.7	-6.9	-8.1	-8.5	-8.4
SOIL WATER AT START OF YEAR	358.8	267.0	192.3	136.4	109.3
SOIL WATER AT END OF YEAR	354.1	260.1	184.2	127.9	100.9
SNOW WATER AT START OF YEAR	0.0	0.0	0.0	0.0	0.0
SNOW WATER AT END OF YEAR	0.0	0.0	0.0	0.0	0.0
ANNUAL WATER BUDGET BALANCE	0.0	0.0	0.0	0.0	0.0

Comparison is based on data for 1997.

497806/infiltrationtables.xls - Table 6

Embankment Slope Showing Water Balance Components
Shown for Section 101+20 (NSA Wall Stationing)



HARTCROWSER

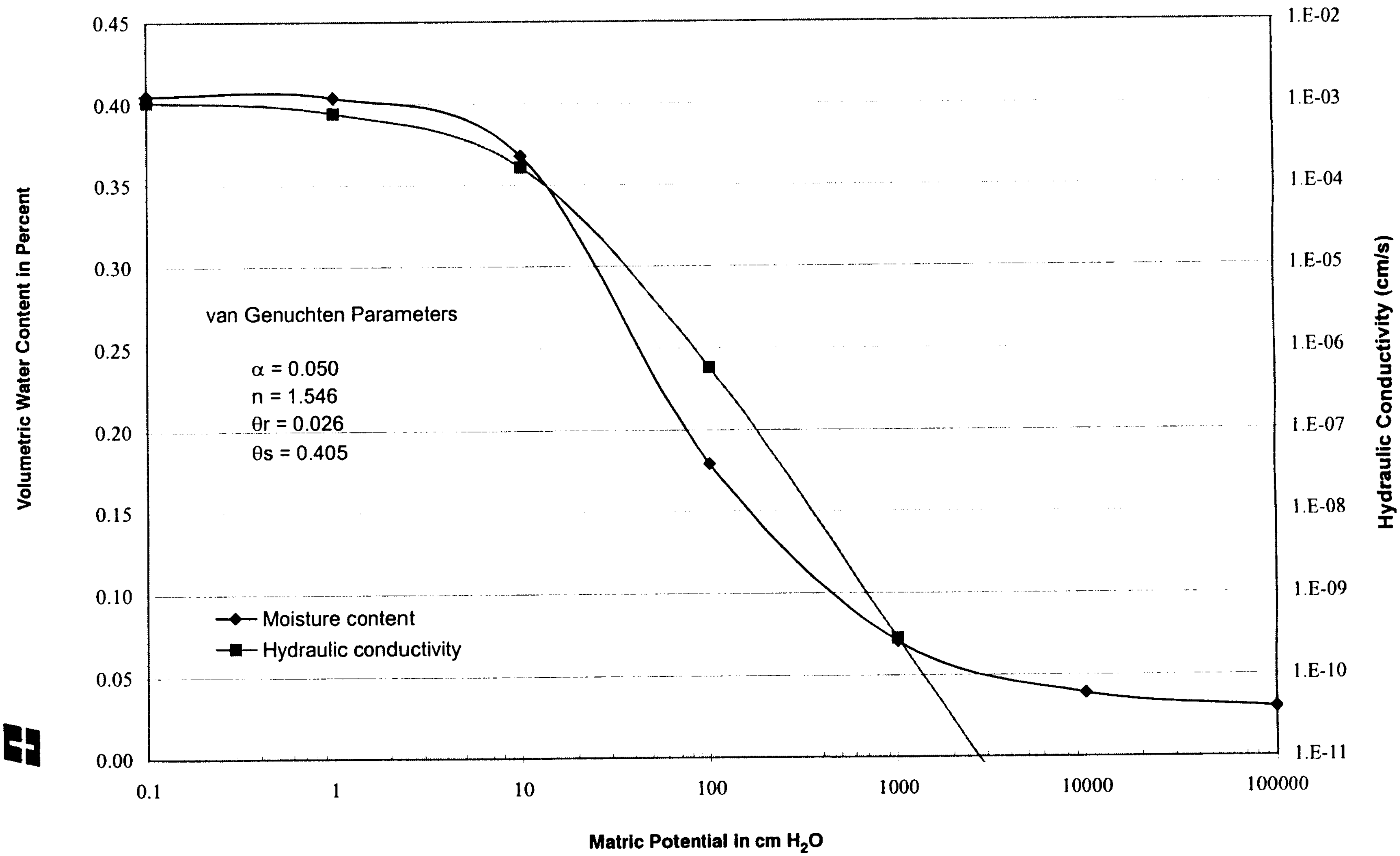
