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101/MFW/86/03/24/REVIEW

MAR 25 1986

MEMORANDUM FOR: Paul Hildenbrand, Project Manager
Basalt Waste Isolation Project, WMRP
Division of Waste Management

FROM: Michael F. Weber, WMGT
Division of Waste Management

SUBJECT: REVIEW OF BWIP DOCUMENTS: SD-BWI-TI-226 AND RHO-BW-CR-150 P

Enclosed please find reviews of the following two BWIP documents: "Piezometer Completion Report for Borehole Cluster Sites DC-19, DC-20, and DC-22," SD-BWI-TI-226; and "PORFLO - A Continuum Model for Fluid Flow, Heat Transfer, and Mass Transport in Porous Media," RHO-BW-CR-150 P. The first document review was prepared by Williams and Associates as a substitute review for RHO-BW-SA-428 P, which is a summary version of TI-226. Nuclear Waste Consultants reviewed RHO-BW-CR-150 P. In the future, Hydrology Section staff may develop additional written reviews of these documents in preparation for workshops or in conjunction with other evaluations of the Hanford Site. Please contact me if you have any questions about these reviews.

/s/
Michael F. Weber
Geotechnical Branch
Division of Waste Management

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See memo to Hildenbrand fm. Weber 3/25/86

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WMGT DOCUMENT REVIEW SHEET

FILE #:

ROCKWELL HANFORD #: SD-BWI-TI-226

DOCUMENT: Jackson, R.L., Diediker, L.D., Ledgerwood, R.K., and Veatch, M.D. July 1984. Piezometer Completion Report for Borehole Cluster Sites DC-19, DC-20 and DC-22. Rockwell Hanford Operations, Richland, Washington, 379 p.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: March 11, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

This report describes the design and installation of multi-level piezometers at three locations designated DC-19, DC-20, and DC-22. The multi-level piezometers monitor different vertical horizons at a cluster location. Each piezometer nest contains three sets of piezometers designated A, C, and D. Nine hydrogeologic units are monitored in the Columbia River Basalt Group including basal Ringold sediments, the Rattlesnake Ridge interbed, the Priest Rapids interflow, the Sentinel Gap flow top, the Ginkgo flow top, the Rocky Coulee flow top, the Cohassett flow top and the Umtanum flow top. The Mabton interbed is monitored at each nest by the D piezometer. A pumping well (designated as borehole B) was completed in the Priest Rapids interflow at the locations of nest numbers DC-20 and DC-22.

We have two major concerns regarding the material presented in the report under review. The first concern regards the assertion that a 92-foot thick flow is present at the DC-19 cluster site between the Cohassett and the Rocky Coulee flows. This 92 foot thick flow does not appear to be present at either the DC-20 cluster or the DC-22 cluster. The effect of this missing basalt flow on the hydraulic potential measurements at the site is not completely clear at this time. It should be noted that the delineation of flow contacts and the identification of each individual flow is not based on core evaluation in the C series cluster wells. These identifications are based on an evaluation of geophysical logs, drilling logs, and chip samples.

Our second concern regarding the report is more appropriately termed a concern regarding information not contained in the report under review. Specifically, the description of the accident at the DC-20C site indicates that two piezometer tubes may have been damaged when the tubing string was inadvertently dropped. The piezometer string emplaced opposite the Cohassett flow top was crimped to such an extent that the pressure transducer cannot be set below the crimp. The Umtanum flow top piezometer was also crimped but a reduced diameter transducer has been fitted into this piezometer at the proper depth. The crimp in the Cohassett piezometer restricted the development of the piezometer for cleaning of residual materials out of the piezometer. The tubing strings were plugged and flushed with Hanford system water; the Cohassett piezometer could not be developed as were the other piezometers. The effect of the alternate development procedures on water density within the piezometer column is not stated. Data derived from the DC-20 Cohassett piezometer must be evaluated with this concern in mind.

BRIEF SUMMARY OF DOCUMENT:

The motivation for the piezometer cluster installations was derived from the July 1983 Workshop conducted between the Nuclear Regulatory Commission and BWIP personnel. The resulting test strategy created the hydraulic head baseline approach represented by these cluster wells.

The report describes the process used by Rockwell Hanford Operations to select the locations for the cluster wells. The stratigraphic setting and general hydrogeologic background of the area is described in the report. Locations for the three cluster sites are noted on the attached figure derived from the report. A design "as built" drawing for the A, B, C, and D series piezometers also is attached to this review.

The DC-19A borehole was placed at the location of the RRL-13 borehole; the RRL-13 borehole was used as a starter hole for borehole DC-19A. All starter holes at the DC-19 site were drilled with a cable-tool rig. DC-19A was completed using a coring rig. A biodegradable polymer-water circulating medium was used with the coring rig. The report states that a total loss of circulation occurred at a depth of 763 feet. Circulation was regained after an estimated total loss of 6,000 gallons of drilling fluid.

Borehole DC-19C was drilled using a rotary rig, which was converted from a bentonite-water drilling fluid to an aerated-water system. The aerated-water system was used below a depth of

1.579 feet. The report states that circulation was maintained throughout the mud-rotary portion of the borehole. The report states that a total loss of drilling fluid occurred temporarily while drilling through the upper Hanford Formation (p. 23). Fluid circulation was regained using lost circulation material.

Borehole DC-19D was completed with a rotary drilling rig using a biodegradable polymer-water system. The polymer-water system was used below a depth of 1,317 feet. The report states that circulation was maintained throughout the drilling operation with the addition of about 10% lost circulation material in the bentonite slurry drilling fluid. The report states that cement circulation was lost while cementing the 9.625 inch casing.

The starter holes at the DC-20 site were drilled using a cable-tool rig. Borehole DC-20A was drilled with a coring rig using a polymer-water circulating medium. The report states that significant fluid losses occurred near the final depth with an estimated loss of 10,800 gallons of drilling fluid in the Rattlesnake Ridge interbed (p. 26). Circulation was regained but only 50% circulation was maintained throughout most of the zone.

A rotary drilling rig was used to complete DC-20B. This hole was completed to 1.560 feet using a bentonite slurry drilling fluid. Minor mud losses occurred during mud drilling but they were controlled by lost circulation material. Casing was cemented in the hole. The report states that circulation was maintained from a depth of 1,560 feet to the final depth of 1,635 feet using a clear water drilling procedure.

Borehole DC-20C was completed using a rotary rig. A bentonite slurry drilling fluid system was changed to an aerated-water system at a depth of 1,581 feet. Circulation was maintained during the mud-rotary portion of the borehole drilling. The report states that minor drilling fluid losses were controlled by using lost circulation material. The report states that losses in circulation occurred during the aerated-water operations but were regained without special conditioning (p. 27).

Borehole DC-20D was completed using the rotary drilling rig. The bentonite slurry drilling fluid was replaced by a biodegradable polymer water system below a depth of 1,250 feet. The report states that circulation was lost temporarily when the hole was at a depth of 543 feet. Lost circulation was estimated to be at about 350 feet and was controlled using lost circulation material.

The starter holes at the DC-22 site were drilled with a cable-tool rig. Borehole DC-22A was completed using a core drill. A biodegradable polymer-water medium was used with the core rig. Minor drilling fluid losses occurred but less than 500 gallons of lost fluid are reported (p. 29).

Borehole DC-22B was completed using a rotary drilling rig. The bentonite slurry system was converted to a clear-water drilling fluid system below a depth of 1,718 feet. Circulation was lost when the borehole was at a depth of 978 feet in the Selah interbed. Lost circulation material was not effective in sealing the hole; the zone was cemented. The circulation problem recurred during the completion of the borehole while cementing the 13.37-inch OD casing to a depth of 1,718 feet.

Borehole DC-22C was completed using a rotary drilling rig. The operation was converted from a bentonite slurry drilling fluid system to an aerated-water system at a depth of 1,709 feet. Circulation was lost during the mud drilling operation at a depth of 966 feet in the Selah interbed. Lost circulation material was inadequate to control circulation losses. The formation was cemented; cementing operations were attempted four different times in order to seal the lost circulation zone.

Borehole DC-22D was completed using a rotary drilling rig. The bentonite slurry drilling fluid system was replaced by a biodegradable polymer-water system at a depth of 1,370 feet. No fluid loss problems were encountered in this borehole (p.32).

The report states that subsurface geology was identified based on "core (A-series boreholes from 600 to 850 feet), on geophysical logs, on examination of selected chip samples, and on drilling penetration rate data for the rotary drilled holes" (p. 33). The report states that on the basis of geophysical log responses and on the basis of stratigraphic position relative to nearby boreholes, flows within the Grande Ronde Basalt are interpreted to be present in all three boreholes except for one flow that is missing between the Cohassett and Rocky Coulee flows in DC-20C and DC-22C. The flow (approximately 92-feet thick) is present in the DC-19C borehole.

