MOCK SITE CHARACTERIZATION REVIEW OF BASALT
The Hanford Site

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MOCK SITE CHARACTERIZATION REVIEW OF BASALT

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INTRODUCTION

Undertaking a mock site characterization review in basalt serves several purposes. First, it prepares the NRC staff for the actual site characterization report by familiarizing them with limitations in existing available data. Second, it allows time for the hydrologists to set up models and perform various sensitivity analyses on these models (parameter value ranges, effects of boundary conditions, effects of important geologic features) in order to get an idea of the system's response to the various imposed stresses. Third, it allows the NRC staff to gain insight into some key issues which have been identified in 10CFR60. Flow modeling can independently assess pre-waste emplacement groundwater travel time requirements (60.112(c)), hydrologic effects of construction (60.123(b)(12)), effects of large scale surface water impoundments (60.123(a)(2)) and some effects of human activities, such as hydrologic changes due to pumping (60.123(a)(31)). Flow modeling also provides the groundwater velocities to be used in modeling the transport of radionuclides through the system. This transport modeling will eventually be used to help determine other key issues such as whether the site meets the E.P.A. standard (60.111(b)(1)).

The development of a realistic model is a complicated task involving many iterations. Many ideas are incorporated into the models and as ideas change so the models must evolve to reflect these changes. The main body of this report therefore, outlines some of the thinking which has gone into the development of the model of the Hanford Reservation. The report discusses the major steps taken to develop the horizontal and vertical

layering schemes, hydrostratigraphic units, determination of boundary conditions, and incorporation of anticlines and other structures which may effect the flow field. The report also discusses preliminary model results.

CONCEPTUAL MODEL FOR FLOW

The first step in the modeling of the Hanford site was the conceptualization of the hydrologic system. All data used during this phase of modeling was obtained from Rockwell Hanford Operations (RHO) publications released by the Department of Energy. Data used to determine the stratigraphy and hydrostratigraphic units were obtained from individual well logs, trend-surface maps and previous modeling studies done by the Rockwell Hanford Operations (RHO) staff.

A three-dimensional model was chosen for preliminary modeling. The alternative, a two-dimensional model following the groundwater flow path, or streamline, was not selected because this flowpath is not yet known. This is due to the current lack of understanding of the deep basalt aquifers and controversy over flow patterns and discharge areas of these aquifers. Three-dimensional modeling was chosen to determine gross flow patterns and to learn about the system through varying boundary conditions and formation parameters. When confidence has been gained in the three-dimensional version, then a streamline can be selected for the finer scale two-dimensional flow and transport model.

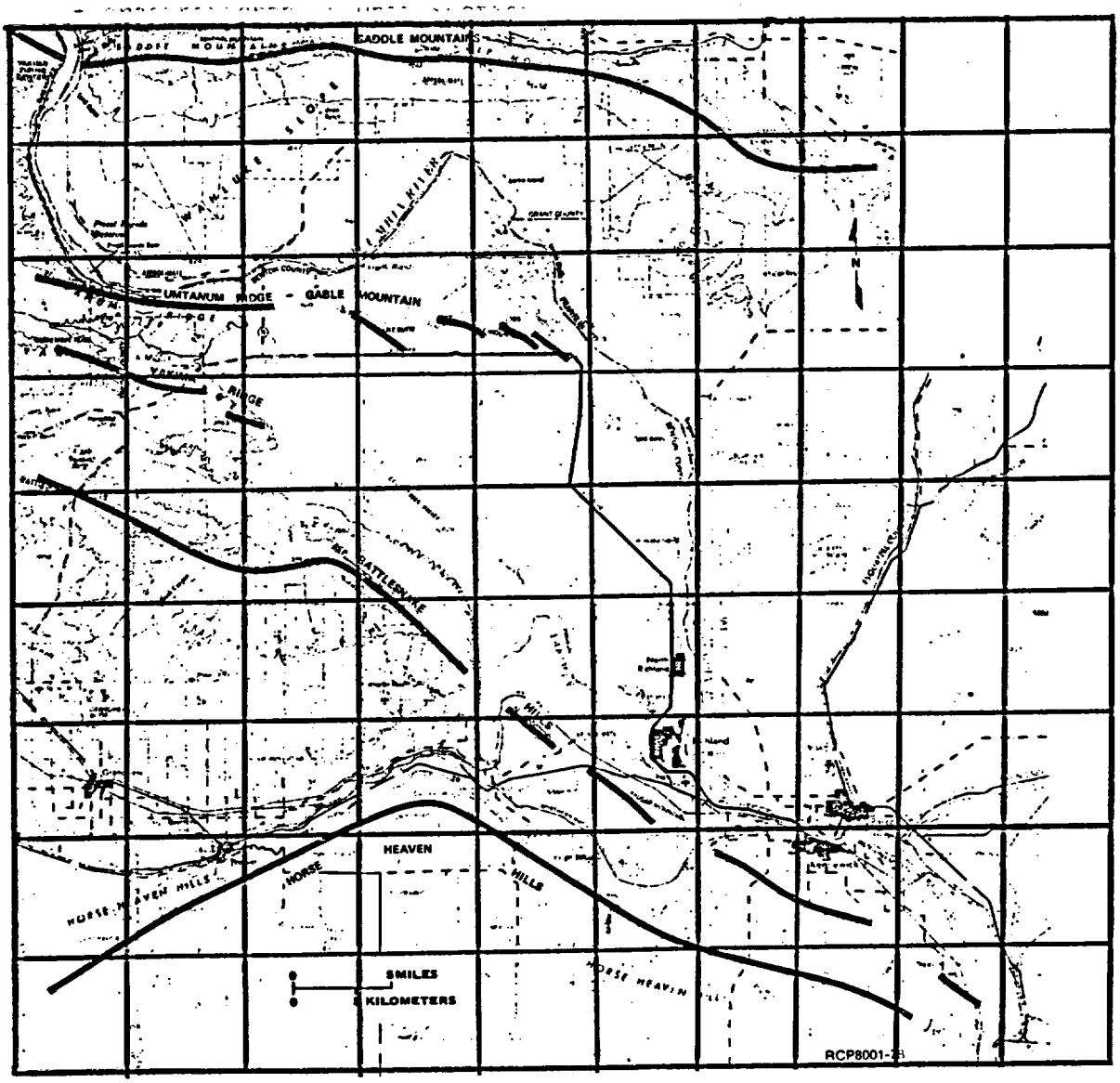
Hydrostratigraphic Unit Section

The plan view grid chosen was the Township and Range lines already present in most of RHO's reports. These grid blocks are 6 mi. x 6 mi. in length (Figure 1.)

