3101.2/MG/84/06/28/0

JUL 10 1984

DISTRIBUTION
WM sf 3101.2
WMGT rf
NMSS rf
RBrowning
MBell
JBunting
MKnapp
MGordon & rf
JPohle
PDR + LPDR
NColeman

MEMORANDUM TO: Malcolm Knapp, Branch Chief
Geotechnical Branch
Division of Waste Management

Robert Wright, BWIP Project Leader
Repository Projects Branch
Division of Waste Management

FROM: Matthew Gordon
Hydrology Section
Geotechnical Branch
Division of Waste Management

SUBJECT: IMPACT OF NEAT CEMENT ZONES ON BASELINE HEAD DISTRIBUTION IN BOREHOLES WITH NESTED PIEZOMETERS

Background:

At the recent NRC/BWIP hydrology workshop (Gaithersburg, Md., June 12-13, 1984), Ron Jackson (RHO) described the design of the nested piezometers recently installed in boreholes DC-19C, -20C, and -22C (see Figure 1 for hole locations). The piezometers are designed to collect downhole pressure data for the zones indicated in Figure 2. The nested piezometers will be used to determine the baseline head distribution around the RRL prior to testing, and to monitor responses to the large scale pump tests currently planned for early next year. Both the baseline monitoring program and the large-scale tests are being carried out by BWIP in response to comments made by NRC (BWIP STP 1.1, NUREG-0960, etc.), USGS, and others. BWIP is currently in the midst of their baseline head monitoring program, which relies heavily on the nested piezometer performance. The following memo identifies a potential problem with the as-built piezometer design, and describes a preliminary numerical modeling study which I have performed to get a rough idea of the significance of the problem. The modeling study has numerous limitations and is intended only to serve as an illustration of the physical concepts involved. The purpose of this memo is to describe the issue and to propose efforts to resolve the issue.

As shown in Figure 2, intercommunication between screened pressure monitoring levels in the flow tops is inhibited by the neat cement seal zones. If these seals do not function properly, and permit significant intercommunication between monitoring zones, the observed heads will not necessarily reflect the true heads in the vicinity of the borehole. In the worst case, if there were

WM Record File 101

WM Project 10
Docket No.
PDR ✓
LPDR ✓

Distribution:

(Return to WM, 623-SS)

921

no neat cement seals (total intercommunication), the head measured at the various levels would all approach a uniform composite head (the average head of all intervals to which the hole is open). In such a case, it would be possible for a zero vertical head gradient to be observed in the hole even if a large vertical head gradient existed in the borehole vicinity. This is an important consideration in licensing since calculations of pre-emplacement groundwater travel times from the disturbed zone to the accessible environment will be very sensitive to the vertical gradient, as NRC indicated in NUREG-0960 (Appendix D).

With this concern in mind, I asked BWIP during the workshop, "What is the permeability of the neat cement?" BWIP replied that the cement has a hydraulic conductivity of 10^{-8} to 10^{-9} meters/second. For comparison, the 1982 BWIP Site Characterization Report "best estimate" of the hydraulic conductivity of the dense basalt was 10^{-10} m/sec (vertical) and 10^{-11} m/sec (horizontal), and 10^{-7} m/sec (isotropic) for the flow tops (less dense, fractured basalt). Based on this information, I became concerned that the neat cement used by BWIP may not provide a sufficient seal between flow top monitoring zones, being of at least one order of magnitude higher conductivity than the dense zones. As a follow-up effort, I have exercised the SWIFT code to perform a simple numerical modeling study of the impact of neat cement zones on the observed vertical head gradient.

Modeling Study:

After scoping out the problem with simple one-dimensional analytical methods, such as the method described on page D-20 of NUREG-0960, it became evident that the problem was inherently at least two-dimensional in nature. Changes in the vertical head gradient for given upper and lower boundary conditions in the borehole would also induce changes in horizontal head gradients between the borehole zones of differing conductivity adjacent to the borehole. For two dimensional (2-D) analysis, the finite difference code SWIFT proved convenient to use, since I have on disk at BNL an input data set used in 1983 to model the BWIP site in 2-D. (This input set was used to simulate the "1-U-1" conceptual model in "Nonisothermal Flow Modeling of the Hanford Site", Gordon and Weber, 3/83). The simplified grid for the conceptual model used is shown in Figure 3. The porosities, hydraulic conductivities, and boundary conditions for this model are the same as for the "1-U-1" model and for the BWIP PORFLO model described in the SCR (Chapter 12). The thicknesses and conductivities are shown in tabular form on Table 1. A horizontal head gradient of 10^{-3} was imposed on the upper and lower boundaries (through constant-grid block pressure "aquifer influence functions" - see Reeves and Cranwell, 1981). The relative vertical gradient observed in RRL-2 (Figure 4) was imposed on the lateral boundaries. (The repository grid blocks originally used in Gordon and Weber's 1-U-1 model were removed for this simulation and a uniform repository horizon was substituted.)