J-4978-28 10/00

Figure C-1

DJH 10/12/00 4978280.cdr

AR 046190

Soil Moisture/Conductivity Characteristic Curves of Outwash Silty Sand



DJH 10/12/00 497828R.cdr

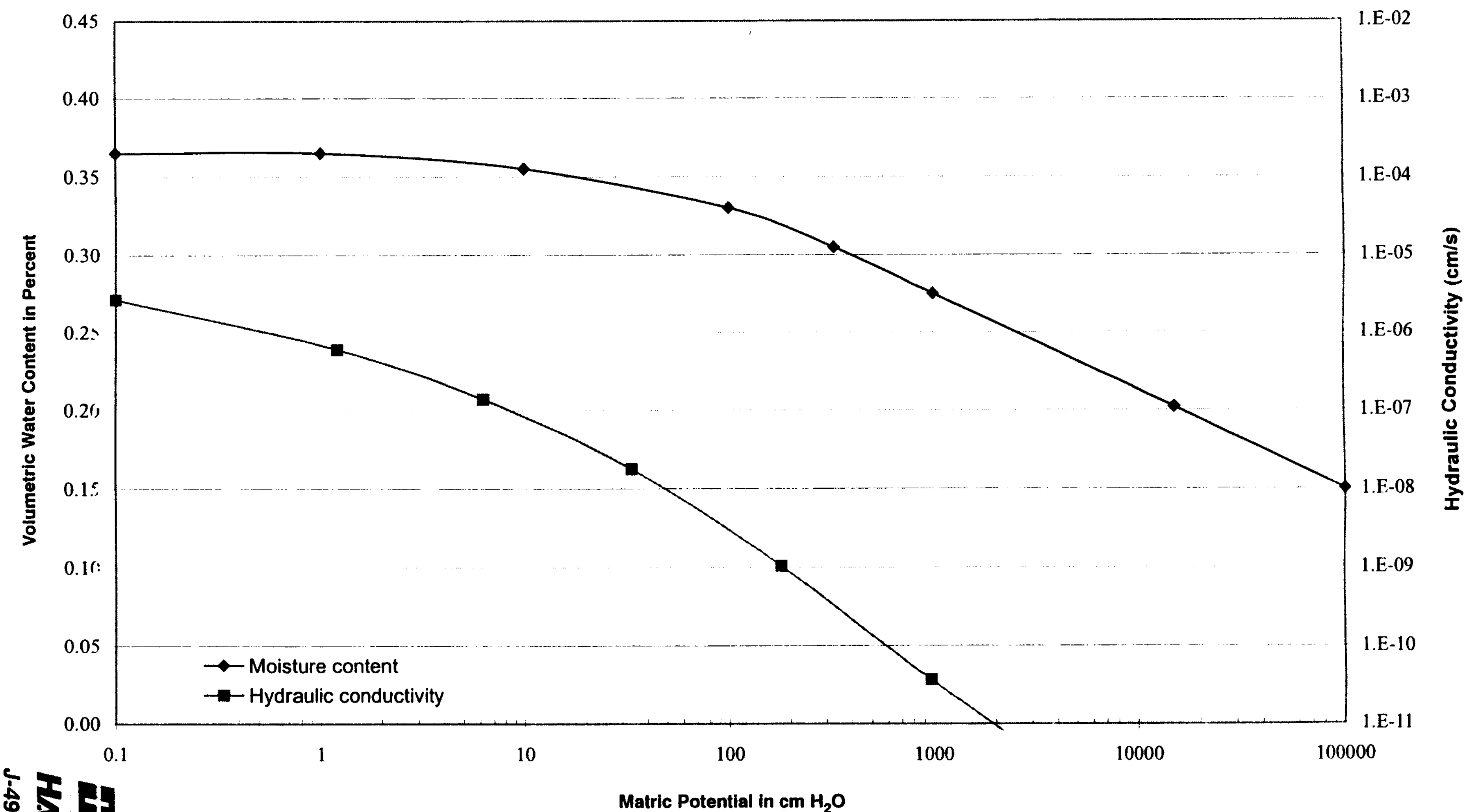
HARTCROWSER

J-4978-28 10/00

Figure C-2

AR 046191

Soil Moisture / Conductivity Characteristic Curves for Glacial Till



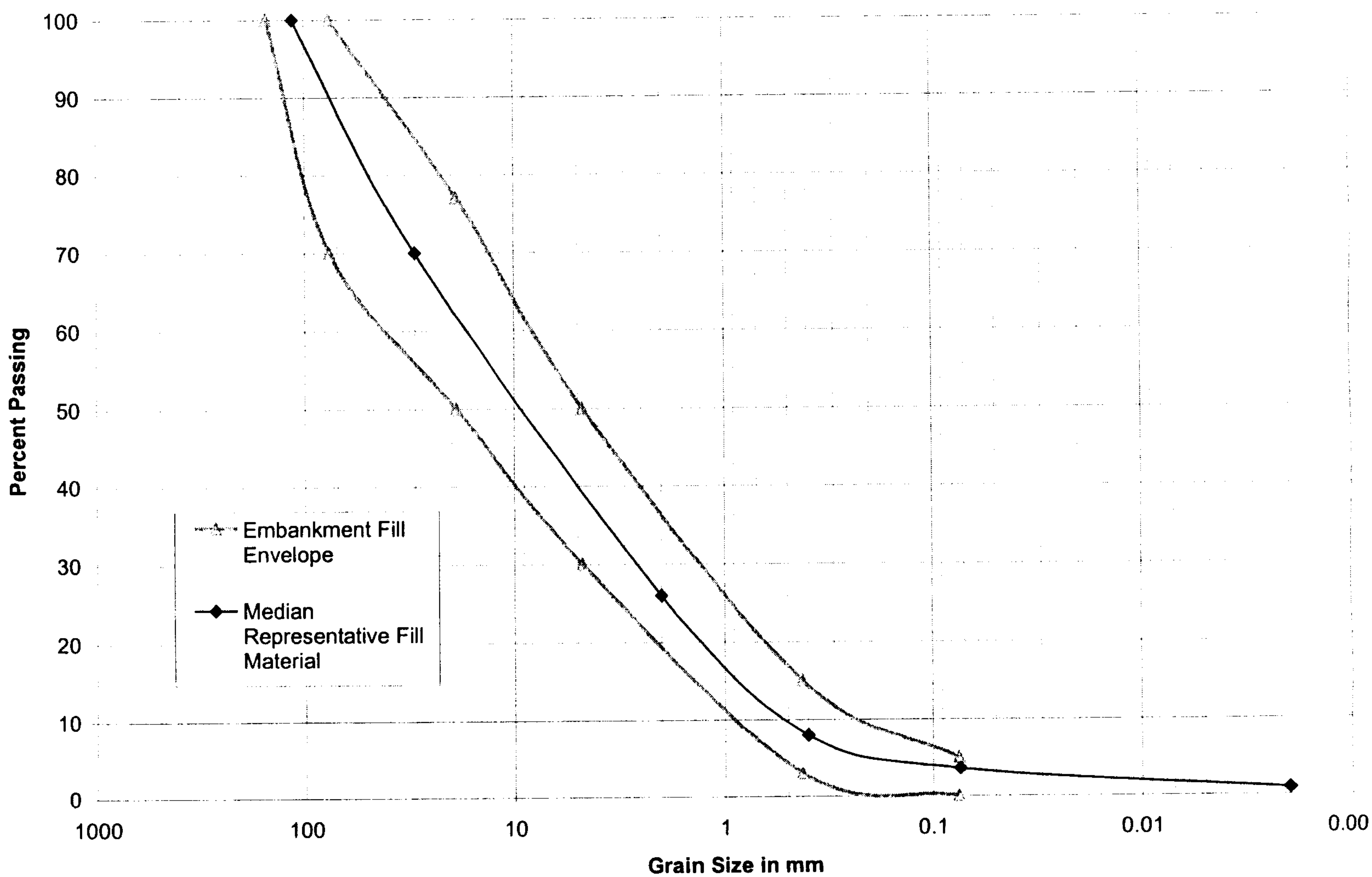
HARTCROWSER

J-4978-28 10/00

Figure C-3

DJH 10/12/00 497828S.cdr

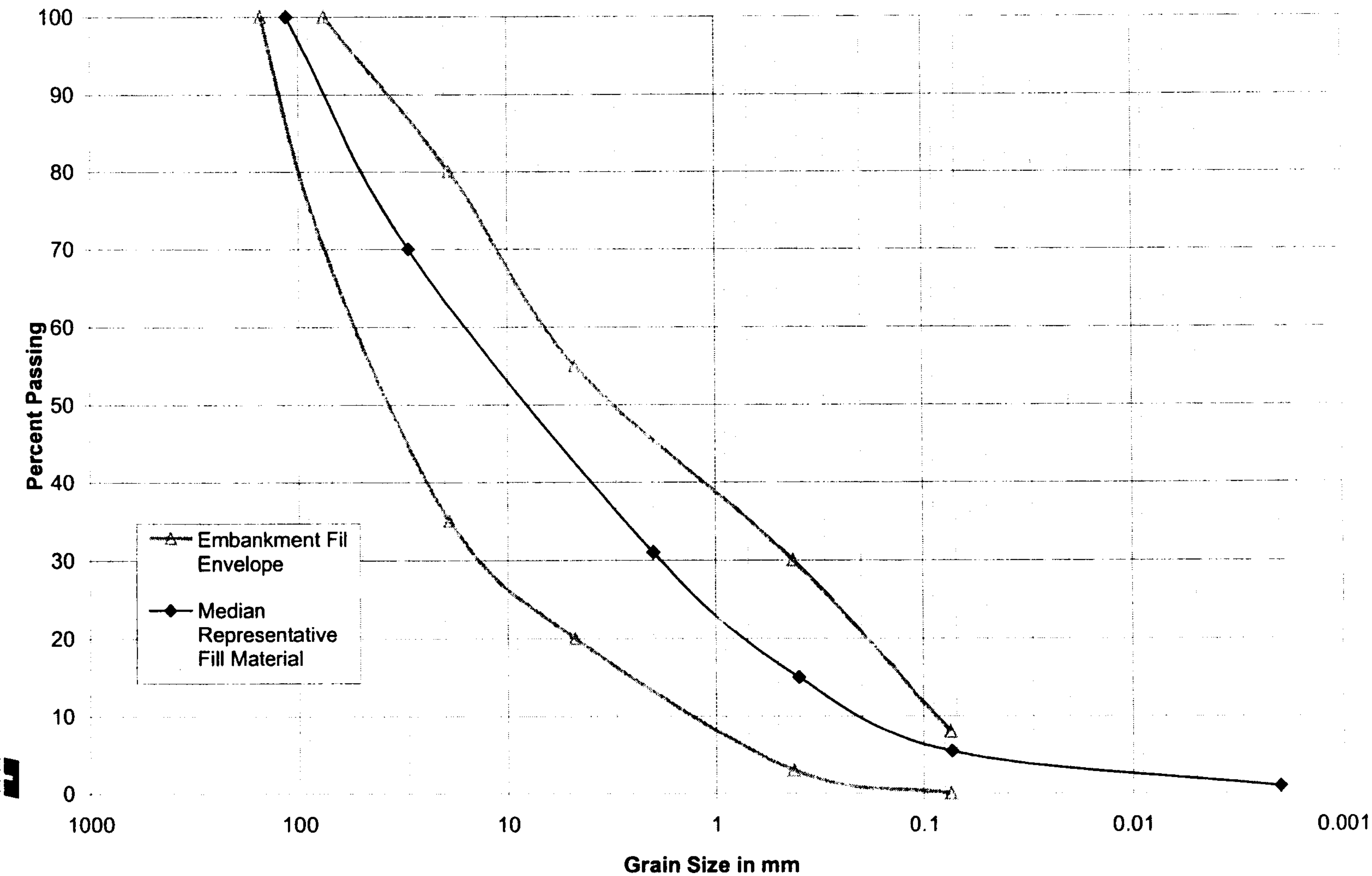
Grain Size Envelope for Group 1A Fill Material