For the vertical gridding, it was decided that hydrologically there were probably three distinct types of units: 1) interflows or flow breccias, where large quantities of water are transmitted predominantly horizontally, primarily through porous flow, with some fracture flow occuring through fractures and large cavities, 2) interbeds, which can be moderately to slightly transmissive with porous flow characteristics and movement predominantly horizontal. 3) dense poorly transmissive basalts which are usually quite fractured and jointed with flow predominantly vertical through the fractures and joints. These three types of units are present in each of the three major stratigraphic formations: the Saddle Mountains, the Wanapum and the Grande Ronde basalt sequences. These sequences are shown as Figure 2. On top of these thick sequences is the unconfined or water table aquifer, present only in the lower elevations of the Pasco Basin. This aquifer is comprised of more recent sediments which have accumulated as a result of flooding, ponding and erosion of the basalt surfaces. It is not present where the basalts outcrop in the higher elevations surrounding the basin.

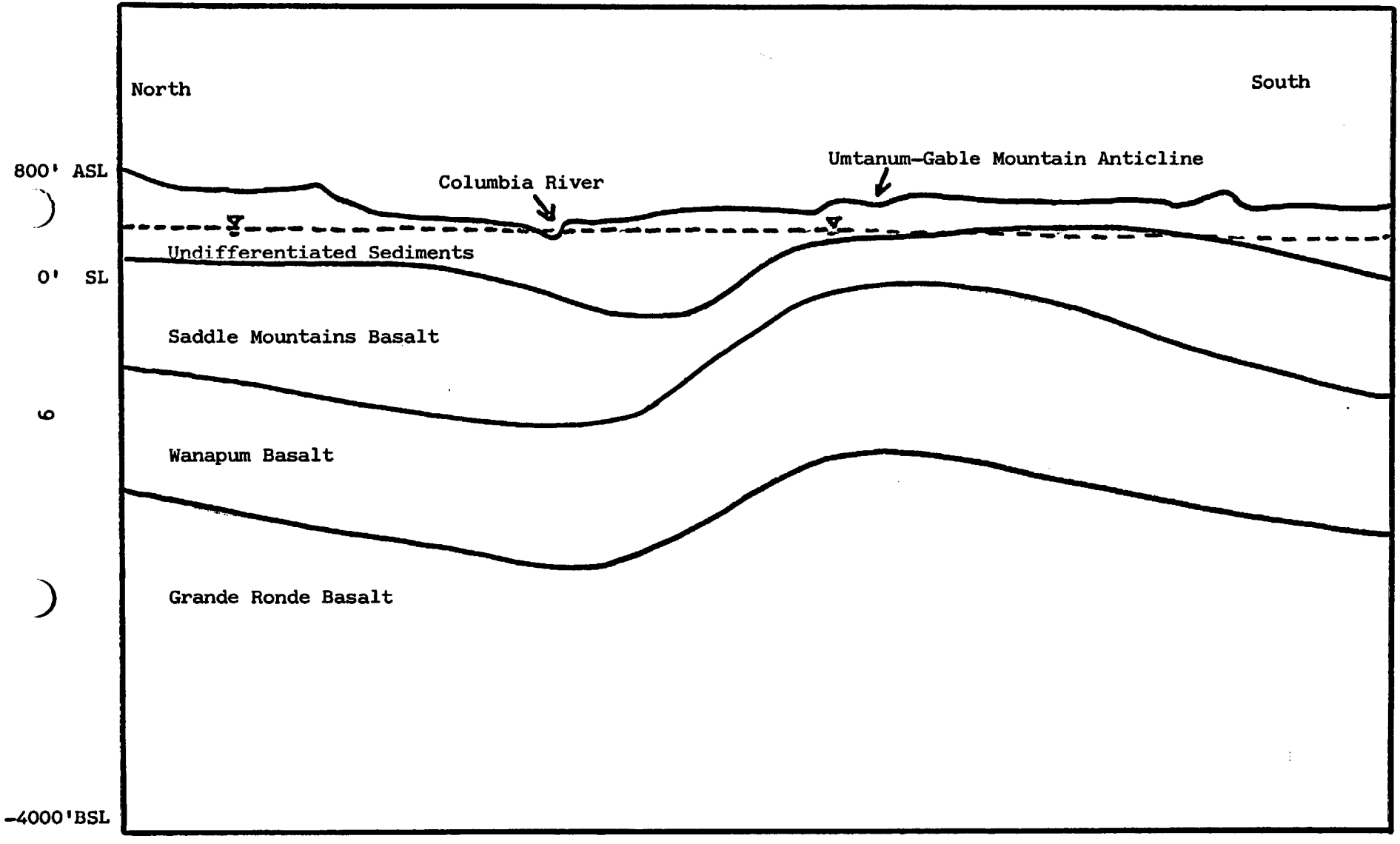
Initial estimates of the thickness of the various units were made by reviewing available well logs. In these wells the thickness of each known interbed was listed and then averaged over all wells. The same process was used for interflows/flow breccias for the Saddle Mountains,

FIGURE 1: PLAN VIEW GRIDDING



After RHO-BWI-ST-4

FIGURE 2: MAJOR STRATIGRAPHIC SEQUENCE



* Adapted from RHO-BWI-ST-5

Horizontal Scale
1" ≈ 2 miles

Wanapum and was tried in the Grande Ronde, but so little data existed for the Grande Ronde that RHO's figures had to be used on faith. The formula for thickness determination was as follows:

Thickness of Interbeds + Thickness of Interflows + Thickness of Dense Basalt = Total thickness of Unit.