The numerical model described above (the "undisturbed" model) was used to generate a steady state "undisturbed" head distribution across the grid for the given boundary conditions and hydraulic properties. The steady-state head contour map generated by SWIFT (Figure 5) may be considered to represent the true "undisturbed" head distribution for this conceptual model. This will be compared to the case where a borehole with alternating neat cement and monitoring zones has been constructed. (This case will hereinafter be called the "neat cement" model.)

The same conceptual model, including hydraulic properties and boundary conditions, was used in the "neat cement" model as for the "undisturbed" model, except for within the segment of the grid schematically representing the borehole. The model representation of the borehole (in grid column 8) is described in Figure 6a and the accompanying Table 2. As shown, the borehole extends from the top of the model (Frenchman Springs #3 flow) to the GR-11 flow top. Below the GR-11 flow top, the undisturbed composite zone (10^{-7} m/sec horizontal hydraulic conductivity, 10^{-10} m/sec vertical hydraulic conductivity) was retained from the "undisturbed" model. The neat cement zones were assumed to have an isotropic hydraulic conductivity of 10^{-8} m/sec. All of the flow tops, the Vantage interbed, and the Cohassett vesicular zone were considered to be monitored in this model, for convenience. The monitoring zones were considered to have the same conductivities as the adjacent conductive zones (generally 10^{-7} m/sec, isotropic, except for the Cohassett vesicular zone (10^{-8} m/sec) and the Vantage interbed ($3 * 10^{-7}$ m/sec), as in the 1-U-1 model). It should be noted for future interpretation of the modeling results that the lower composite zone has the lowest vertical hydraulic conductivity (by two to three orders of magnitude) within column #8. The "borehole" in this model has a width of 400 meters. While this is clearly an absurdly high value, it was used in this model for convenience, to avoid regridding of the original 1-U-1 model, which would have taken considerable time. As such, the results may tend to exagerrate the significance of the borehole on the head distribution. (For more discussion see "Model Limitations" and "Recommendations for Future Work".)

<u>Results and Discussion:</u>

Figure 5 shows the "undisturbed" model head distribution across the grid as calculated by SWIFT. Figure 7 shows the "neat cement" model head distribution across the grid as calculated by SWIFT. Figure 8a shows a comparison of the two model results for the head distrubution across the grid; Figure 8b compares the observed head distribution in the borehole (column 8 only) for the "undisturbed" model and the "neat cement" model. As shown in Figure 8b, the observed ("neat cement" model) vertical head gradient in the borehole (grid depth 0 to about 500 meters) is very slightly higher than the actual ("undisturbed" model) head gradient down to about 200 m below the top of the grid; and is much lower than the actual head gradient from 200 m to the bottom of the borehole (about 500 m). For the 200-500 meter zone, the average vertical gradient in the borehole for the "undisturbed" case is about $3.4 * 10^{-3}$; for comparison, the average vertical gradient in the borehole for the "neat cement" case is $9.4 * 10^{-4}$. This difference between actual and observed gradient by a factor of about 3.6 would cause an error of roughly the same magnitude in calculations of pre-emplacement groundwater travel time. The actual error in the observed vertical head gradient at the nested piezometer sites may be more or less, depending on the assumed hydraulic and geometric properties, and boundary conditions. Since the single conceptual model was the only one studied, the sensitivity of the error to the assumptions used is not yet known. However, this study is useful in that it indicates that the as-built design of the piezometers might have significant limitations for baseline head estimation which I think that BWIP should consider and NRC should further investigate.

Limitations of the Model:

This was a scoping study performed in a very limited time frame for the purpose of seeing if the neat cement properties would have any potentially significant effects on the vertical head distribution. As stated earlier, the conceptual and numerical models utilized in this study were chosen more for convenience than for proper analysis of the problem. While the results described cannot be considered conclusive, they do provide some insight into system behavior and can be used to evaluate the need for further study. Having stated this, the limitations of the model include:

1) the aforementioned exaggerated "borehole" width;
2) the assumed two-dimensionality of the problem rather than the three-dimensionality;
3) The lack of sensitivity analyses on assumed hydraulic properties and boundary conditions;
4) The model described is steady-state; no calculations were made to estimate the time frame necessary to reach steady-state.

Recommendations for Future Work:

What I propose to do, pending instructions from you:

1) Distribute this memo to the rest of the hydrology section soliciting reviews or discussion. In particular I would like my fellow NRC hydrologists to address these questions:

a) Was the modeling described above conducted properly?
b) Have I neglected addressing certain limitations of the model?
c) Is further work on this topic warranted?
d) What work?

2) Distribute this memo to our BWIP T.A. contractors for review. The same four questions (1a) through d) above) would be addressed by our contractors.