The distribution of dense and less dense layers in the Rocky Coulee flow are identified using several pieces of evidence. The geophysical logs indicate alternating zones of relatively low density and high apparent porosity interspersed with zones of higher density and lower apparent porosity. The drilling rates are higher in the Rocky Coulee flow ,as would be anticipated in an apparent high porosity zone. A probable or at least possible groundwater production zone exists between depths of 2,820 feet and 2,860 feet in borehole DC-20C. Evidence for this groundwater production zone is based on a dynamic fluid temperature log. Larger volumes of neat cement were required to isolate the Cohassett piezometer; the cementing difficulties occurred opposite the Rocky Coulee flow interior. A TV camera survey of the borehole (DC-20C) also provided evidence for the distribution of relative rock properties of the Rockv Coulee flow. The report presents several explanations for the apparent anomalous Rockv Coulee densitv distribution. The first explanation is that the zone is composed of several flow lobes (p. 48). The second explanation assumes that the zone is composed primarilv of flow top material with thin zones of dense rock. The final explanation assumes that the base of the flow is composed of pillows formed during emplacement of the flow in water.

The polymer based drilling fluids were broken down using a calcium hypochlorite solution. Water was placed in the hole using a tremie pipe. The report states that the initial development of the C holes was accomplished indirectly bv using an aerated water drilling procedure. Two additional pumping phases were emploved in these C series holes after completion of drilling. The first phase of pumping was accomplished bv pumping composite intervals. The second phase of pumping was accomplished bv using inflatable straddle packers to isolate the proposed monitoring intervals. Pumping was conducted by using either a line shaft turbine pump, an air-lift pump svstem, or a submersible pump. The A and D series boreholes were not pumped prior to installing piezometer strings. These holes were not pumped to prevent the sloughing of sedimentarv interbeds into the borehole.

The report presents approximate estimates of transmissivities based on the pumping development of the boreholes. Zones where fluid loss occurred during drilling cannot be compared to the zones for which transmissivities are estimated. The zones that were pumped during development are not the same zones in which drilling fluid losses occurred. At borehole DC-19C, the highest transmissivitv was observed in the Priest Rapids interflow and in the Ginkgo flow top. Moderate transmissivitv was noted for the Umtanum and Sentinel Gap flow tops. The lowest transmissivitv was noted for the Rockv Coulee flow top. Equipment problems prevented the estimation of transmissivitv for the Cohassett flow top.

Transmissivitv estimates for borehole DC-20C are based on pumping during borehole development. The highest transmissivities were associated with the Sentinel Gap flow top. Moderate values are associated with the Umtanum and Ginkgo flow top. The lowest transmissivity is associated with the Cohassett flow top. Transmissivities were not estimated for the Rocky Coulee flow top due to poor packer seating conditions.

Relative transmissivities are not reported for borehole DC-22C. Equipment malfunctions and poor packer seating conditions precluded the estimation of transmissivities at this site.

The piezometers installed in the holes have a seating nipple located approximately two feet above the piezometer screen. The piezometer screens consist of continuous slot wire wound screen jacket over a perforated pipe base. The screens were surrounded by a filter pack consisting of two different types of gravel pack. The size distribution for the gravel packs is presented in the report under review.

The piezometers and wells were sealed using two methods, bentonite or Portland neat cement. Bentonite was used solely in the uppermost seals at the A series sites. The Portland neat cement was used at all other sites. American Petroleum Institute (API) Class A or B cements were the basic cements. Calcium chloride (CaCl) was added to the Class B cement on several occasions to accelerate the setting of the cement. Cellophane flakes were added to control slurry loss during cementing operations of "seal 6 at DC-20C" (p. 63). We believe that "seal 6" is opposite the Roza Member of the Wanapum Basalt.

The installation of the multi-level piezometers was not without incident. The report states that the tubing string was inadvertently dropped at DC-20C. The tubing fell approximately 400 feet into an unset neat cement slurry. The tubing came to rest at a depth of about 1,754 ±1 foot (p. 67). The tubing was fished out of the hole and the cement seal was allowed to set up. The report states that a crimp occurred in the Cohassett piezometer tubing string at a depth of about 1,754 feet. A partial constriction also was noted in the Umtanum piezometer at the same depth (p. 67). The constriction in the Umtanum piezometer was large enough for the seating nipple plug to pass through it. The constriction in the Cohassett tubing string prevented the use of a seating nipple plug for subsequent cleaning of the tubing and integrity testing.

The piezometer tubes were integrity tested by filling them with water and measuring the water level decline in the tubing. The constriction in the Cohassett piezometer tubing string prevented using the same criterion for water level decline in the tubing. The measured rate of decline in the Cohassett tubing was compared to a rate that would be expected for water moving down the length of the Cohassett piezometer tubing string and out through the screen section and the sand filter pack into the Cohassett flow top. The report states that RHO does not believe the tubing is perforated and/or leaking opposite the wrong hydrostratigraphic unit.

The constriction in the Cohassett tubing string prevents setting the transducer at the proper depth. The transducer is seated at the constriction at a depth of 1,754 feet. A one-inch diameter downhole pressure transducer is required for the Umtanum piezometer (p. 68).

The piezometers were developed after emplacement of the neat cement seals. Development was by air-lift pumping for up to several days. The report states that the procedure involved "(1) installing a plug in the seating nipple, (2) simultaneously scrubbing the tubing and circulating a detergent solution, (3) flushing with clear water, and (4) removing the seating nipple" (p. 70). The report states that the Cohassett piezometer at DC-20C was an exception to this procedure because of the constriction at a depth of 1,754 feet.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This report is important to the program because it describes the completion of the only multi-level water level and pressure monitoring facility at the BWIP site. These facilities provide the only long-term comprehensive water level and pressure data for the site. Water level data and pressures are required to ascertain the direction of groundwater flow and the magnitude of the hydraulic gradients both areally and vertically. Valid hydraulic gradients are critical to the determination of groundwater flow paths and travel times.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report states (p. 33) that a 92-foot thick basalt flow is present in borehole DC-19C but it is not present in boreholes DC-20C or DC-22C. The absence of the 92-foot thick flow is of concern because of its potential impact upon hydraulic continuity in an areal sense. The hydraulic gradients that are estimated based on data derived from the cluster sites imply hydraulic continuity of flow path. The absence of the subject basalt flow at the DC-20C and DC-22C sites implies that there may be greater vertical hydraulic interconnection at the pinch-out of this flow than will be found where the flow is present (DC-19C). The presence and absence of this flow and possibly other flows will have to be scrutinized for conceptualizing groundwater flow paths at the BWIP site. STP 1.1 and analogous RHO documents present testing strategies that require the existence of this conceptual model.

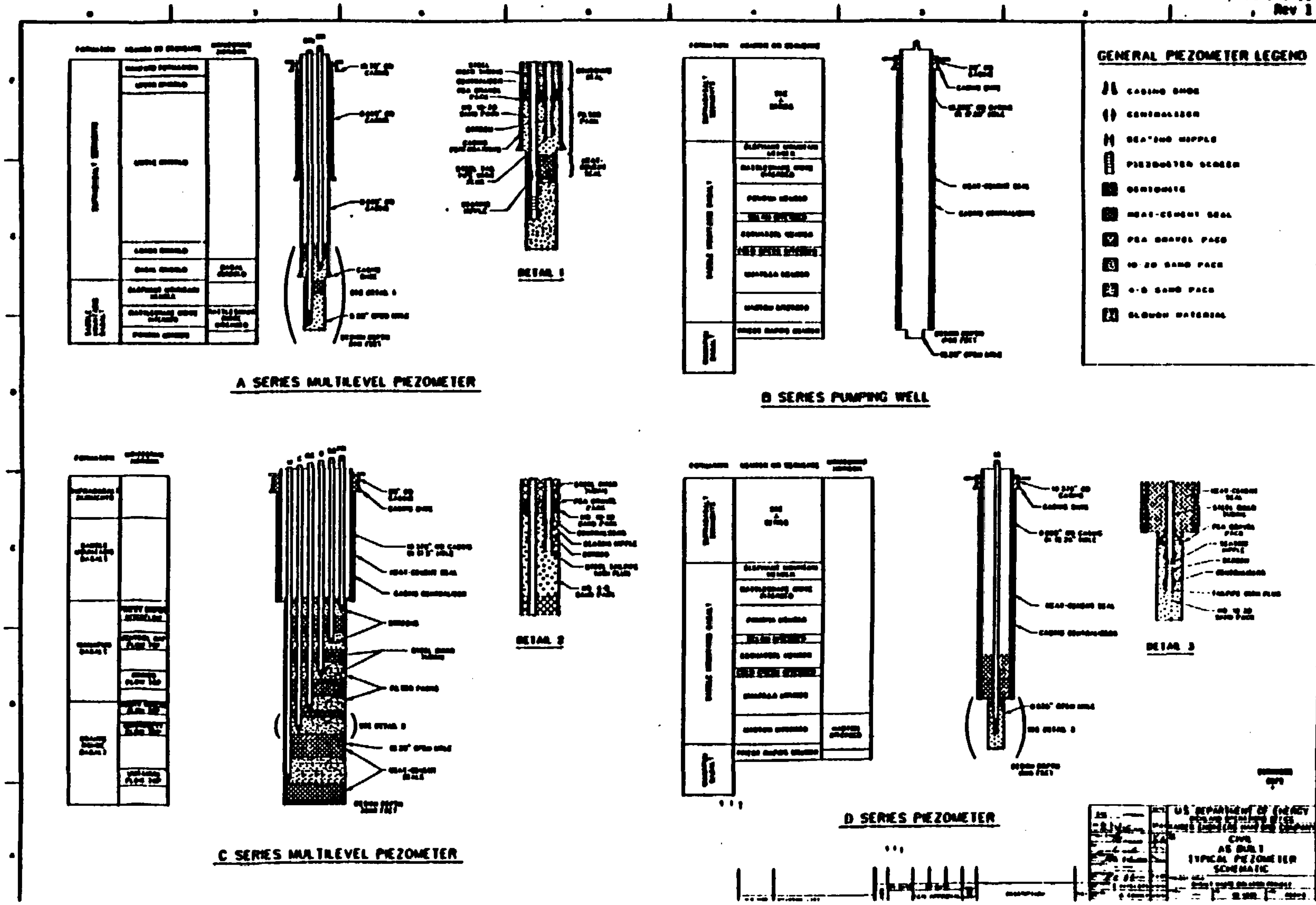
The process used to clean the piezometers at the DC-20C site should be reviewed. As noted above and in the report, the Cohassett piezometer has a constriction in it due to the dropping of a tubing string. The constriction in the Cohassett tubing precludes the use of the seating nipple which was intended to isolate the tubing for both integrity testing and subsequent cleaning of the tubing. The procedures for detergent flushing, air-lift pumping, and injection of Hanford system water were different for this piezometer than for the other piezometers. Questions exist regarding the quality of the water below the constriction at a depth of 1,754 feet. We assume that the lower section of the piezometer tubing is filled with Cohassett flow top water. Hanford system water apparently exists above the constriction. A zone of diffusion undoubtably exists in the vicinity of the constriction. The presence or absence of variable fluid density water in the tubing raises questions about interpretation of downhole pressure data. The analyses of water level data and downhole pressure data are used to interpret groundwater flow directions and hydraulic gradients. The three-point solution requires that all three sites be used (DC-19, DC-20, and DC-22). The loss of a single site due to concerns about the integrity of the facility causes significant problems with respect to the interpretation of the data.