Based on these calculations, the values shown in Figure 3 were used in the model layering. This layering model became known as the Zero Order model. Note that because of computer limitations, each layer in the Zero Order model is a combination of many smaller natural units. The model assumes that the beds are of the same thickness and have the same properties across the entire basin. This is not likely, but at this point it is a necessary simplification.

The hydraulic properties assigned to the various layers were chosen from the overlap of the reported RHO values and the values contained in Sandia's Basalt Reference Repository report (Nimick and Guzowski). The values chosen represent the middle of the range of values. Later, sensitivity runs will include conductivity and porosity measures from the entire reported range. Table 1 lists the values chosen.

Hydrostratigraphic Unit Review

The Zero Order system was useful for initial model development since the principal concern during this portion of the work was exercising the computer code. However, several levels of review were required to achieve optimum layer definition. Initially some consideration was given to averaging hydraulically different layers to conserve computer space.

FIGURE 3

ZERO ORDER MODEL LAYERING

Layer 1	Alluvial water table aquifer	200 ft.
Layer 2	Interbeds Saddle Mountains Fm.	72 ft.
Layer 3	Dense Basalt Saddle Mountains Fm.	488 ft.
Layer 4	Interflow Saddle Mountains Fm.	240 ft.
Layer 5	Interbeds Wanapum Fm.	308 ft.
Layer 6	Dense Basalt Wanapum Fm.	605 ft.
Layer 7	Interflows Wanapum Fm.	187 ft.
Layer 8	Interbeds Grande Ronde Fm.	180 ft.
Layer 9	Dense Basalt Grande Ronde Fm.	592 ft.
Layer 10	Dense Basalt Grande Ronde Fm.	592 ft.
Layer 11	Dense Basalt Grande Ronde Fm.	593 ft.
Layer 12	Dense Basalt Grande Ronde Fm.	593 ft.
Layer 13	Interflows Grande Ronde Fm.	450 ft.

TABLE 1

HYDRAULIC PROPERTIES USED IN PRELIMINARY MODELS

Rock Unit	K_x	K_y	K_z	Ø
Alluvial Aquifer	10^3	10^3	10^{-1}	.25
Dense Basalt	10^{-6}	10^{-6}	10^{-5}	.05
Interflows	10^{-3}	10^{-3}	10^{-3}	.25
Interbeds	10^1	10^1	10^{-3}	.20

* All conductivity in feet/day

K = hydraulic conductivity
Ø = porosity

Staff from the NRC, Sandia Laboratories and Sandia's hydrology consultant, CGS, Inc. discussed this issue and decided in the interest of future transport modeling, not to average over dissimilar hydrostratigraphic units. When modeling transport, combination of the layers would blur identification of potentially important units and would require averaging of the retardation factors. An example problem which was considered representative of the Hanford site was done by the group to determine the effect of averaging on interstitial velocities. The horizontal velocities could be underestimated by a factor of twenty (20) and vertical velocities coule be underestimated by several orders of magnitude if the simplified layers were used. A comparison between CGS's layering ideas and the NRC's proved to be similar with the exception of some averaging which was done by CGS in the upper units. CGS preferred more detail around the repository area, since they intended to use a 2-D model immediately rather than beginning with three dimensions. The first order model shown in figure 4 resulted from the discussions.

Once the modellers had decided on the appropriate level of averaging, some geologists from the Siting Group were consulted to determine the most useful vertical layering. Concurrently the stacking of the layers was varied to determine the significance of the layering choice. A flow chart (Figure 5) shows how the relation of the various tasks. The members of the Siting Group and the Performance Assessment Group compared available geologic and hydrologic information with the present model geometry (First Order model). The members also checked the original calculations done to determine the thickness of the layers. The original calculations for thickness were correct although there were some questions about the amount of each material (interbeds, interflows, dense basalts) present in the separate formations.