DJH 10/12/00 497828T.cdr

HARTCROWSER
J-4978-28 10/00
Figure C-4

Grain Size Envelope for Group 1B Fill Material



DJH 10/12/00 497828U.cdr

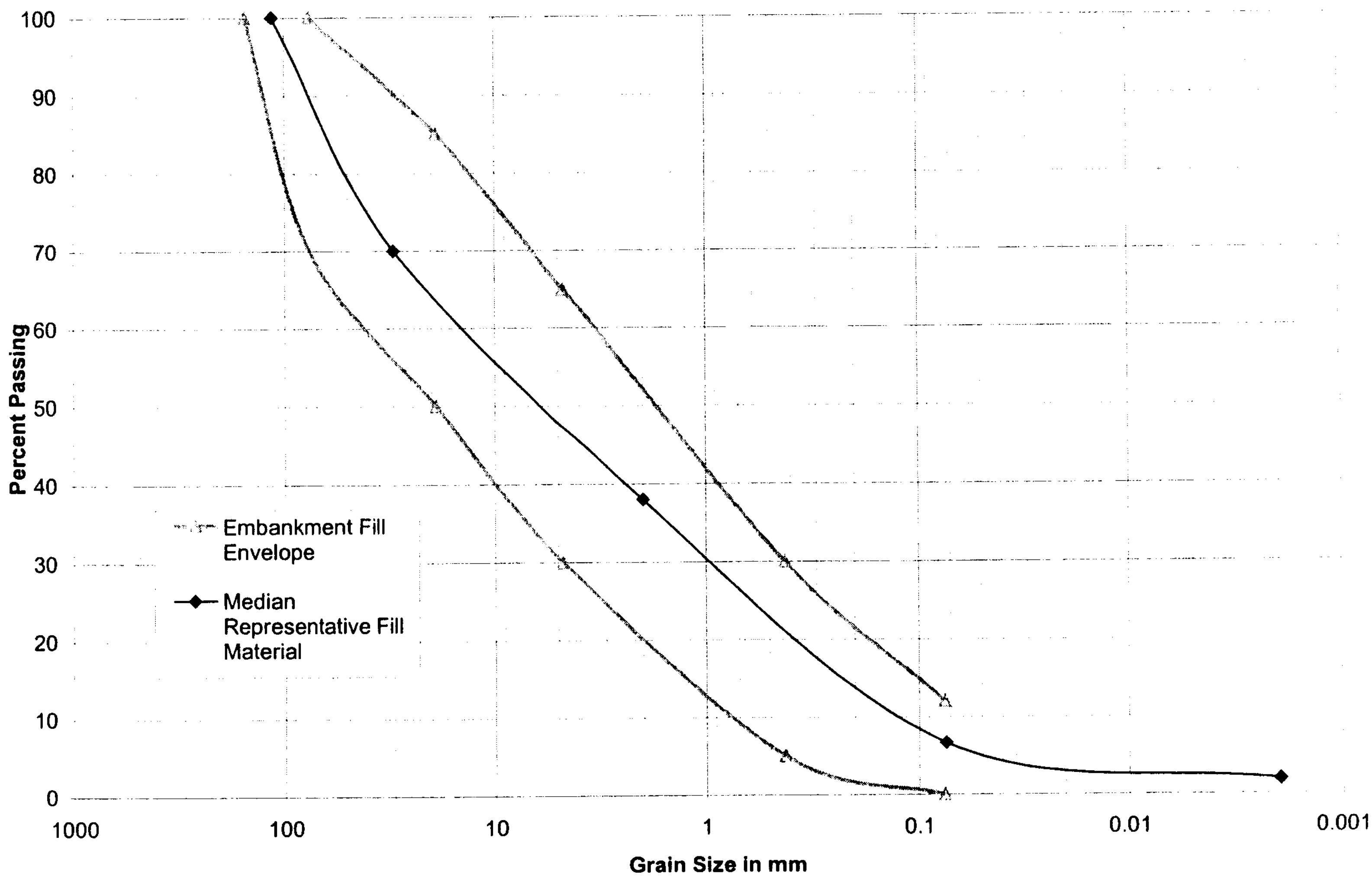
HARTCROWSER

J-4978-28 10/00

Figure C-5

AR 046194

Grain Size Envelope for Group 2 Fill Material



DJH 10/12/00 497828V.cdr

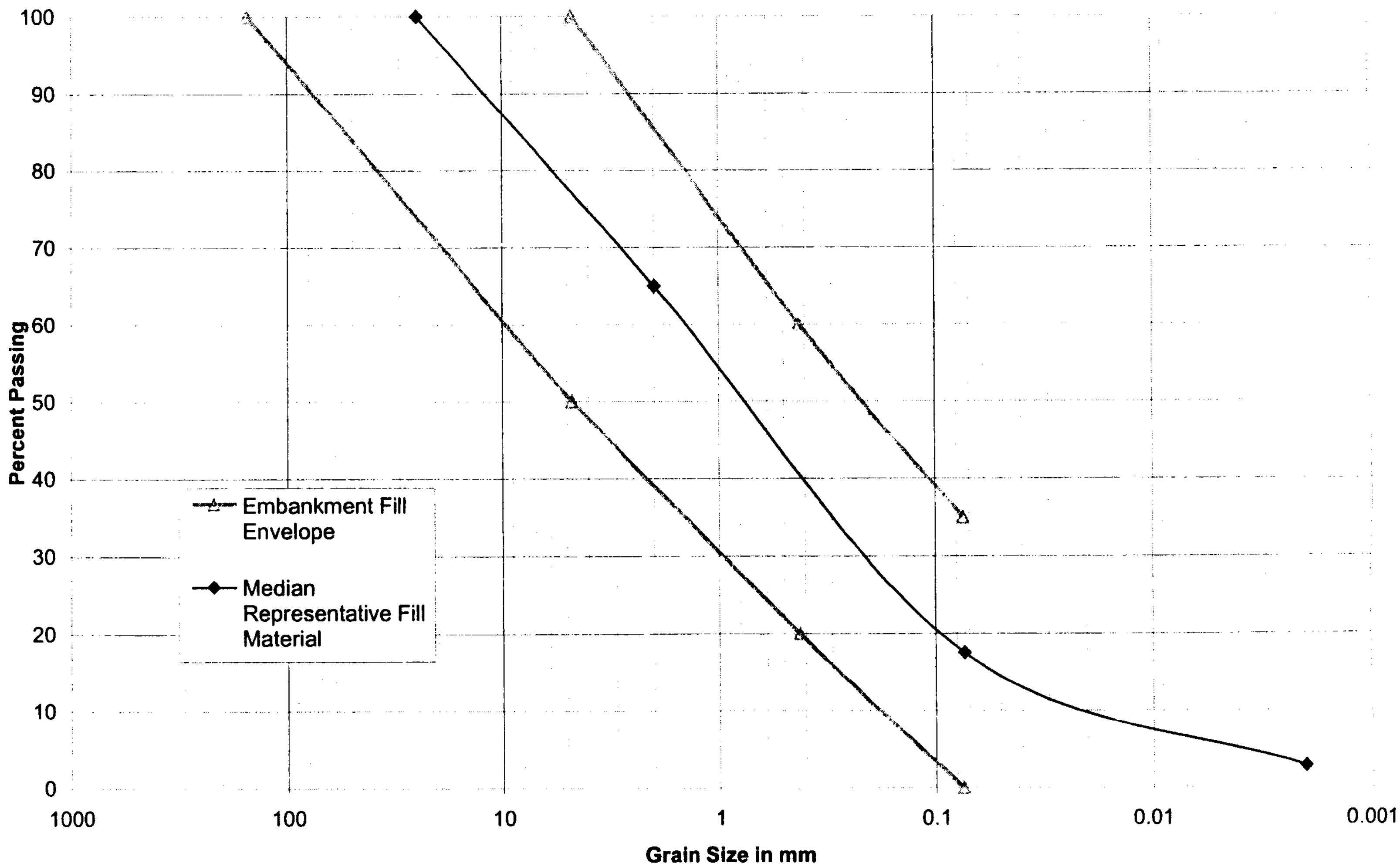
HARTCROWSER

J-4978-28 10/00

Figure C-6

AR 046195

Grain Size Envelope for Group 3 Fill Material

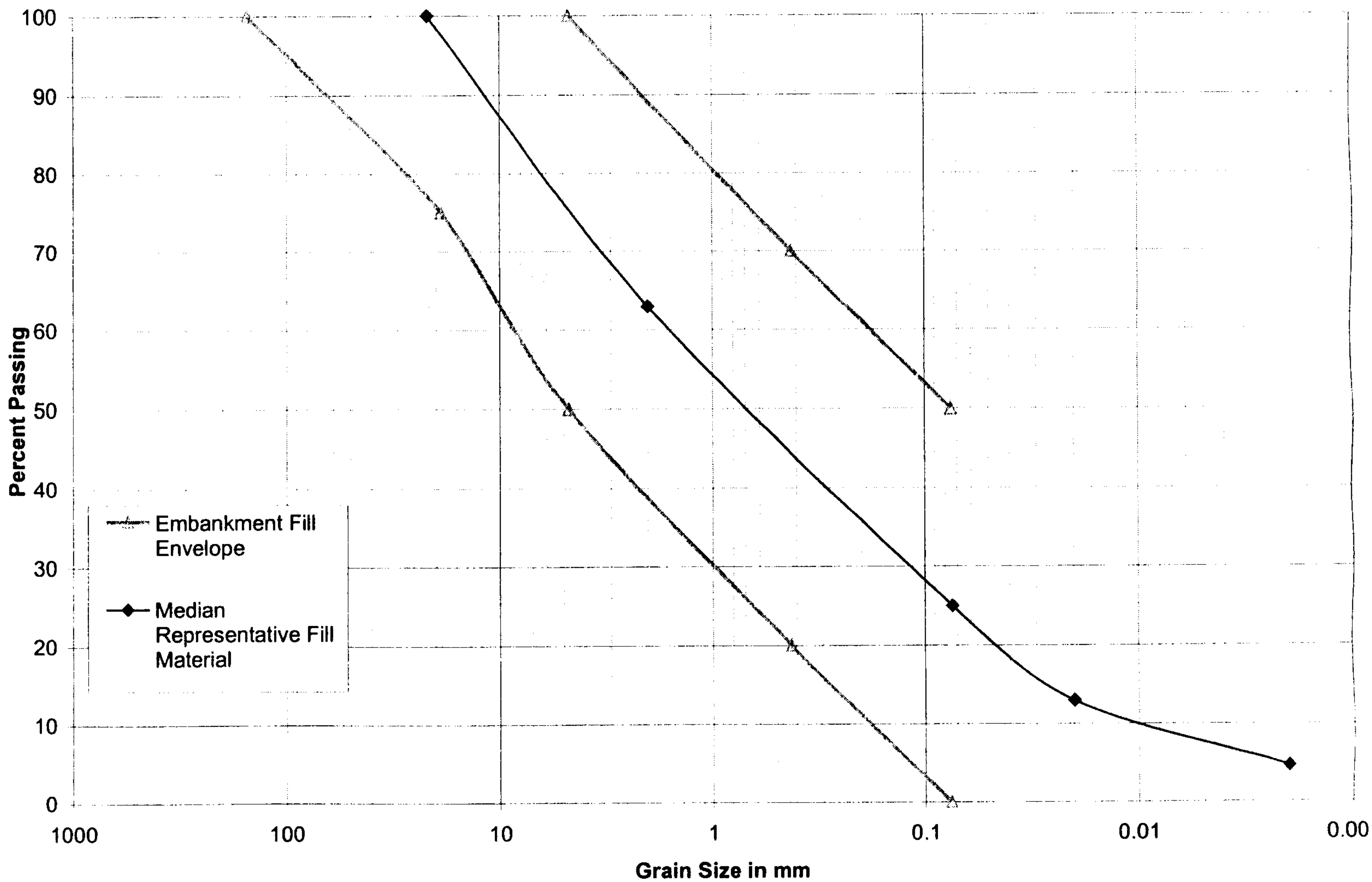


DJH 10/12/00 497828W.cdr

HARTCROWSER
J-4978-28 10/00