The testing and data gathering at the DC-20C site indicate that the Rocky Coulee flow interior may have a significantly higher vertical hydraulic conductivity than is evidenced by data collected at the other sites or other flow tops at the sites. The pumping of the Rocky Coulee flow top piezometer (DC-20C) created a measured drawdown in the Cohassett flow top piezometer (DC-20C). This relationship implies that rapid vertical communication exists across the Rocky Coulee flow interior. The two piezometers supposedly are separated by a 70-foot thick neat cement seal (p. 71). The report cites additional evidence such as geophysical log responses to indicate that the Rocky Coulee flow interior at the DC-20C site is different from the Rocky Coulee flow interior noted at the other two cluster sites. The evidence suggests that the communication across Rocky Coulee flow interior is due to a finite hydraulic conductivity of the flow interior as opposed to a failure of the cement seal. A failure of the cement seal is not evident at any of the other sites or flow interiors. The evidence supplied at the DC-20C site for the Rocky Coulee flow interior suggests that some flow interiors may be very heterogeneous with respect to their vertical hydraulic properties. This information is very important with respect to the design and analysis of future large-scale hydraulic stress test planned for the BWIP site.

A minor concern exists because of an item noted in the drilling activity log in the report under review (Table B8, p. 147). The table indicates that the drilling operations at DC-20C encountered gas problems. The hole was drilled from 3,745 to 3,759 feet whereupon the drilling crew spent 1-1/4 hours regaining circulation. The hole was then deepened to 3,781 feet with another quarter hour allowed for circulation. The report states that the hole began "blowing after tripping halfway out of hole". The drilling crew allowed the hole to exhaust gas prior to running the PNL geophysical log. The natural gamma logging tool was going to be used to determine stratigraphic position. Approximately 300 feet of the bottom of the hole was logged whereupon 3,500 feet of logging cable and probe were blown out of the hole. The current water level data from the piezometers may be affected by a continuing release of gas from these deep basalts.

GENERAL NOTES

U.S. DEPARTMENT OF ENERGY


GENERAL PIEZOMETER LEGEND
CASING SHOE
CENTRALIZER
SEATING NIPPLE
PIEZOMETER SCREEN
BENTONITE
NEAT-CEMENT SEAL
PEA GRAVEL PACK
10-20 SAND PACK
4-8 SAND PACK
SLOUGH MATERIAL
A SERIES MULTILEVEL PIEZOMETER
DETAIL 1
B SERIES PUMPING WELL
C SERIES MULTILEVEL PIEZOMETER
DETAIL 2
D SERIES PIEZOMETER
DETAIL 3
U.S. DEPARTMENT OF ENERGY
CIVIL
AS BUILT
TYPICAL PIEZOMETER
SCHEMATIC

1.0 INTRODUCTION

TITLE: RHO-BW-CR-150 P - "PORFLO - A Continuum Model for Fluid Flow, Heat Transfer, and Mass Transport in Porous Media"

AUTHORS: A.K. Runchal, B. Sagar, R.G. Baca, and N.W. Kline

DATE: September 1985

REVIEWERS: Dr. Catherine Kraeger-Rovey, Fred Marinelli, Michael Galloway (Terra Therma), and Adrian Brown (NWC).

DATE: February 28, 1986

SCOPE: General review of concepts presented in document and suitability of the concepts and code logic, assumptions, and operation to assess performance of the repository at the BWIP site. Reviewed within the context of probable hdyrogeologic conceptual models of the BWIP site, as presented in this review.

KEYWORDS: 2-Dimensional, Porous Media, Fluid Flow, Heat Transfer, Mass Transport, Conceptual Models, Test Cases, Computer, Model, Porflo.

DATE APPROVED: Mark J. Logsdon, NWC Project Manager

2.0 SUMMARY OF DOCUMENT AND REVIEW CONCLUSIONS

2.1 SUMMARY OF DOCUMENT

The document received presents the PORFLO model theory, including equation development for each of three processess; fluid flow, heat transfer, and mass transport. The document provides the basis and assumptions of the governing equations and demonstrates the coupled and decoupled options of the model. The results of three test cases are discussed. This document is not a "user's" manual for the PORFLO program nor does it contain a listing of the code.

2.2 SUMMARY OF REVIEW COMMENTS

PORFLO is a two-dimensional (2D) finite difference continuum model that couples fluid/heat floow and radionuclide transport. The model incorporates mathematical assumptions which are common to other numerical models having similar capabilities (e.g. MAGNUM2D). Equations presented in theh document and results of the test examples suggest that PORFLO, when properly used, is capable of adequately simulating the physics of two-dimensional continuum groundwater flow/transport problems with heat. If it can be demonstrated that a two-dimensional, equivalent porous medium approach is valid (or conservative) for assessing certain performance aspects of the BWIP site, it is Terra Therma's view that PORFLO can be a useful analytical tool for accomplishing the required analyses.

Several limitations of the PORFLO to model conditions at the BWIP site have been identified and are summarized below. In most cases, these limitations would apply not only to PORFLO, but to all 2-D continuum finite difference models.

1. The model is restricted to a two-dimensional geometry that would generally be applied to a horizontal plane or vertical section of the flow region. For the range of conceptual flow models currently beingn considered at the BWIP site, a 2-D approach may be valid or invalid, conservative or nonconservative, depending on the model selected. If models ultimately adopted for BWIP can be adequately (or conservatively) simulated in two dimensions, PORFLO will be a useful tool for quantifying these models. If, however, the adopted conceptual models require three dimensional simulations, PORFLO may have significant limitations.

2. The model uses an equivalent porous medium (continuum) approach to model fluid flow, heat transfer, and mass transport in a fractured media. This would generally require that mesh elements are sufficiently large to represent a representative elemental volume (REV) of the fractured medium. the size of REV's for various hydrostratigraphic units (HSU's) at the BWIP site have not been determined and may vary significantly within an HSU depending on the process under consideration (fluid flow, heat flow, radionuclide transport). Increasing the size (scale) of mesh elements increases the probability of satifying REV requirements but reduces the capability of incorporating detail. Thus, it is anticipated that PORFLO,

if applicable, will be used for mid and far field simulations, but will not be appropriate for modeling groundwater flow/transport very close to the repository. It is also possible that dimensions of the HSU's (e.g. thickness of flow interiors) may be too small to allow definition of REV's at any grid scale.

3. It is not clear whether the model can simulate the effects of time-varying boundary conditions or parameter values by updating these effects "mid-run". This may be required, for example, if near-field repository models are used to define mid-field boundary conditions as input to PORFLO.