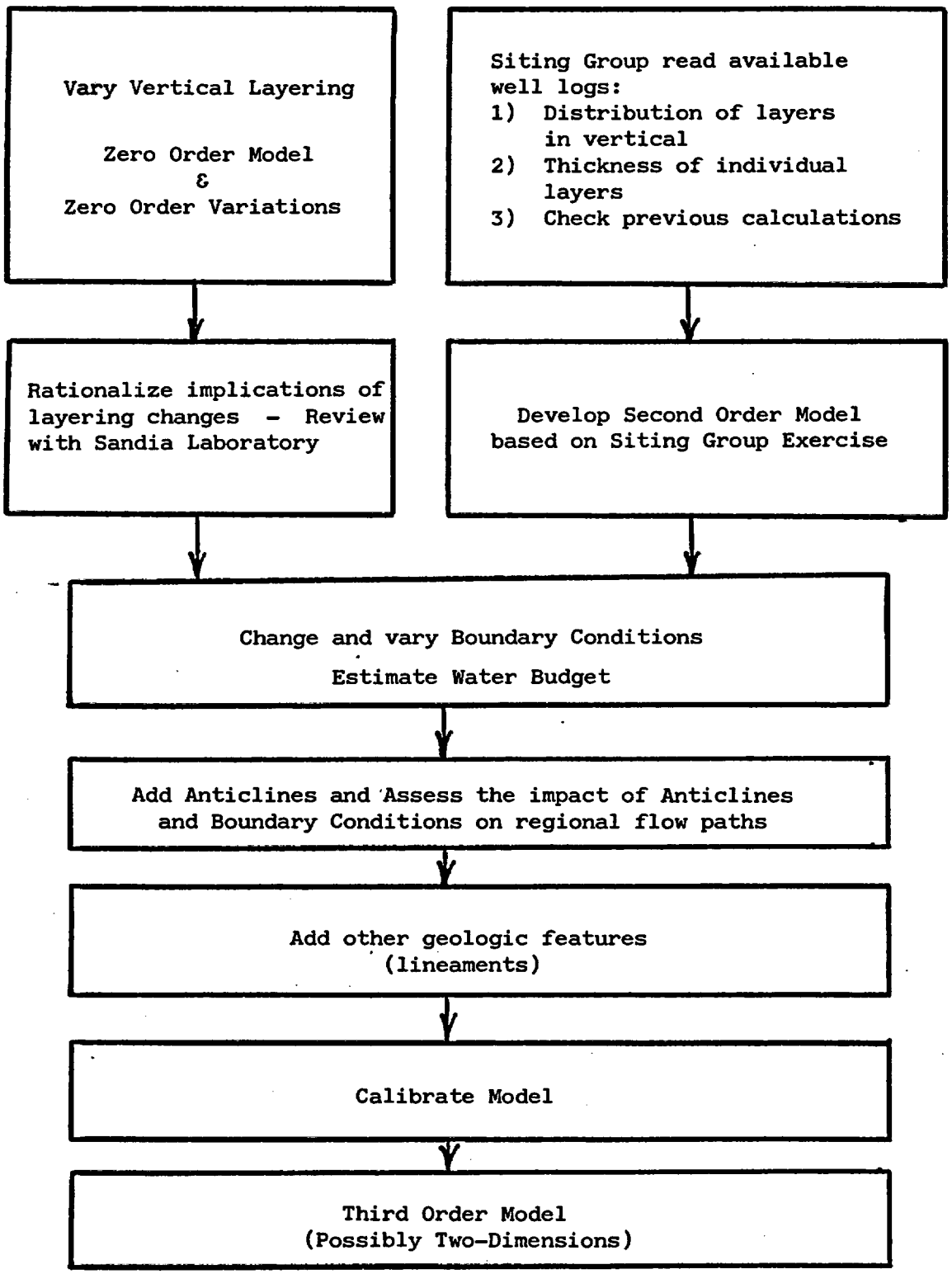
FIGURE 4

FIRST ORDER MODEL LAYERING

Layer 1	Alluvial Water Table Aquifer		200 ft.
Layer 2	Interbeds	Saddle Mountains Fm.	72 ft.
Layer 3	Dense Basalt	Saddle Mountains Fm.	488 ft.
Layer 4	Interflows	Saddle Mountains Fm.	240 ft.
Layer 5	Interbeds	Wanapum Fm.	308 ft.
Layer 6	Dense Basalt	Wanapum Fm.	605 ft.
Layer 7	Interflows	Wanapum Fm.	187 ft.
Layer 8	Dense Basalt	Sentinel Bluffs Unit (G.R.)	1050 ft.
Layer 9	Interbeds	Sentinel Bluffs Unit	150 ft.
Layer 10	Interflows	Sentinel Bluffs Unit	90 ft.
Layer 11	Dense Basalt	Umtanum Unit Grande Ronde	200 ft.
Layer 12	Interflows	Grande Ronde Fm.	90 ft.
Layer 13	Dense Basalt	Grande Ronde	1200 ft.

FIGURE 5

FLOW CHART



Stratigraphic columns for three drill holes (DC-4, DC-6, DC-8) were constructed and percentages listed in Table 2 were determined. Values for the Saddle Mountain layers correspond well to those quoted by RHO and those used in the calculations for the Zero Order model. Differences in the lower units were substantially larger. The larger percentage of dense basalt reflects in part a natural trend toward thicker units in the lower section. However, the large difference is also caused by the interpretation of the drilling logs. When flow breccias were recognized, they were listed explicitly in the log; the rest of the material was identified as some type of dense basalt (i.e., vesicular, slightly fractured, dense basalt). Inability to determine the limits of dense basalt and flow breccias resulted in an overestimate of the dense basalt units.

Several trends were evident from the columns: (1) a decrease in the number of sedimentary interbeds with depth; (2) an increase in the percentage of brecciated basalt; and (3) a nearly constant percentage of dense basalt in the deeper units. These general trends and the calculated percentages were used to form the Second Order model (Figure 6). In this version, a dense basalt was inserted between the water table aquifer and the first interbed. This relationship was seen in the columns and prevented an overestimate of the connection between the water table and lower units. Detail around the Umtanum Unit has been removed since it is not consistent with the general regional nature of the model. The Umtanum Unit is now contained within a larger dense layer and the depth is considered consistent with well logs. When a 2-D version is selected, the detail can easily be reinserted into the layering and will be consistent with the general stratigraphy.

TABLE 2

QUANTITY OF VARIOUS ROCK TYPES

SADDLE MOUNTAINS

Rock Type	DC-4		DC-6		DC-8		Average
Interbed	370'	41%	124'	17%	227'	26%	28%
Flow Top	46'	5%	112'	15.5%	39'	4%	8.2%
Dense Basalt	484'	54%	-	67.4%	601'	69%	63.5%

Rock Type	Lasala & Doty Estimates	RHO Estimates
Interbeds	42%	30%
Flow Top	4%	9%
Dense Basalt	54%	61%

WANAPUM BASALTS

Rock Type	DC-4		DC-6		DC-8		Average
Interbed	13'	1%	.3'	.27%	5'	.5%	.59%
Flow Top	86'	7%	201'	18.57%	124.9'	11%	12.17%
Dense Basalt	1061'	91%	878'	81%	1023.4'	89%	87%

Rock Type	Lasala & Doty Estimates	RHO Estimates
Interbed	28%	28%
Flow Top	11%	17%
Dense Basalt	61%	55%