Figure C-7

AR 046196

Grain Size Envelope for Group 4 Fill Material

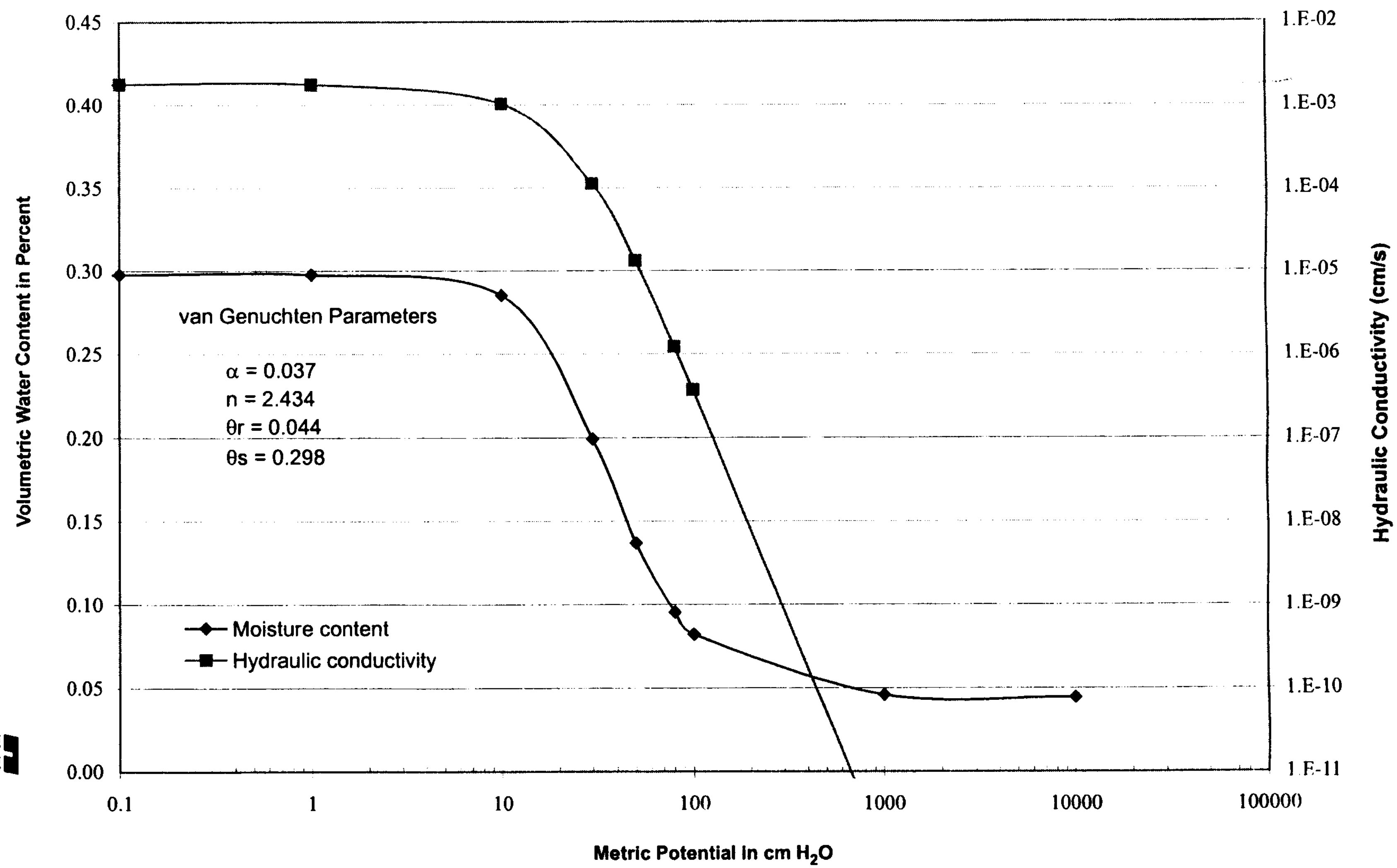


DTN 10/12/00 497828X.cdr

HARTCROWSER
J-4978-28 10/00
Figure C-8

AR 046197

Soil Moisture/Conductivity Characteristic Curves for Group 1B Fill Material



DJH 10/12/00 497828Y.cdr

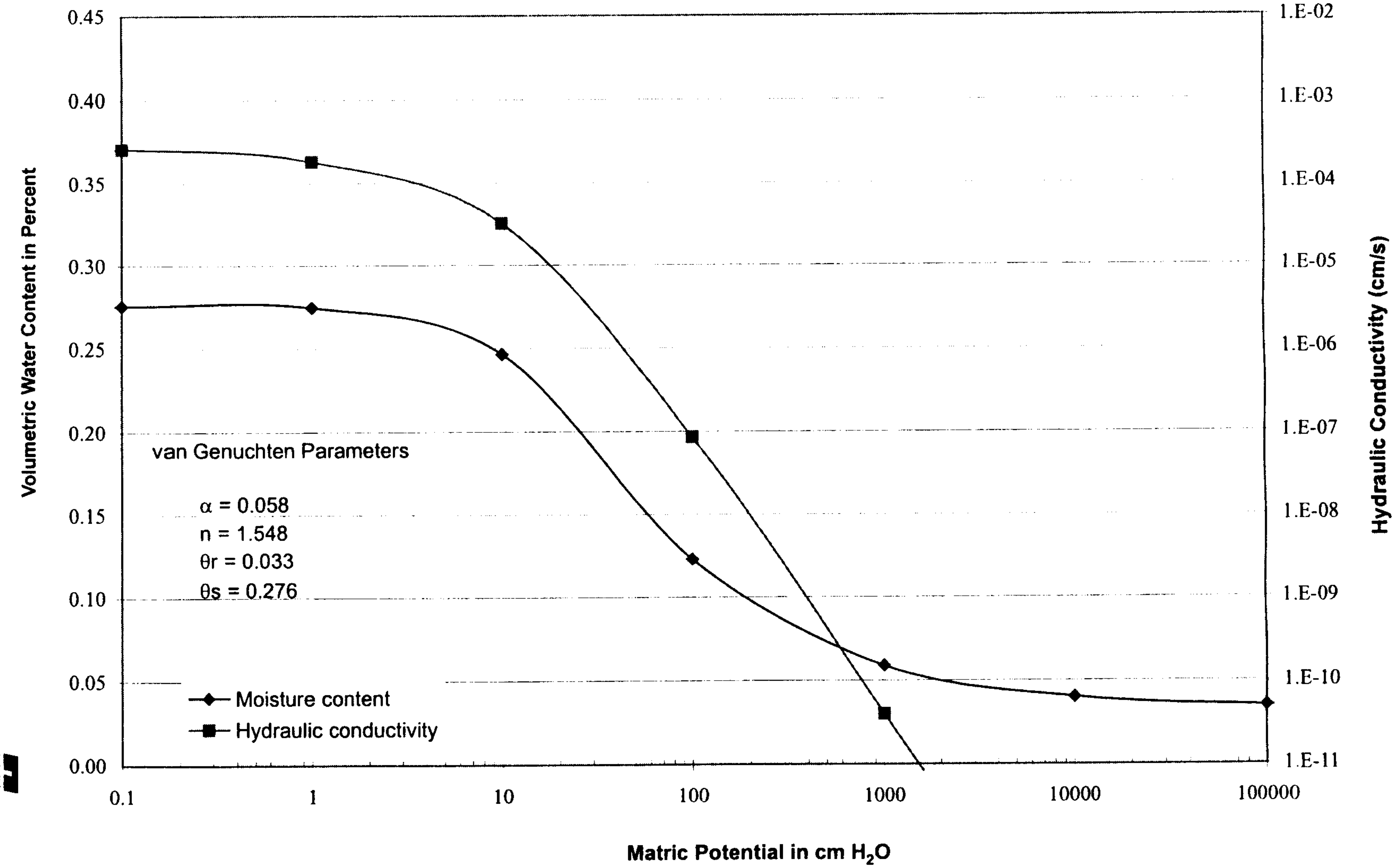
HARTCROWSER

J-4978-28 10/00

Figure C-9

AR 046198

Soil Moisture/Conductivity Characteristic Curves for Group 3 Fill Material



DJH 10/12/00 497828Z.cdr

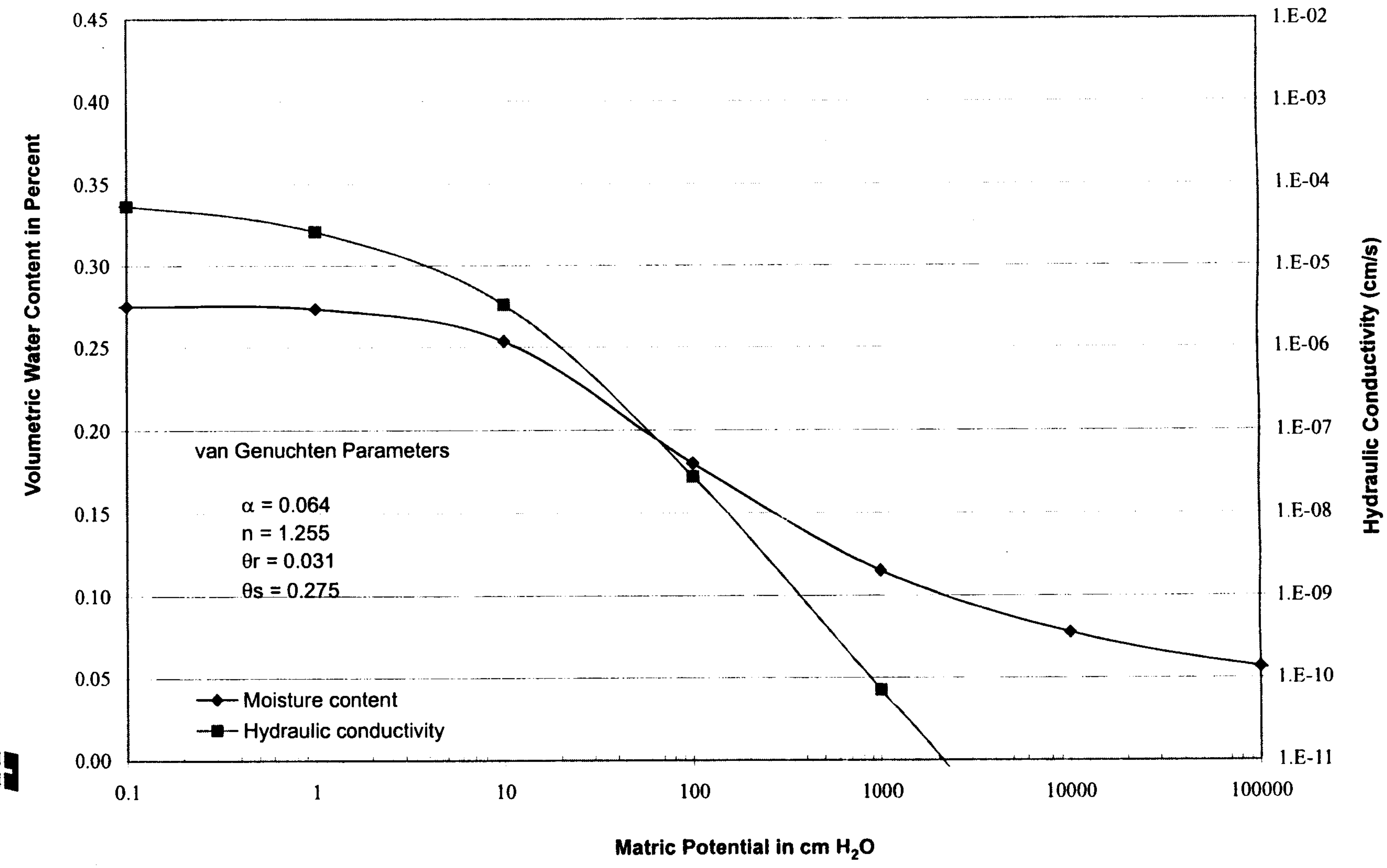
HARTCROWSER

J-4978-28 10/00