4. The sequential coupling of fluid flow, heat flow, and solute transport within a time-step, along the foward-time method of updating parameter values, may lead to instability or inaccuracy if time steps are too large or the mesh too coarse. Instability may also occur if greatly contrasting parameter values exist in adjacent elements. Defensible application of PORFLO may require parallel runs using different ttme steps and mesh sizes to insure that a stable and accurate solution has been achieved.

5. Although a minor limitation, the finite difference mesh geometry used in PORFLO may be inconvenient if the modeled region has very irregular shape or requires detail (i.e., smaller elements) in specific areas.

The use of PORFLO to assess performance of the BWIP site is discussed within the context of six conceptual models presented in this review. Since conceptual models for the BWIP site are not within the scope of this review, the proposed models are not fully developed and documented, but are presented for comparison purposes only. The models represent possible "generic" models of the BWIP system to serve as a basis for evaluating the PORFLO model.

3.0 SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM

It is generally expected that licensing of a HLW repository wil depend, to a siginificant extent, upon performance assessments based on computer modeling. It is generally considered that at least some of this modeling will require analysis in zones where the effects elevated temperatures on fluid flow and solute transport must be considered. Programs with this capability, including PORFLO, will presumably be used for this task, and hence form a potentially important tool in licensing.

4.0 GENERAL COMMENTS ON REPORT

4.1 DESCRIPTION OF PORFLO

The PORFLO model is a coupled fluid, heat, and radionuclide transport simulator. The fluid flow component is similar in concept to a number of other published two-dimensional, finite difference groundwater flow simulation models, including Prickett-Lonnquist and McDonald-Harbaugh. Minor differences between the fluid flow aspects of PORFLO and other models include the treatment of buoyancy effects and density and viscosity variations. Additional features of the model include components for simulating convective and conductive heat flow and radionuclide transport, which are coupled to the fluid flow component to simulate the dependence of these phenomena on fluid flow. Reciprocal effects of thermal energy and heat transfer on fluid flow are also modeled.

Three governing equations, one each for fluid flow, heat transfer, and radionuclide transport, are numerically solved in PORFLO. These equations are coupled sequentially, rather than solved simultaneously. At each time step, the fluid flow equation is first solved, resulting in a new pressure field throughout the model. Convective velocities are determined from these pressure values. The velocities are used as coefficients in the heat flow equation, which is next solved for temperature. The temperature field is used to update the coupling terms, i.e., the hydraulic conductives, through their dependence on fluid density and viscosity, buoyancy, an fluid expansion.

Pressure dependence of water density and viscosity is negligible as compared with temperature dependence, and has been ignored in PORFLO.

The adjusted hydraulic conductivity values will be used in the next subsequent time step. The concentration equation for radionuclide transport is solved last. There is only a one-way coupling between the flow (pressure) equation and the concentration; i.e., the pressure values generated in the flow equation affect the concentration equation, but concentration does not affect the flow equation. The pressure and concentrations are coupled through the convective velocities generated from the pressure field.

4.2 LIMITATIONS

PORFLO exhibits several limitations that are common in two-dimensional, finite difference models, including a "grid" geometry that is sometimes inconvenient if the region being modeled has an irregular shape, and may lead to an unstable solution under certain conditions. The grid geometric limitations can generally be overcome by varying grid sizes and selectively refining the mesh acording to the geometry of the modeled region and the need for detail in specific areas. Numerical solution instabilities can be overcome by avoiding large disparities in grid sizes and selecting a time increment sequence that is compatible with the rate of change in heads throughout the region, under artificially imposed stresses as well as natural conditions.

However, there are two major limitations of the PORFLO model that may seriously limit its applicability for assessing repository performance at the

BWIP site: (1) the model's restriction to handling two-dimensional geometry and (2) its use of the "equivalent porous medium" approach in simulating flow of mass, heat, and radionuclides through a fractured medium. Specific ramifications of these two features, and other minor limitations are discussed in following paragraphs, relative to a series of conceptual models that have been considered for the BWIP site at Hanford.

From the existing documentation, it is not clear to what extent the PORFLO model incorporates the capability to simulate certain hydraulic boundary stresses that may be associated with "repository performance" including: (1) simulation of desaturation, including hysteresis effects and alteration of material properties; and resaturation, (2) time variant fluid or material properties or those that change in mid-run, (to simulate staged excavation and placement of waste, for example), (3) pressure-dependent permeability values, (4) repository geometry. Some of these complicated factors and processes can be adequately represented by simplified data sets or boundary conditions, so that the PORFLO model can provide an acceptable simulation. However each proposed application of this model should be judged individually, to determine whether the required complexity of the simulation and/or accuracy of the result exceeds the capability of the PORFLO model.

Of significant concern to this review is that the case studies presented in the available documentation of PORFLO do not address the question of whether PORFLO can successfully simulate hydrogeologic conditions potentially existing at the BWIP site. The documentation contained several case studies, some of which show that the PORFLO model can reproduce certain idealized solutions.

Other case studies compare PORFLO results to the results of another model (MAGNUM 2D). None of the case studies attempted to match model results with an extensive set of field measurements, particularly for a site with as complex a set of hydrologic conditions as the BWIP site. It is recognized that data for history-matching may be scarce, and will probably available for flow only. Prior to applying this model in a "production" mode, however, at least one, but preferrably several test cases should be run, to test model results against field hydrologic measurements at the BWIP site. This might include simulation and comparison of the stresses imposed by LHS testing.

4.3 POTENTIAL CONCEPTUAL MODELS

4.3.1 Introduction

Evaluation of site performance at BWIP will require quantification of a site conceptual model (or series of conceptual models). A groundwater conceptual model for the site must provide the minimum features of the hydrogeologic system which are needed to quantitatively determine the relevant behavior of the flow system. This includes a description of:

1. subsurface materials including stratigraphy, lateral variability, and relative values of hydraulic properties for each material type.

2. flow system boundary conditions including physical boundaries and recharge/discharge relationships.

3. transient and steady-state potential gradients driving groundwater flow.

For performance assessment, it is not generally necessary that the conceptual model include all aspects of the real flow system. However, if simplifying assumptions are applied, it must be demonstrated that these modifications will have a negligible influence or lead to conservative results when the conceptual model is quantified (e.g., provide underestimates of radionuclide travel times). It is Terra Therma's view that site conceptual models and (associated numerical models) should be raised only to the level of sophistication required to conservatively evaluate groundwater flow/transport mechanisms and to answer the relevant questions regarding site performance.

Development of conceptual models for the BWIP site is an ongoing activity to be coordinated with information obtained from the hydrologic and geologic testing program. To date, there is insufficient information to allow delineation of a single flow/transport conceptual model for the site. Thus, a series of potential models have been formulated based on available data. As new data are obtained (e.g., from LHS testing), it is anticipated that the individual models can be refined and/or eliminated.

4.3.2 Conceptual Models Currently Considered

Currently, a high degree of uncertainty exists regarding groundwater flow and transport at the BWIP site. As such, potential conceptual models to be considered at this stage of site characterization cover a wide range of possible hydrogeologic conditions. Conceptual models consistent with current information and uncertainty are summarized below.

1. Continuously layered; both interflows and flow interiors are relatively homogeneous with assigned bulk parameter values.

2. Continuously layered; interflows are highly heterogeneous with a wide range of parameter values; flow interiors are relatively homogeneous with assigned bulk parameter values.

3. Continuously layered; interflows are relatively homogeneous with assigned parameter values; flow interiors are heterogeneous with isolated high permeability features.

4. Continuously layered; interflows are heterogeneous with a wide range of parameter values; flow interiors are heterogeneous with isolated high permeability structures.

5. High permeability discontinuities within the flow system combined with either 1, 2, 3, or 4.

6. Low permeability discontinuities within the flow system combined with either 1, 2, 3, or 4.

These conceptual models for performance assessment are illustrated in Figures 1 through 6, respectively. As new data become available for the BWIP site, it is anticipated that certain aspects of the above models will be refined, combined, or eliminated from consideration.

4.4 APPLICATION OF PORFLO FOR QUANTIFYING CONCEPTUAL MODELS

4.4.1 Geometric Limitations.

The following discussion of appropriate applications of the PORFLO model applies to all three transport modes simulated: mass, heat, and radionuclides. Geometric limitations of the model determine its adequacy for depicting pertainent characteristics of the host medium, which in turn affect all three modes of transport. Though minor variations may exist as to the effect of PORFLO's geometric limitations on the simulation of each mode of transport, the overall effects on all three modes are anticipated to be quite similar. Therefore the present discussion does not differentiate among them, except where exceptions to the generalization are specifically discussed.

Geometric Options Available

The geometry of the BWIP site is in fact three-dimensional, while the PORFLO model is capable of simulating variations in only two dimensions. The model can be applied either to a planar, cartesian system (no variation in the third dimension), or to a radially symmetrical, cylindrical system (no variation around the axis of symmetry). In general, the regional geometry is more compatible with the cartesian system; faults, fractures, and axes of synclines and anticlines are more or less linear and fairly straight. However, there may be limited applications in localized areas where use of the axisymmetric model geometry will be appropriate.