GRANDE RONDE

Rock Type	DC-4		DC-6		DC-8		Average
Interbed	0'	0%	0'	0%	0'	0%	0%
Flow Top	149'	11%	309'	14%	226.4'	16%	13.7%
Dense Basalt	1173'	89%	1871'	86%	1150.9'	84%	86.3%

TABLE 2 CONTINUED

Rock Type	Lasala & Doty Estimates	RHO Estimates
Interbed	6%	6%
Flow Top	32%	15%
Dense Basalt	62%	79%

FIGURE 6

SECOND ORDER MODEL LAYERING

Layer 1	Alluvial Water Table Aquifer	300 ft.
Layer 2	Dense Basalt Saddle Mountains Fm.	122 ft.
Layer 3	Interbeds Saddle Mountains Fm.	96 ft.
Layer 4	Dense Basalt Saddle Mountains Fm.	366 ft.
Layer 5	Interflows Saddle Mountains Fm.	72 ft.
Layer 6	Interbeds Saddle Mountains/Wanapum	144 ft.
Layer 7	Dense Basalt Wanapum Fm.	462 ft.
Layer 8	Interflows Wanapum Fm. ,	330 ft.
Layer 9	Dense Basalt Wanapum Fm.	308 ft.
Layer 10	Interflows Grande Ronde Fm.	350 ft.
Layer 11	Dense Basalt (Umtanum included)	1150 ft.
Layer 12	Interflows Grande Ronde Fm.	350 ft.
Layer 13	Dense Basalt Grande Ronde Fm.	950 ft.

Determining the percentages of the different units in the various formations was more difficult because of the range of values. The percentages for the Saddle Mountains layers were not changed from the First Order model. In the Wanapum and Grande Ronde, the dense basalt values were averaged. The interflow and interbeds were averaged separately and then combined since the geologic logs did not show many interbeds in the lower units. This averaging should provide a realistic estimate since the conductivity of the interflows is higher than the interbeds. All the percentages of units calculated fell within the general range quoted for the Hanford basalts - 25% to 75% dense basalt, 10% to 30% flow top breccias.

Determination of Boundary Conditions

The choice of boundary conditions for the initial runs was quite arbitrary. The elevation of the water table is known where the alluvial aquifer is present, i.e., in the lower elevations of the basin, but the potentiometric surface of the confined system present under the outcropping basalt was not known. Therefore, as a first approximation, the elevations used by Intera, for their modeling exercise under contract to Los Alamos Technical Associates was used. This estimate is roughly 200 ft below the land surface. This pressure boundary was probably very high in some parts of the basin.

The range of the boundary conditions was varied over the levels thought to be the maximum and minimum expected conditions. Therefore, the original choice of boundary conditions was considered a maximum, and a minimum of 500 ft above sea level (ASL) was chosen based on the elevations of the water table at the margins of the outcrops.

The following comprise the major types of boundary conditions used in the analyses.

BC-Original = Pressure boundaries on the margins of the basin are set to represent a potentiometric surface elevation 200 ft. below the land surface.

BC-1 = Pressure boundaries on the margins of the basin are all set to approximately 500 ft. ASL.

BC-2 = Pressure boundaries on the margins of the basin are all set to approximately 700 ft. ASL.

BC-3 = The pressure boundaries on the western side of the basin are set to 500 ft. ASL and the pressure boundaries on the eastern and northern sides of the basin are set to 700 ft. ASL.

BC-4 = Pressure boundaries on the western side of the basin are set to 700 ft. ASL and on the eastern and northern sides are set to 500 ft. ASL.

Of the five separate conditions, BC-4 was the most realistic set used based on our general knowledge about the structure and hydrology of the basin. NRC is actively working with RHO to obtain accurate estimates of these pressures. Changing the boundary conditions does significantly affect the flow patterns and discharge areas; more accurate data is needed since the model is very sensitive to these pressures.

Vertical Layering Problem

The effects of varying the layering were assessed by comparing variations of the Zero Order model, the First Order model and the Second Order models. The layering changes in the Zero Order model were chosen to reflect the effect of placing exteme values of hydraulic conductivity next to each other in the sequence. The result was three variations of the Zero Order model, Zero-A, Zero-B, and Zero-C, shown as Figures 7-9. These combinations were all run with original boundary conditions which will be discussed below, and results compared. Results of these runs with the Zero Order and runs with the First and Second Order models indicated very little difference in the gross flow field patterns due to layering changes.

Anticlines and Other Geohydrologic Features - Effect on Flow Field

During the analyses previously discussed, the grid remained flat; no structures inside the basin were simulated. Data on the site showed that several of the structures in the basin had strong effects on groundwater flow. Possibly the most important feature is the basin in the Gable Mountain - Gable Butte anticline. This is part of a series of anticlines and synclines which are thought to control flow in the basin.

The anticline structure was added to the 2nd order model and run with the various boundary conditions. This required complete regridding of the three dimensions simulation. In order to obtain more detail in the Gable Mountain areas, nodes had to be removed along the sides and southern boundary in order not to exceed the storage capacity of the computer. An additional grid block was added in the y direction and four other blocks

FIGURE 7

ZERO-A ORDER MODEL LAYERING

Layer 1	Alluvial Water Table Aquifer	200 ft.
Layer 2	Dense Basalt Saddle Mountains Fm.	488 ft.
Layer 3	Interflows Saddle Mountains Fm.	240 ft.
Layer 4	Interbeds Saddle Mountains Fm.	72 ft.
Layer 5	Dense Basalt Wanapum Fm.	605 ft.
Layer 6	Interflows Wamapum Fm.	187 ft.
Layer 7	Interbeds Wanapum Fm.	308 ft.
Layer 8	Dense Basalt Grande Ronde Fm.	592 ft.
Layer 9	Dense Basalt Grande Ronde Fm.	592 ft.
Layer 10	Dense Basalt Grande Ronde Fm.	593 ft.
Layer 11	Dense Basalt Grande Ronde Fm.	593 ft.
Layer 12	Interflows Grande Ronde Fm.	450 ft.
Layer 13	Interbeds Grande Ronde Fm.	180 ft.