Figure C-10

AR 046199

Soil Moisture/Conductivity Characteristic Curves for Group 4 Fill Material



DJH 10/12/00 497828RR.cdr

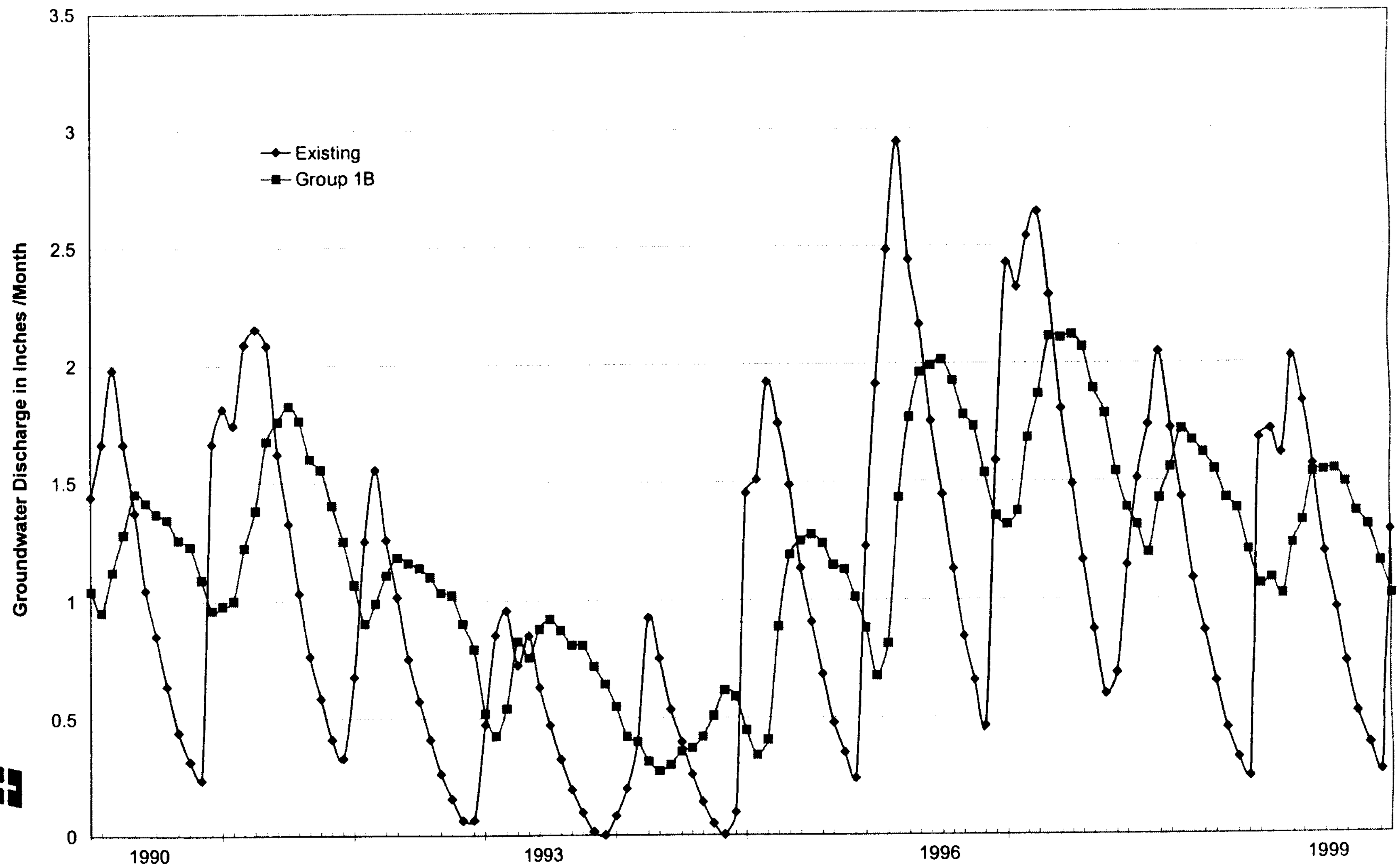
HARTCROWSER

J-4978-28 10/00

Figure C-11

AR 046200

Simulated Groundwater Discharge Rates for Existing Conditions and Group 1B Fill



DJH 10/12/00 497828AA.cdr Sheet 1 of 4

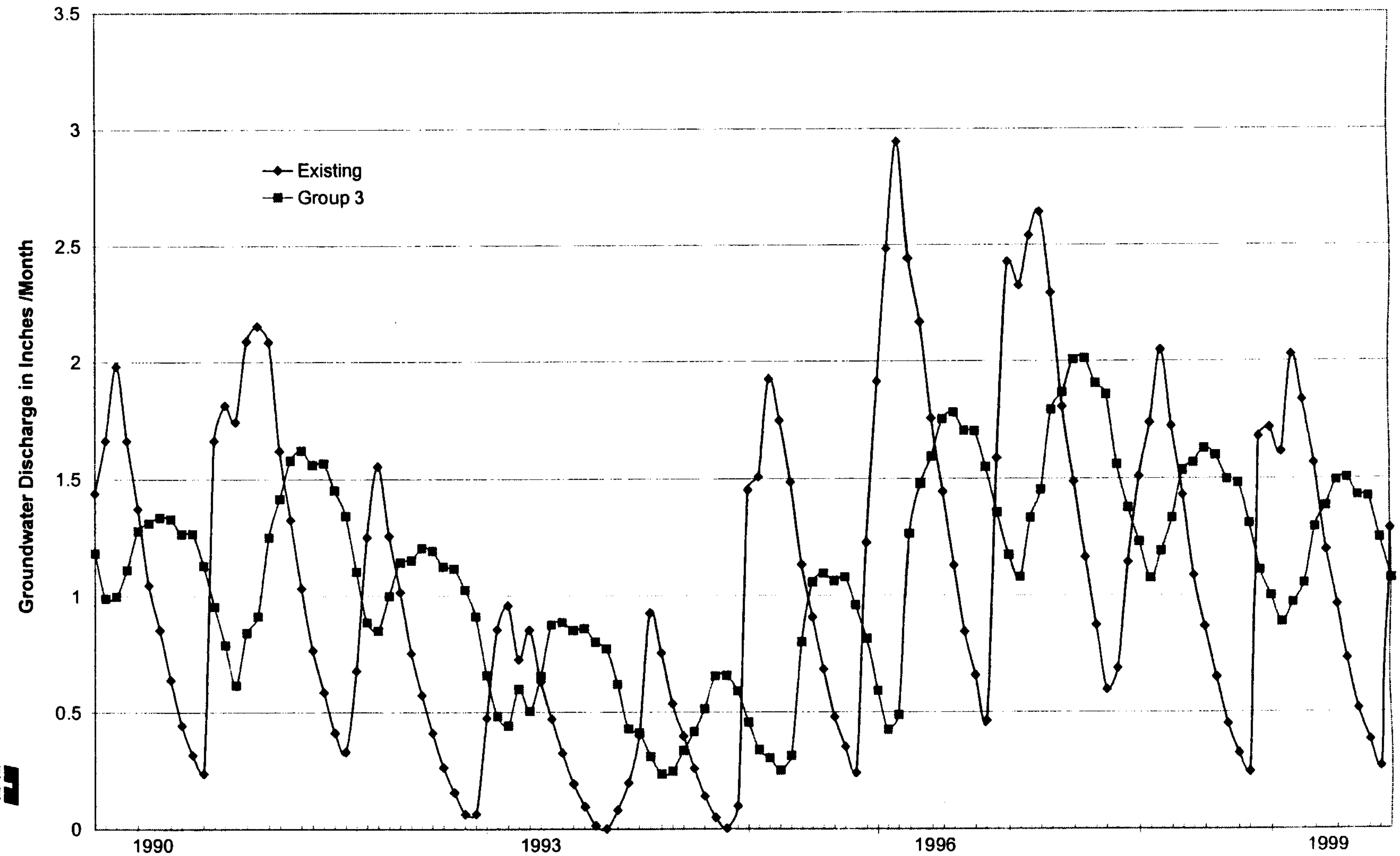
HARTCROWSER

J-4978-28 10/00

Figure C-12

AR 046201

Simulated Groundwater Discharge Rates for Existing Conditions and Group 3 Fill



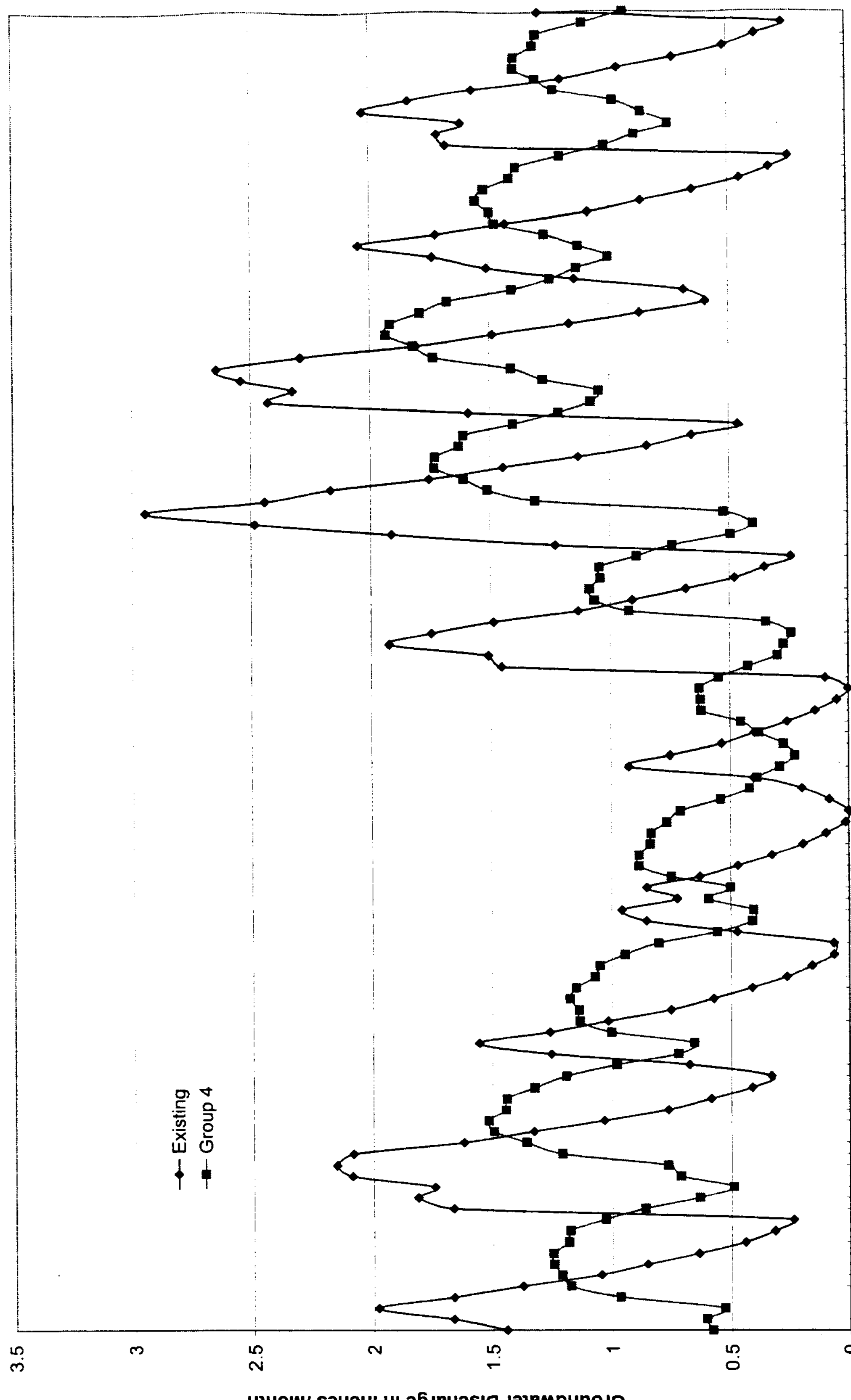