Cartesian Geometry

A two-dimensional, horizontal model geometry could be applied to simulation of regional flows under Concepts 1 or 2, where both diffuse and discrete vertical transport through the flow interiors can be neglected or applied uniformly without large error. (A possible exception is that flow interiors with low hydraulic conductivity may have significant thermal conductivities that should not be neglected or "blanketed" in the model). Assuming that thermal conductivity of the flow interior is, along with the other transport characteristics of the flow interior, relatively low, the two-dimensional, cartesian model could be applied to a horizontal section of a single flow or interflow, in which either homogeneous or heterogeneous aquifer characteristics can be simulated. It is recommended for this type of application that only a single interflow be modeled, in preference to modeling an entire flow or sequence of flows.

The two-dimensional model could be applied to a vertical section under Concepts 1 and 2 if the model can be aligned parallel to the regional direction of horizontal flow, if interflow heterogeneities do not appreciably alter local horizontal flow directions, and if interflow heterogeneities can be incorporated into the model using bulk parameter values. In this case, flow interiors, as well as interflows, would be modeled as "active cells".

For Concepts 3 and 4, a horizontal, cartesian geometry may be appropriate, if the isolated, high-permeability flow interior features either do not exist in the modeled area, or can be defined adequately using source/sink terms. It is doubtful that the model could be applied in vertical section because interflows would have some degree of radial (non-two-dimensional) flow towards the isolated high permeability features.

For Concepts 5 and 6, the applicability of a two-dimensional model in horizontal plane would be very limited because flows of mass, heat and radionuclides may be dominated by three-dimensional geometry. Applications would probably be limited either to relatively small regions, where major structural discontinuities are not present, to very large regions, where the scale of the model is much larger than the effective spacing of major structural discontinuities or to areas for which the discontinuities can be treated as boundary conditions or line source/sinks. The two-dimensional model could be applied in vertical section if the modeled area is aligned parallel to the regional flow direction and roughly perpendicular to the discontinuities (to minimize non-uniformity in the third dimension not modeled).

Axisymmetric Geometry

An axisymmetric geometry, with its assumption of angular uniformity, implies uniform characteristics in concentric rings around some single axis. The layered nature of basalt flows does not allow this symmetry to exist around a horizontal axis. A model with axisymmetric geometry in vertical section may be useful in depicting conditions in a localized situation, where flow is dominated by movement toward or away from a center, such as a dewatered repository zone. The axisymmetric geometry around a vertical axis would be applicable to Concept 1 an may possibly be applied to Concept 2 if interflow heterogeneities (1) can be incorporated using bulk parameter values and (2) do not result in appreciable variations from radial flow to/from the axis of symmetry. It is doubtful that an axisymmetric simulation could be applied to Concepts 3 and 4 since isolated high permeability features would be of limited lateral extent. Axisymmetric geometry would also not apply to Concepts 5 and 6 because tectonic structures tend to be linear.

4.4.2 Equivalent Porous Media Limitations

Transport Phenomena In Fractured Media

It is generally recognized that the medium at the BWIP site is fractured, that the major flow of groundwater occurs through flow tops, (particularly for Concepts 1 and 2) and also through structural discontinuities (Concepts 5 and 6). Changes in fluid pressure may affect the permeability; pressure decreases can result in a reduction in fracture aperture. Under certain conditions, fracture flows may not be laminar, and permeabilities can change significantly over a moderate change in Reynolds number. The basalt flow interiors occupy a majority of the rock volume, yet typically exhibit low permeabilities relative to the flow tops. These flow interiors can however contain localized features that are highly permeable, including fractures, joints, spiracles, and brecciated zones.

Fracture Flow and Transport Models

There are very few models that realistically simulate flow through fractured media; even though the logic exists, there is seldom sufficient data to accurately describe the fracture system: location, size, direction, frequency, etc. To compensate for the lack of available data (and the fact that it is prohibitively expensive and impractical to collect), most fracture flow models incorporate a stochastic algorithm to describe the flow system. In most applications, equivalent porous medium models are much more practical to use than fracture flow models, and provide a level of detail consistent with existing data.

Assumptions of EPM Models

PORFLO is a deterministic, rather than a stochastic model, that simulates mass flow by replacing the discrete fracture flow system with a porous medium that is intended to produce the same rate of diffuse flux as the fracture system would produce under similar imposed stresses such as hydraulic or thermal gradients. The use of this "equivalent porous medium" representation carries with it the assumption that each grid cell is a homogeneous (though possibly anisotropic) porous medium, with fluid and solid matrix properties considered uniform. The solid matrix is treated as a equivalent porous medium, and fluid flow through this matrix is assumed everywhere laminar. Permeability is considered independent of fluid pressures, velocities, and gradients.

In general, the difficulty with using PORFLO and other EPM models to simulate transport through fractured media is that the "equivalent porous medium" can be forced to mimic the behavior of the real fracture system only under a relatively narrow range of stresses. This is because the hydraulic properties of the equivalent medium are not pressure or Reynolds number-dependent. Additionally, the three modes of transport PORFLO simulates (mass, heat, and radionuclides) do not necessarily share a single relationship with pressure, velocity, and other variables (e.g. thermal conductivity may exhibit a much weaker dependence on Reynolds number than hydraulic conductivity). Furthermore, it is possible for the EPM assumption to be acceptable for groundwater and heat flow, but totally inappropriate (and nonconservative) with regard to radionuclide transport.

Consideration For Effective Application of PORFLO At The BWIP Site

It would, at first, appear that PORFLO is not at all applicable to the BWIP site due to the major limitation of simulating a fractured medium as a equivalent porous medium. However, the key to using the PORFLO model effectively is to apply the model cautiously and conservatively; i.e.: (1) apply the model only in those regions where the geometric or EPM limitations are not grossly exceeded, using a geometry that aligns as closely as possible with the dominant features of the site in terms of hydrology, heat and contaminant transport; (2) to compensate for the lack of a stochastic algorithm, conduct sensitivity runs, using reasonable ranges of all major parameter values, rather than just one estimated or average value; (3) make appropriate parameter adjustments, where appropriate, to compensate for the EPM simplification (e.g. recognize that the EPM hydraulic conductivity may accurately predict mass flux, but not actual flow velocity; the contaminant transport diffusion coefficients should be coupled to the fracture, rather than to the EPM hydraulic conductivity.); (4) interpret model results conservatively, examining the assumptions and limitations of each run to ensure that possible "worst-case" conditions have not been neglected.

The following paragraphs discuss specific concerns of applying PORFLO at the BWIP site, relative to the purpose and required accuracy of any proposed application, selection of an appropriate model scale, and considerations for simulating heat and radionuclide transport in addition to mass flux. It is anticipated that these considerations will be equally important regardless of what overall conceptual model of the geohydrologic system is adopted. Therefore, the following discussion does not differentiate according to conceptual models as described above.

Proposed Applications

Since none of the case studies presented in the model documentation indicates whether PORFLO is capable of simulating flow and transport behavior at the hydrologically complex BWIP site, it is recommended that test runs be made to attempt to match available data on site. However, it will not be possible to "history match" repository performance conditions, which have not yet taken place. Therefore, the safest course to ensure reasonable and valid results is to set up modeling scenarios that depart to the minimum possible extent from existing or previously observed conditions.

For example, it is known that "repository performance" will include significant thermal loading conditions that have not previously been observed at the BWIP site. If possible, the simulation of this "anticipated" thermal effect should be superimposed on "previously observed" hydrologic conditions. If instead, an attempt is made to simultaneously model "anticipated" thermal loading and a previously unobserved hydrologic regime, the simulation could exceed the capability of the model, and it would be difficult to judge whether the results are reasonable, given so many unknowns in the input dataset. This recommendation follows conventional modeler's wisdom to "vary only one parameter at a time"; in the case of the possible application of PORFLO at the BWIP site, the value of this practice is emphasized, given the many yet-undiscovered site characteristics, and the open question of applicability of this particular model.

Model Scale Selection

The first consideration in selecting a model scale is that it is compatible with the required detail of the site geometry, available data, and also with the required level of detail of results. In order to achieve a stable solution, it is best to limit the variation in grid size to one or at most two orders of magnitude in either of the two dimensions in a cartesian system. For a standard application of an axisymmetric system, where the activity "driving" the model is located at or near the axis of symmetry, more than an order of magnitude of radial grid dimension can be tolerated, because the large, outer grid cells are relatively inactive.

Beyond these considerations, adverse effects of the EPM assumption can best be minimized by selecting a model scale large enough to encompass a representative number and size of the ubiquitous fractures present in the basalt flows, yet small enough to allow individual model grid cells to be used to simulate the effects of major structural discontinuities. Without a more detailed definition of the location of a proposed model application, it is not known whether the model scale can be sized to avoid intersecting a major structural discontinuity. These structural discontinuities may be relatively small in cross-section, so that a model grid may have to be sized substantially smaller than surrounding grids to provide a geometrically similar configuration to the real system. If this presents a stability problem for grid sizing, the size of the grid can be increased so that its size is compatible with the rest of the model, and the numerical values describing its transport properties can be adjusted downward to compensate for the larger size (i.e. the "EPM" concept is applied to the discontinuity, just as it is to the rest of the material in the modeled area.)