FIGURE 8

ZERO-B ORDER MODEL LAYERING

Layer 1	Alluvial Water Table Aquifer		200 ft.
Layer 2	Interbeds	Saddle Mountains Fm.	72 ft.
Layer 3	Interflows	Saddle Mountains Fm.	240 ft.
Layer 4	Dense Basalt	Saddle Mountains Fm.	488 ft.
Layer 5	Dense Basalt	Wanapum Fm.	605 ft.
Layer 6	Interflows	Wanapum Fm.	187 ft.
Layer 7	Interbeds	Wanapum Fm.	308 ft.
Layer 8	Interbeds	Grande Ronde Fm.	180 ft.
Layer 9	Interflows	Grande Ronde Fm.	450 ft.
Layer 10	Dense Basalt	Grande Ronde Fm.	592 ft.
Layer 11	Dense Basalt	Grande Ronde Fm.	592 ft.
Layer 12	Dense Basalt	Grande Ronde Fm.	593 ft.
Layer 13	Dense Basalt	Grande Ronde Fm.	593 ft.

FIGURE 9

ZERO-C ORDER MODEL LAYERING

Layer 1	Alluvial Water Table Aquifer		200 ft.
Layer 2	Dense Basalt	Saddle Mountains Fm.	488 ft.
Layer 3	Interbeds	Saddle Mountains Fm.	72 ft.
Layer 4	Interflows	Saddle Mountains Fm.	240 ft.
Layer 5	Interflows	Wanapum Fm.	187 ft.
Layer 6	Interbeds	Wanapum Fm.	308 ft.
Layer 7	Dense Basalt	Wanapum Fm.	605 ft.
Layer 8	Dense Basalt	Grande Ronde Fm.	592 ft.
Layer 9	Dense Basalt	Grande Ronde Fm.	592 ft.
Layer 10	Dense Basalt	Grande Ronde Fm.	593 ft.
Layer 11	Dense Basalt	Grande Ronde Fm.	593 ft.
Layer 12	Interbeds	Grande Ronde Fm.	180 ft.
Layer 13	Interflows	Grande Ronde Fm.	450 ft.

were scaled down in size to simulate the anticline. A total of 6 blocks were used to simulate the structure in the y direction. These smaller grid blocks range in size from the original 6 miles to 2 miles.

Figure 10 shows the original grid and figure 11 shows the system including the anticline. Initial estimates of the height of the anticline came from depths pulled from various cross sections and from selected points on the trend-surface maps. Values used were composites of the most comparable locations from the various sources. These values were used to determine the highest elevations along the anticlinal ridge. The thickness of each layer was maintained in the anticline because inadequate data exists for the systematic thinning of the units in the anticline.

Based on the numbers obtained above, the anticline was simulated by raising each separate unit up by the number of feet appropriate to gain the elevation needed. This raising was done all the way down the stratigraphic column in an equal amount, for each grid blockin the x direction. Since the anticline is steeper on its northern flank, the model uses only two steps up in order to simulate this distance, and 3 steps down on the southern slope to give a more gentle southern limb. Figure 12 shows the cross section of gridding through the anticline. The anticline is also plunging towards the east so the top grid block elevations are gradually lowered to reflect this plunge. The plunging stops before the anticline reaches the Columbia River to the east.

Hydraulic conductivity of layers in the anticline has not been changed although some investigators feel that stresses along the anticline have induced fracturing causing increased vertical hydraulic conductivity.