DJH 10/12/00 497828AA.cdr Sheet 2 of 4

HARTCROWSER

J-4978-28 10/00

Figure C-13

Simulated Groundwater Discharge Rates for Existing Conditions and Group 4 Fill



DJH 10/12/00 497828AA.cdr Sheet 3 of 4

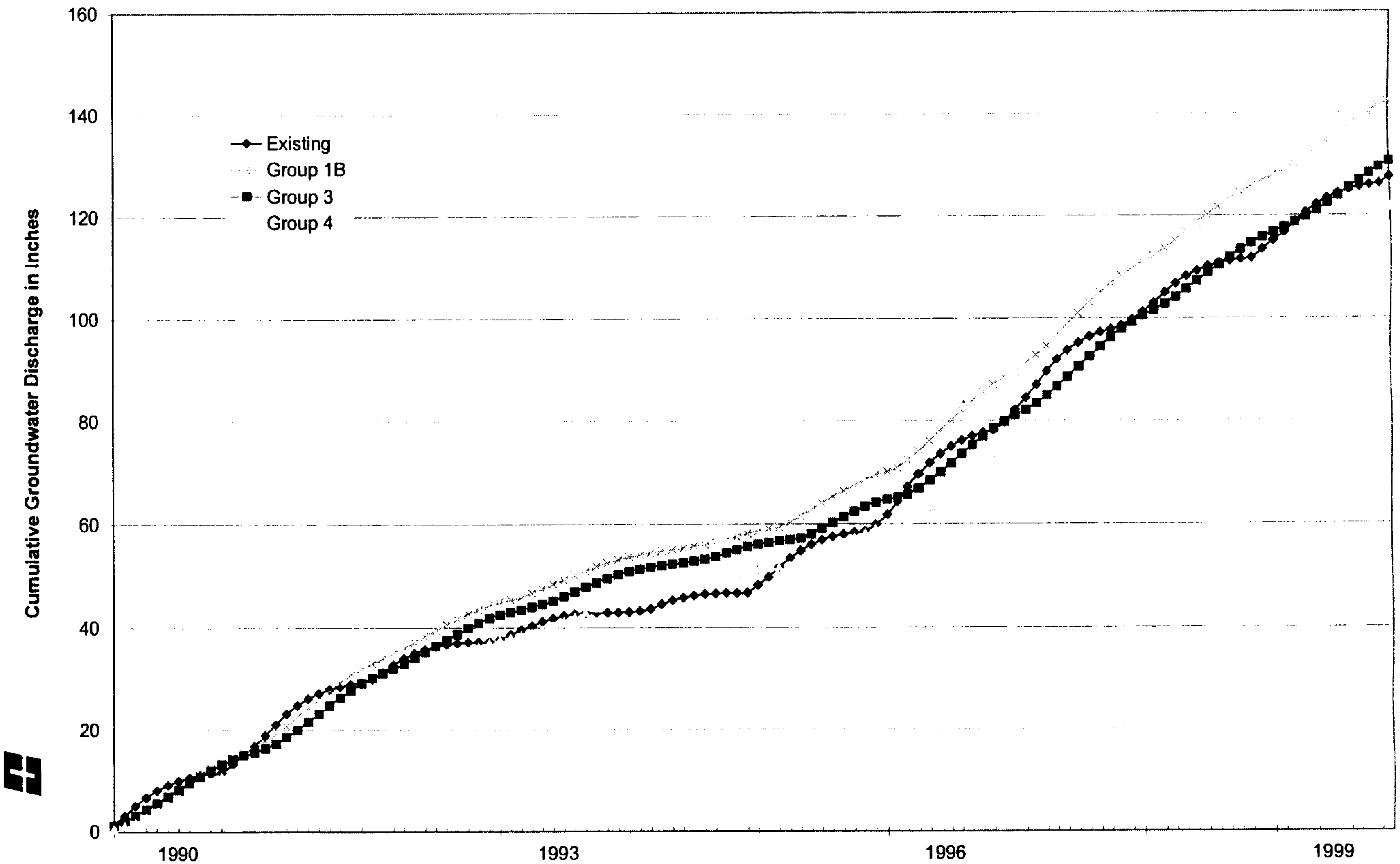
HARTCROWSER

J-4978-28 10/00

Figure C-14

AR 046203

Cumulative Plot of Simulated Groundwater Discharge Rates



DJH 19/12/00 497828AA.cdr Sheet 4 of 4

HARTCROWSER

J-4978-28 10/00

Figure C-15

AR 046204

www.hartcrowser.com

Anchorage
2550 Denali Street, Suite 705
Anchorage, Alaska 99503-2737