Mass, Heat, and Radionuclide Transport

The PORFLO model may be used most safely in predicting mass flows; the relationship between hydraulic conductivity and both thermal conductivity and dispersion of radionuclides suggests that contaminant transport, in particular should be coupled to the maximum fracture hydraulic conductivity, rather than to the EPM "average" conductivity. The relationship between hydraulic and thermal conductivity is even more tenuous; analyses of BWIP data by some investigators has indicated that the thermal conductivity may be relatively independent of the hydraulic conductivity; thermal effects may actually "drive" the hydraulics.

5.0 RECOMMENDATIONS

The underlying concern in reviewing the PORFLO model document is the lack of stress testing data from the BWIP site with which this model, or any model, can be evaluated. At this stage in the site characterization and performance assessment, models are being compared to other models, rather than existing site data. Although we recognize that model to model comparison can provide verification of the model's ability to solve physics and chemistry problems, it does not demonstrate that the model can simulate real conditions at the BWIP site. We also recognize the lead time required in developing relatively complex models, but would caution against proceeding so far ahead of the actual data collection process, that one loses sight of the constant feedback required between modeling efforts and data needs. Data which has been collected to date will permit analytical analyses to test various conceptual models, but a full-scale stress test is required to provide a sufficient database for model verfication. Comparing models to models will not provide the necessary confidence to assess repository performance.

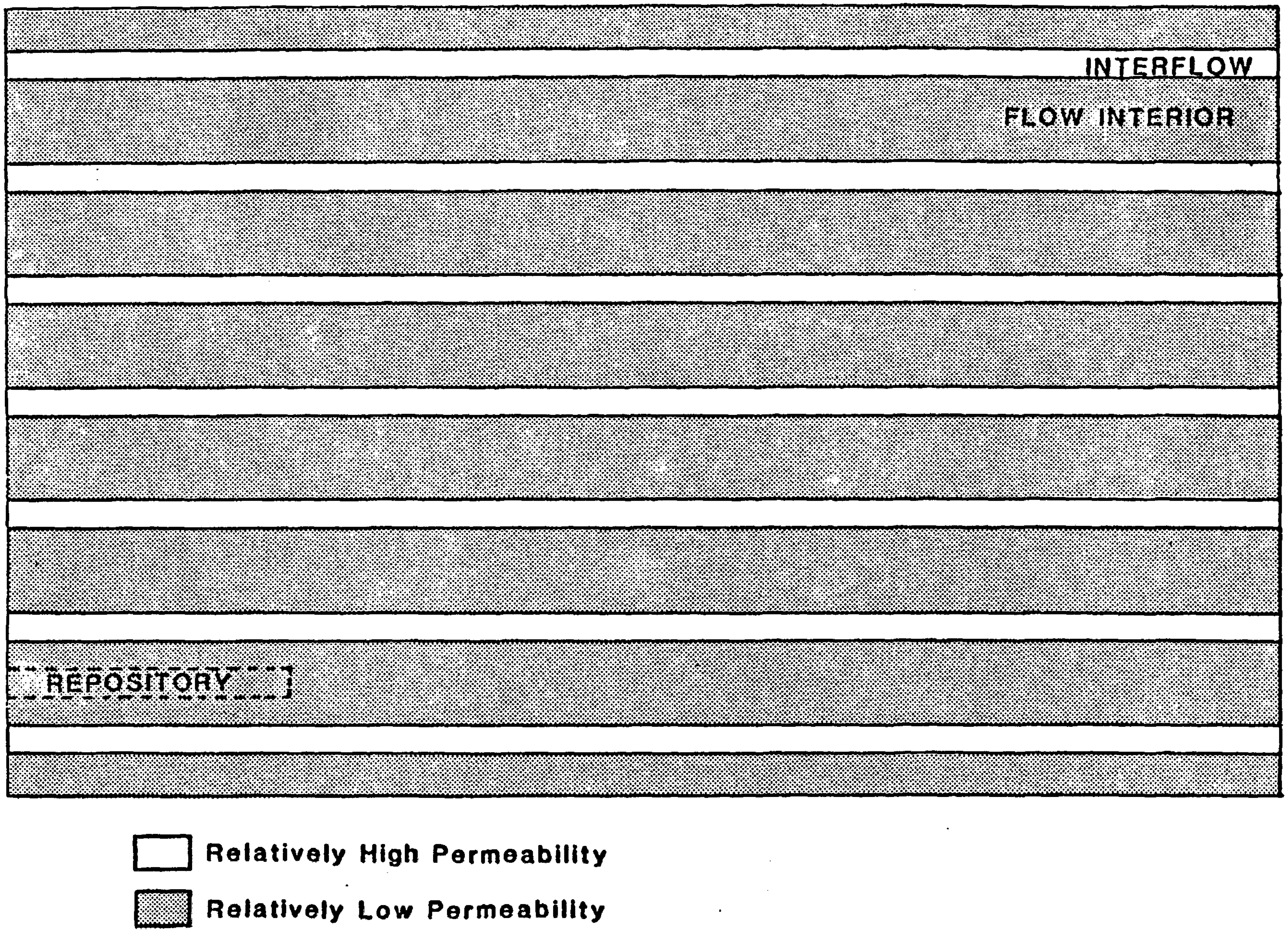
Several detailed recommendations concerning the use of PORFLO, given its limitations within the context of probable conceptual models, are listed:

1. Since none of the case studies presented in the model documentation indicates whether PORFLO is capable of simulating flow and transport behavior at the BWIP site, it is recommended that test runs be made to attempt to match available data on site. The PORFLO model may also be set

up in the expectation that LHS test data may be available in the near future.

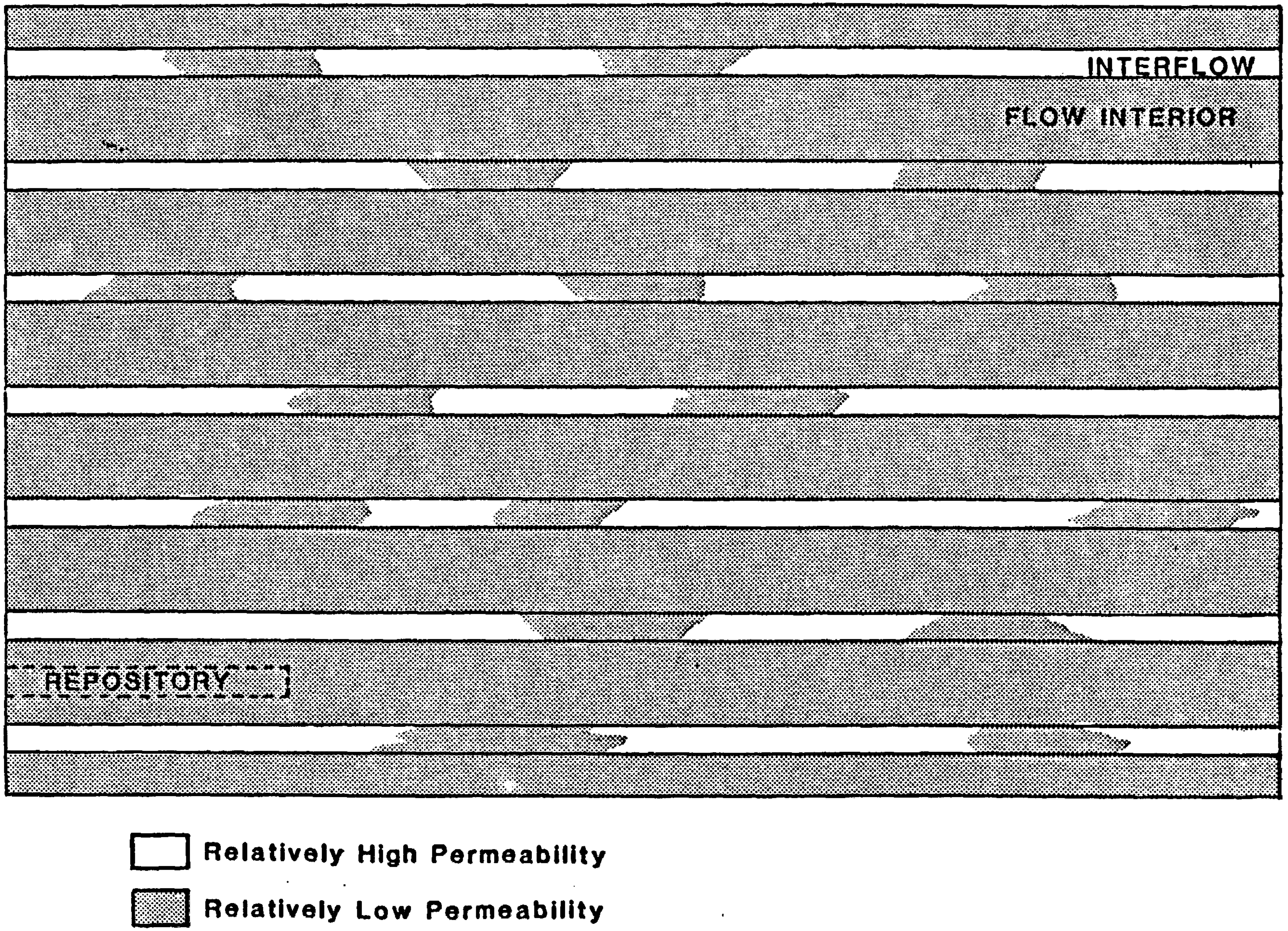
2. Adverse effects of the EPM assumption can best be minimized by selecting a model scale large enough to encompass a representative number and size of the ubiquitous fractures present in the basalt flows, yet small enough to allow individual model grid cells to be used to simulate the effects of heterogeneity and the presence of major structural discontinuities.