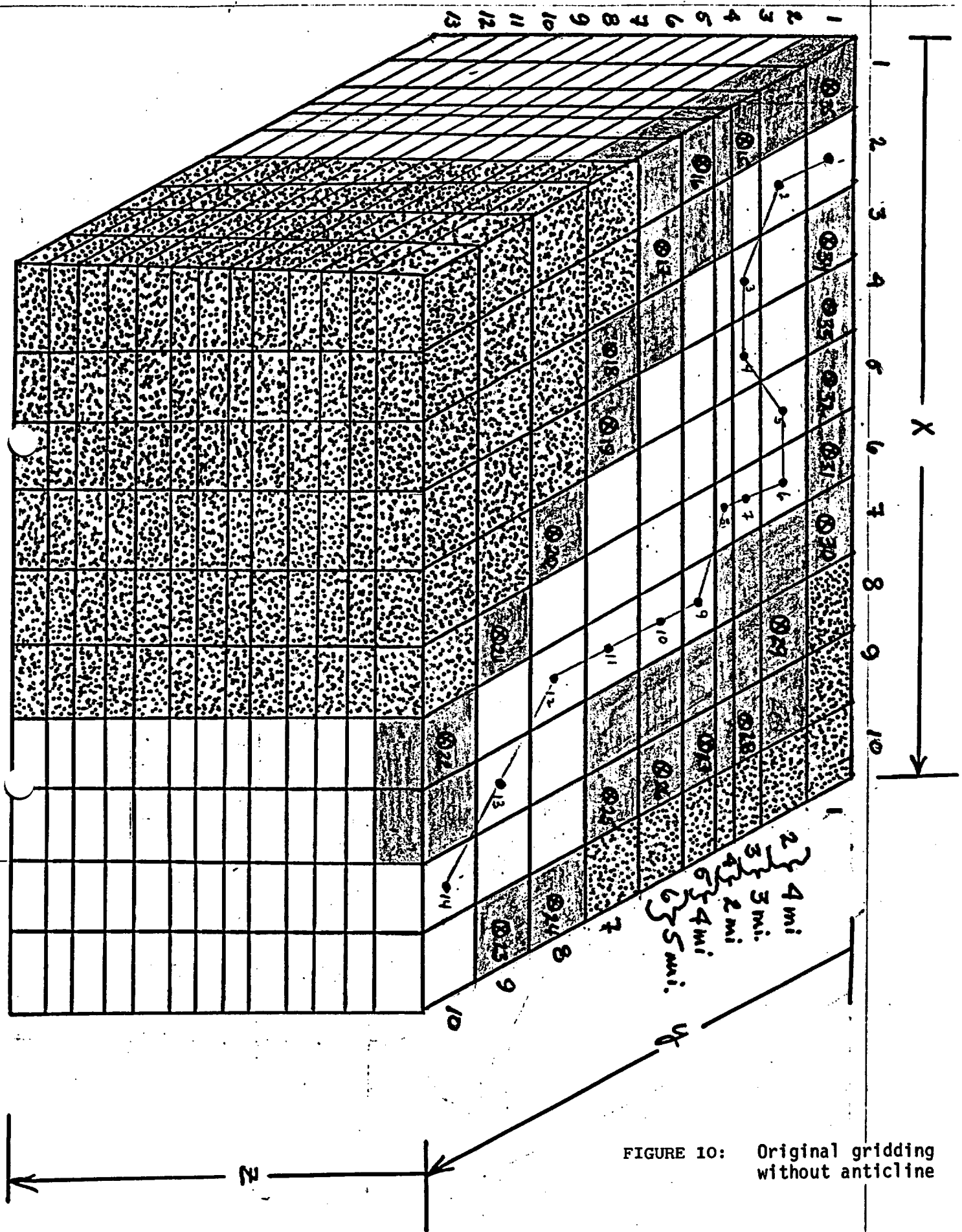


FIGURE 10: Original gridding without anticline

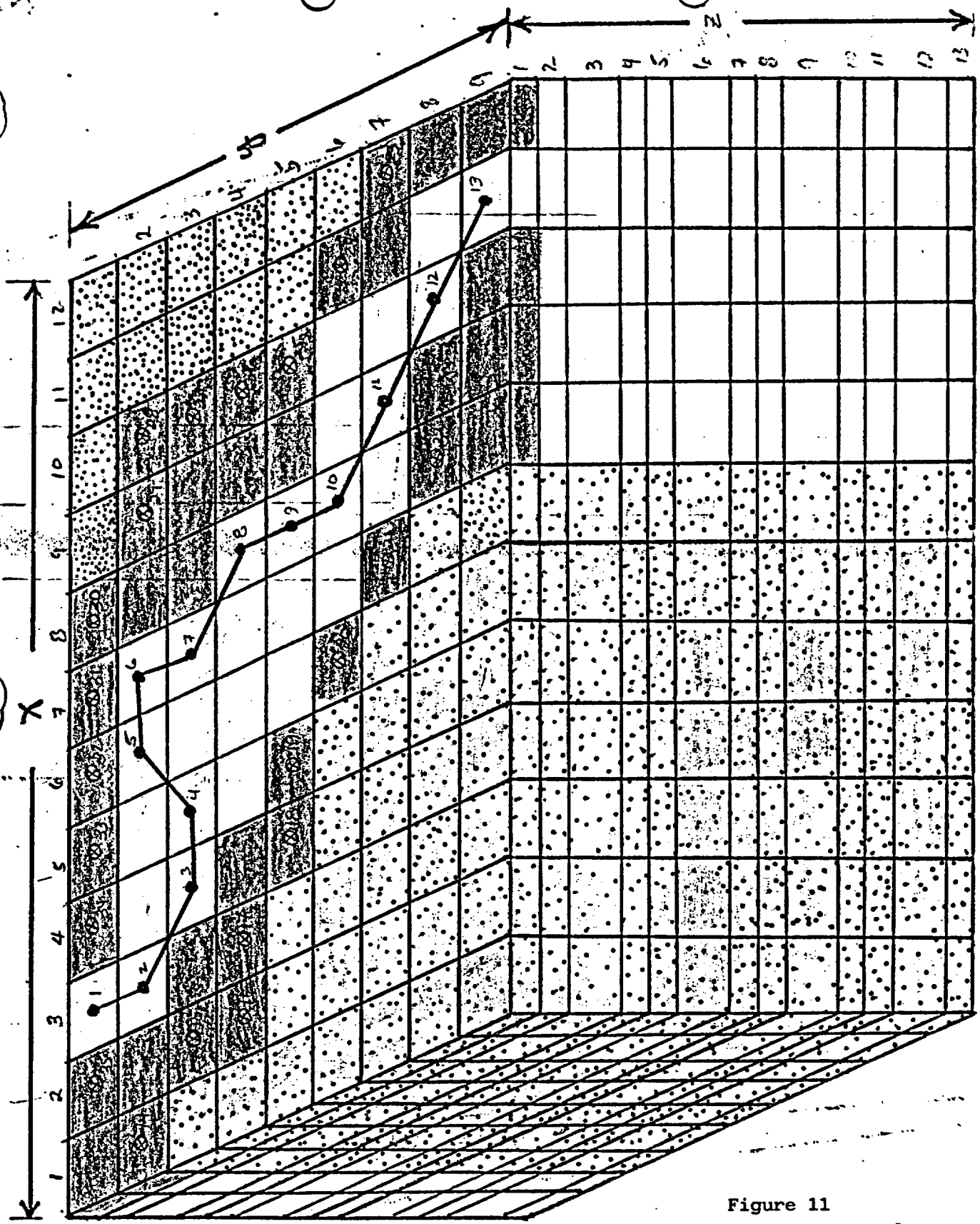
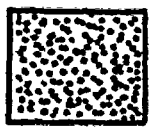


Figure 11
Second Order Model
with Anticline Added

LEGEND FOR FIGURES 10 AND 11

Grid blocks which have been blocked out (zero transmissivity) in the first layer only. They are used whenever basalt is outcropping and the alluvial water table aquifer is missing.