Fax 907.276.2104
Tel 907.276.7475

Boston
100 Cummings Center, Suite 347C
Beverly, Massachusetts 01915-6123
Fax 978.921.8164
Tel 978.921.8163

Denver
274 Union Boulevard, Suite 200
Lakewood, Colorado 80228-1835
Fax 303.987.8907
Tel 303.986.6950

Edmonds
120 Third Avenue South, Suite 110
Edmonds, Washington 98020-8411
Fax 425.778.9417
Tel 425.775.4682

Eureka
1257 Main Street
Fortuna, California 95540
Fax 707.726.9146
Tel 707.726.9145

Fairbanks
1896 Marika Street, Unit 1
Fairbanks, Alaska 99709-5545
Fax 907.451.6056
Tel 907.451.4496

Jersey City
[illegible] Warren Street, Second Floor
Jersey City, New Jersey 07302-6443
Fax 201.985.8182
Tel 201.985.8100

Juneau
[illegible] Seward Street, Suite 1
Juneau, Alaska 99801-1173
Fax 907.586.1071
Tel 907.586.6534

Long Beach
One World Trade Center, Suite 2460
Long Beach, California 90831-2460
Fax 562.495.6361
Tel 562.495.6360

Portland
Five Centerpointe Drive, Suite 240
Lake Oswego, Oregon 97035-8652
Fax 503.620.6918
Tel 503.620.7284

Seattle
1910 Fairview Avenue East
Seattle, Washington 98102-3699
Fax 206.328.5581
Tel 206.324.9530

AR 046205