3. The key to using the PORFLO model effectively is to apply the model cautiously and conservatively; i.e.: (1) apply the model only in those regions where the geometric or EPM limitations are not grossly exceeded, using a geometry that aligns as closely as possible with the dominant features of the site in terms of hydrology, heat and contaminant transport; (2) to compensate for the lack of a stochastic algorithm, conduct sensitivity runs, using reasonable ranges of all major parameter values, rather than just one estimated or average value; (3) make appropriate parameter adjustments, where appropriate, to compensate for the EPM simplification (e.g. recognize that the EPM hydraulic conductivity may accurately predict mass flux, but not actual flow velocity; the contaminant transport diffusion coefficients should be coupled to the fracture, rather than to the EPM hydraulic conductivity.); (4) interpret model results conservatively, examining the assumptions and limitations of each run to ensure that possible "worst-case" conditions have not been neglected.



INTERFLOWS AND FLOW INTERIORS HOMOGENEOUS

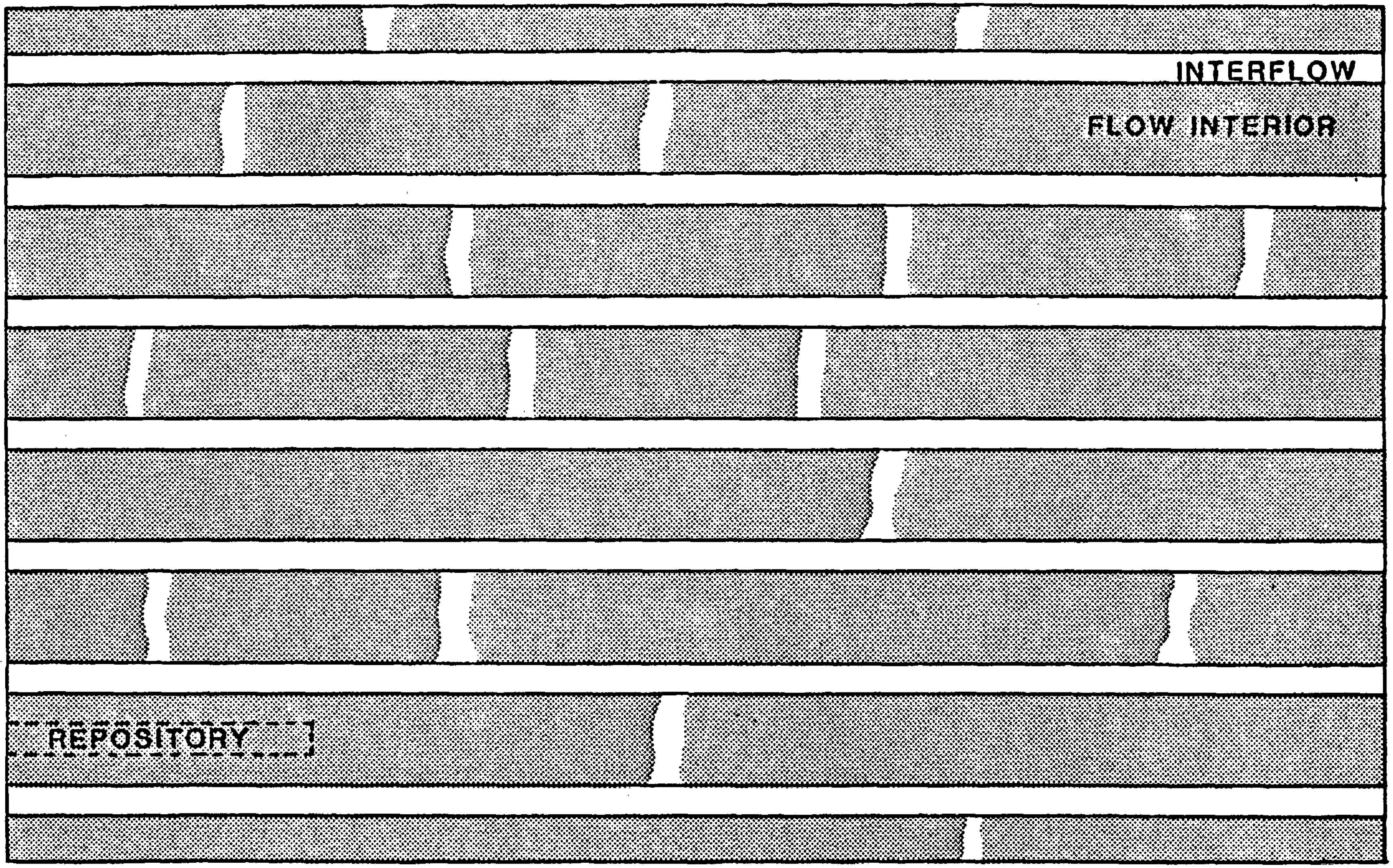
Figure 1



INTERFLOWS HETEROGENEOUS;
FLOW INTERIORS HOMOGENEOUS

Figure 2

INTERFLOWS HOMOGENEOUS;
FLOW INTERIORS HETEROGENEOUS



Relatively High Permeability

Relatively Low Permeability

Figure 3

INTERFLOWS AND FLOW INTERIORS
HETEROGENEOUS

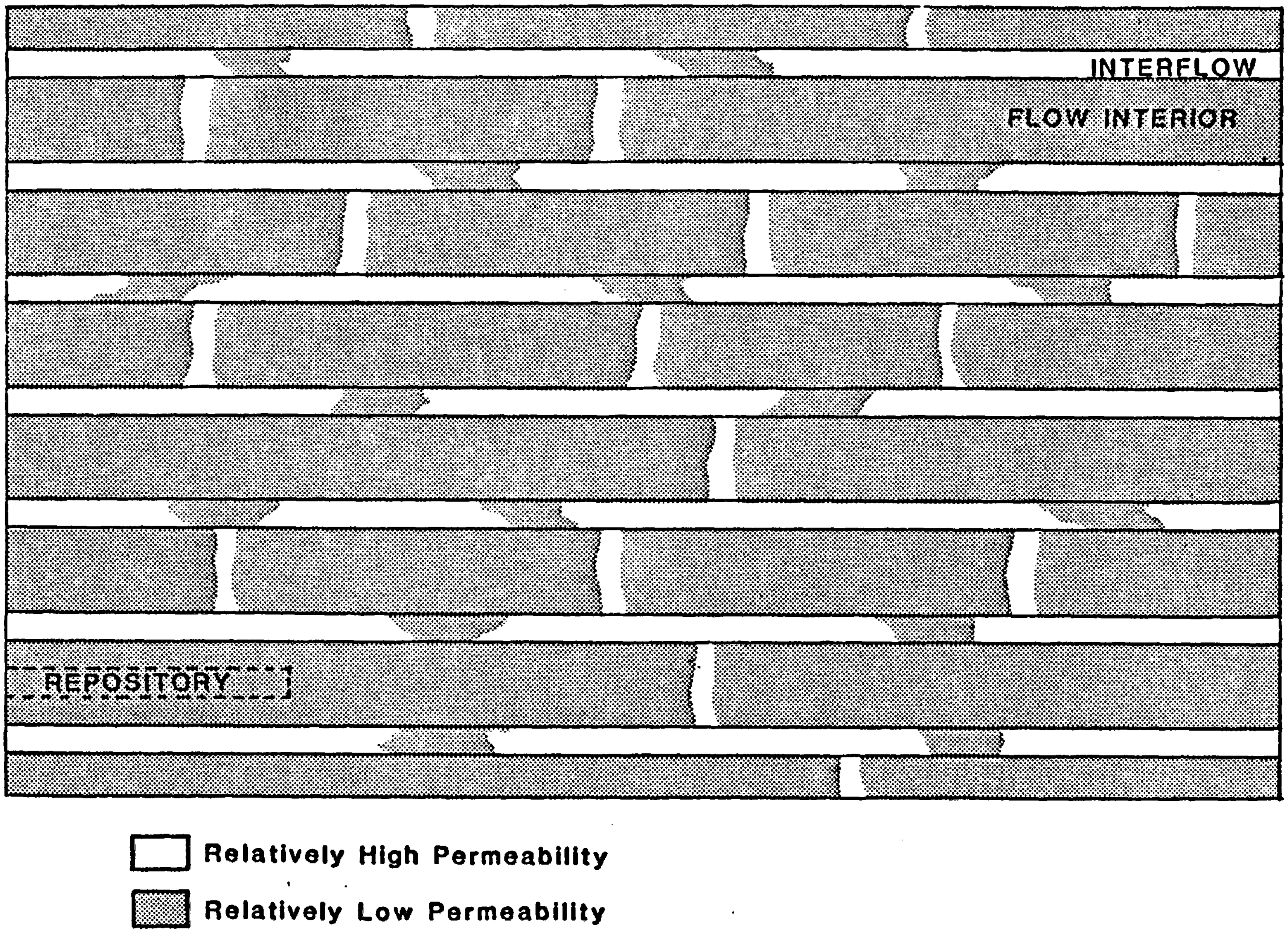


Figure 4

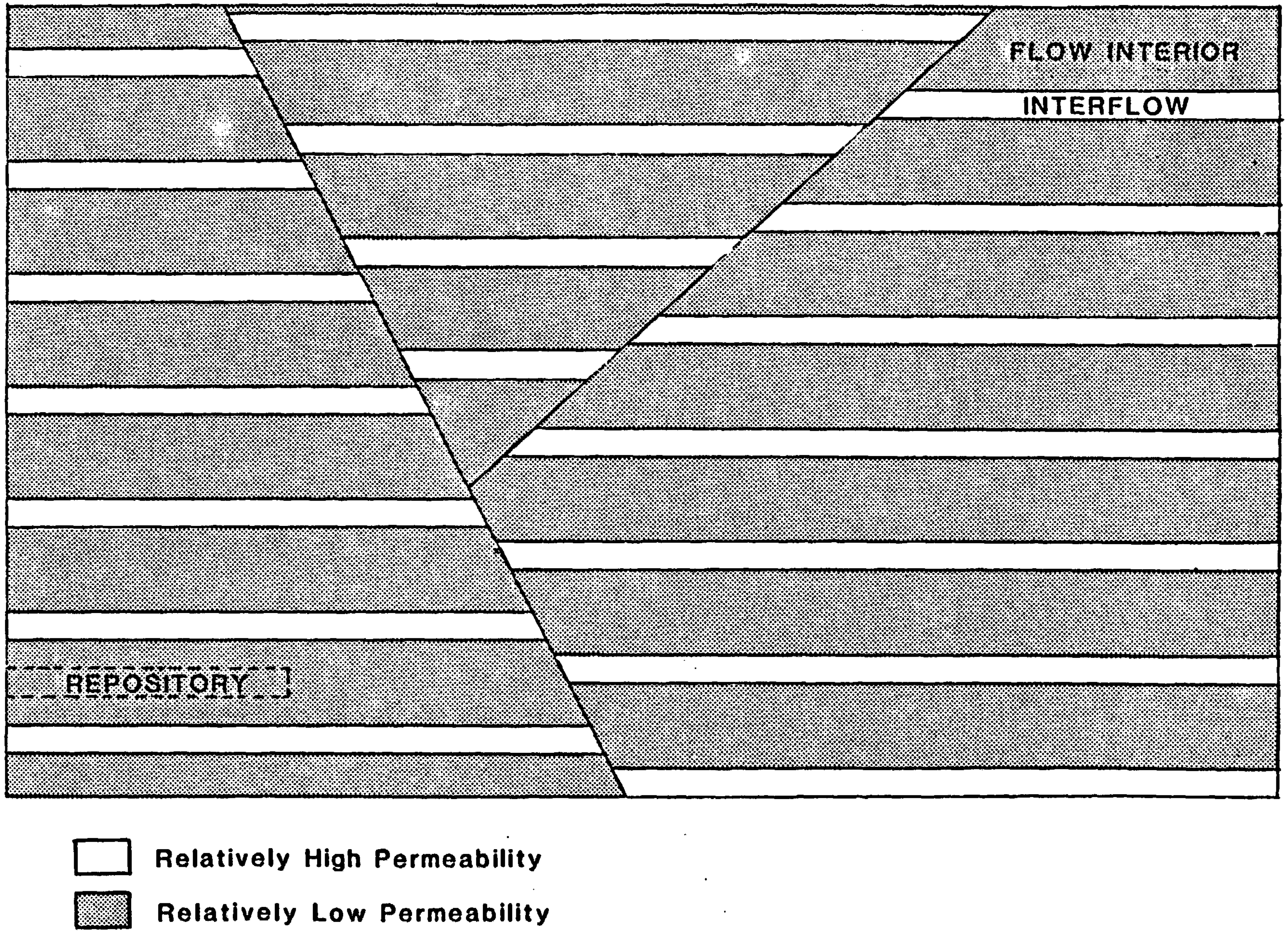
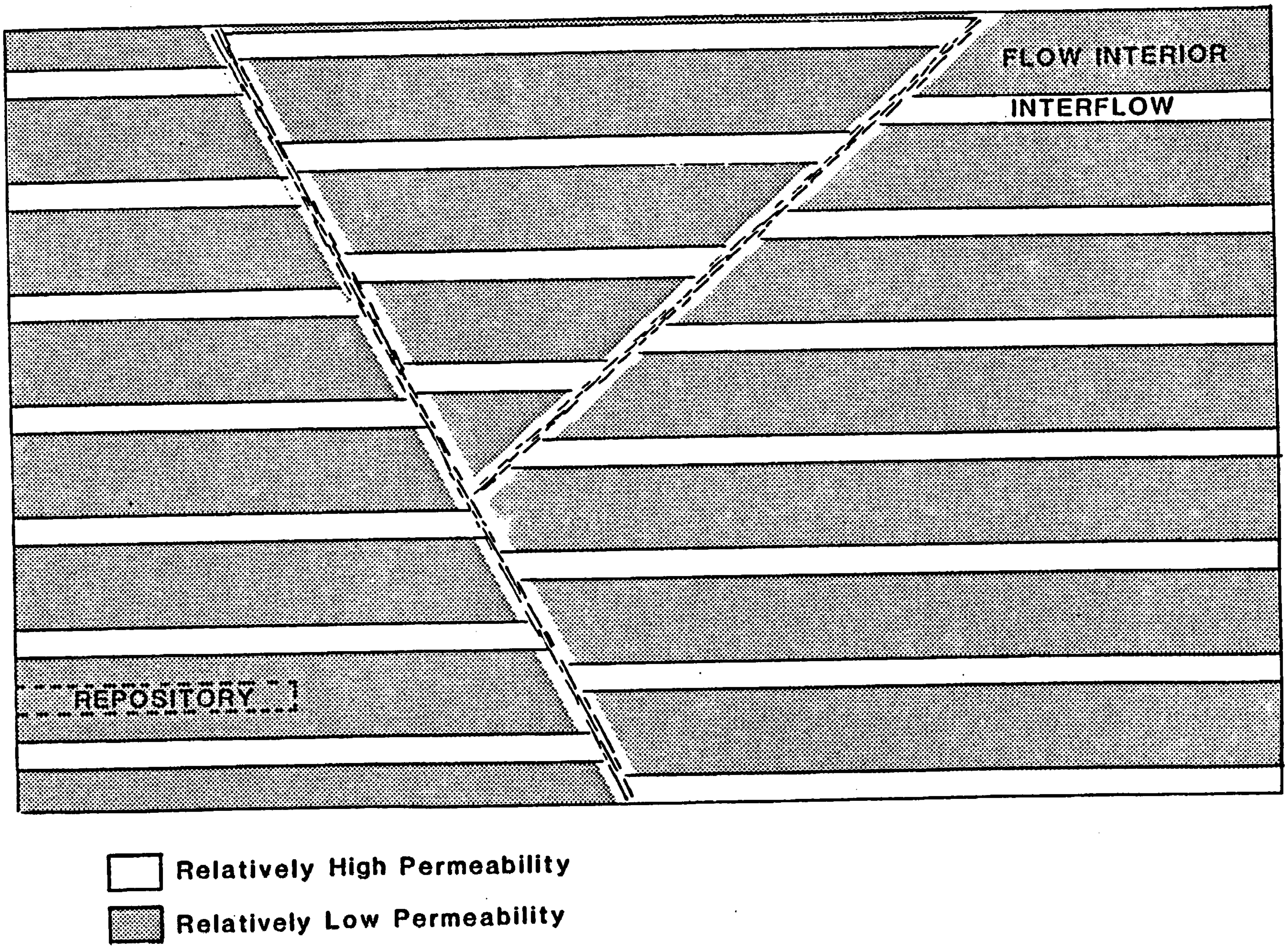


Figure 5
LOW PERMEABILITY TECTONIC STRUCTURES



HIGH PERMEABILITY TECTONIC STRUCTURES

Figure 6