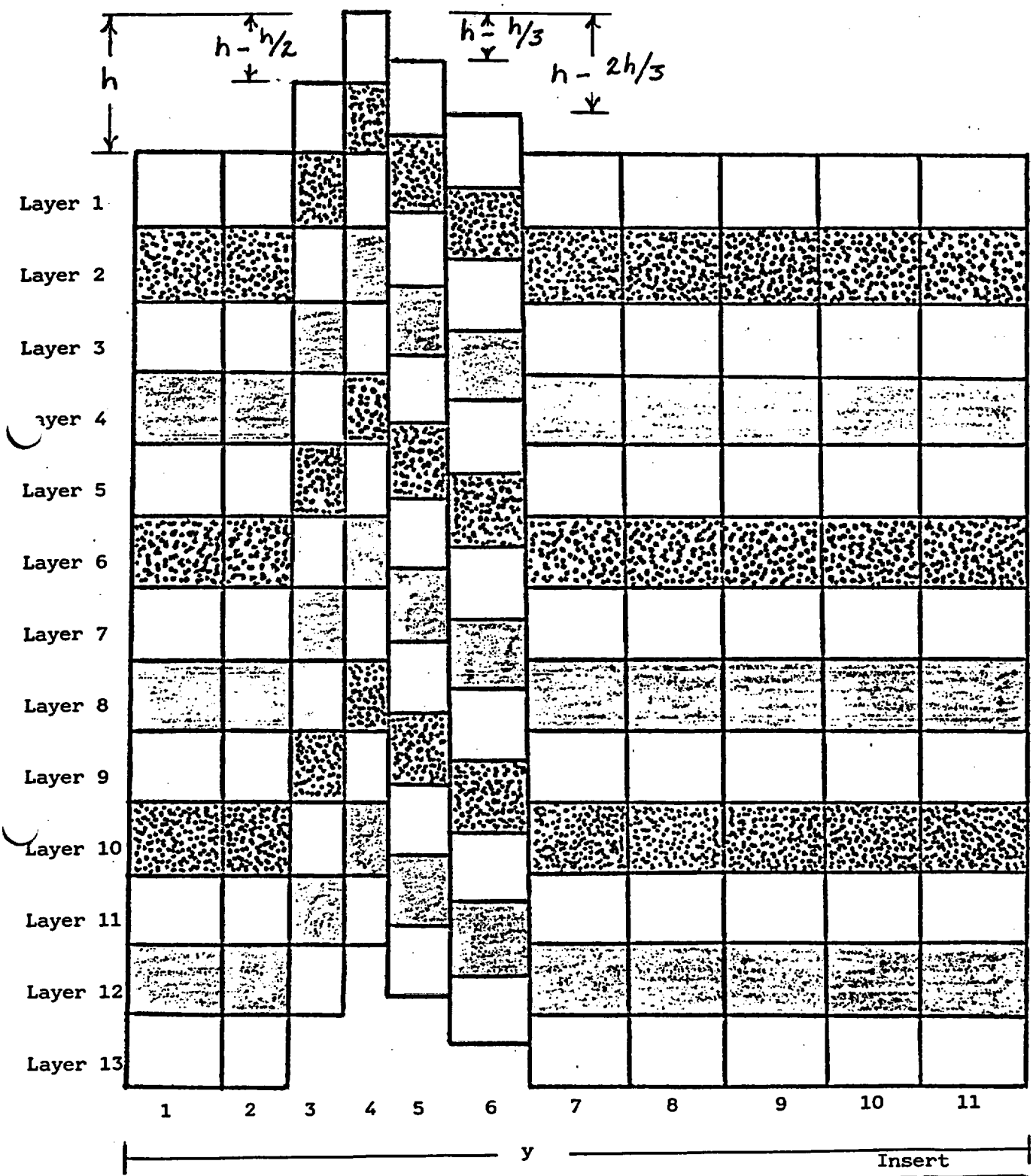
Grid blocks which have been blocked out (zero transmissivity). These blocks are out in the entire sequence (z direction). These blocks represent areas outside the Pasco Basin and are not used in the model.

Wells used to simulate the Columbia River

Wells used to simulate recharge

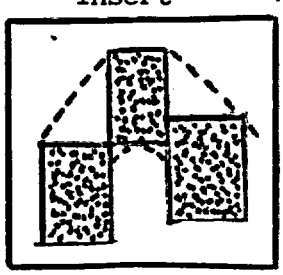
*Unless otherwise noted, grid blocks are 6 miles x 6 miles in the X and Y directions.

FIGURE 12 ANTICLINE CROSS-SECTION SCHEMATIC



Note- The mathematics in the model sees the staggered layers as continuous. See insert.

Insert



Effects of increased conductivity should be assessed in later modeling studies.

Preliminary runs using this grid indicate that the presence of these anticlines does have an effect on the overall flow system since the water appears to be diverted around the structure. This structure should be included in future modeling and its detail may need to be refined.

Other features such as the Olympic-Wallowa Lineament may exert considerable influence on the hydrology of the Pasco Basin. For example, in the western part of the basin, this lineament is thought to be a significant hydraulic barrier. Effects of this lineament will have to be assessed in future modeling efforts.

CONCLUSIONS

The Mock Site Modeling effort has proved useful in familiarizing the staff with the available data, flow system, and issues regarding the Hanford Site.

The main items which can be concluded from the preliminary modeling exercise are:

1) The vertical layering sequence does not have much impact in evaluating the regional flow on the deep aquifer system. The layering will become more important when radionuclide transport is modeled.

2) Choice of boundary conditions does have an important effect in model application and more precise data must be gathered in this area. (Water budget, interbasin flow)

3) Anticlines are important features which must be considered in future model work.

4) Other features such as the Olympic-Wallowa Lineament should be examined in future modeling work.

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