3) Estimate the resources necessary and the resources available to do the following proposed additional work:

a) regrid the SWIFT model to more ideally represent the problem being studied;
b) analyze the sensitivity of the model to the assumed hydraulic properties and boundary conditions;
c) extend the model to a three-dimensional (3-D) case and perform a) and b) (above) for the 3-D case.
d) perform all of the above for the transient case to determine the time scale at which cement effects are important.

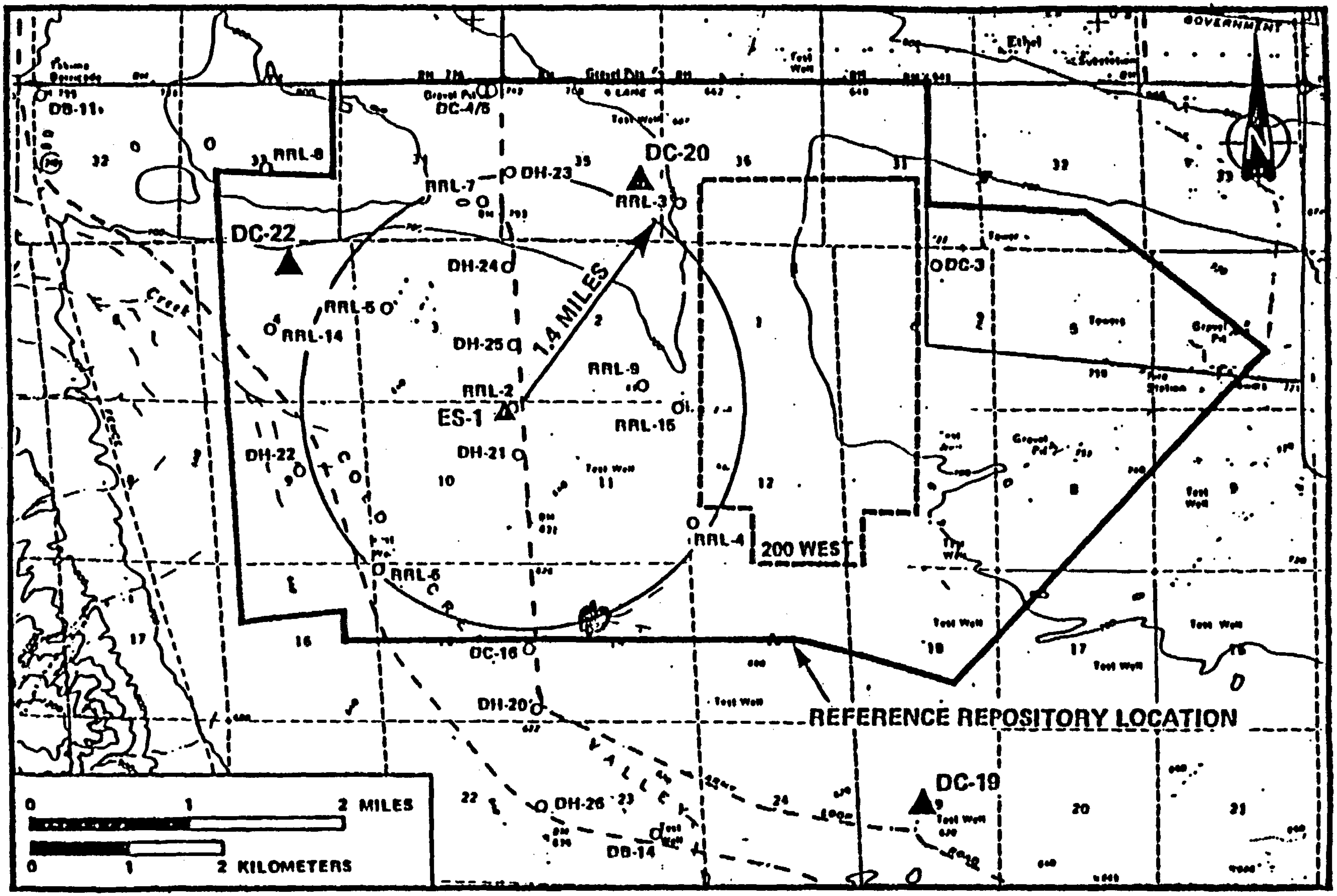
I await your direction in this matter.

/s/

Matthew Gordon
Hydrology Section
Geotechnical Branch
Division of Waste Management

[illegible] repository horizon was substituted.)

OFC	WMGT	WMGT				
NAME	MGordon	JPohle				
DATE	84/07/3	84/07/3				



SD-BWI-TC-016
REV A-0

FIGURE 1. Existing and Planned Boreholes In and Around the Reference Repository Location.

(From RHO-document SD-BWI-TC-016).

6

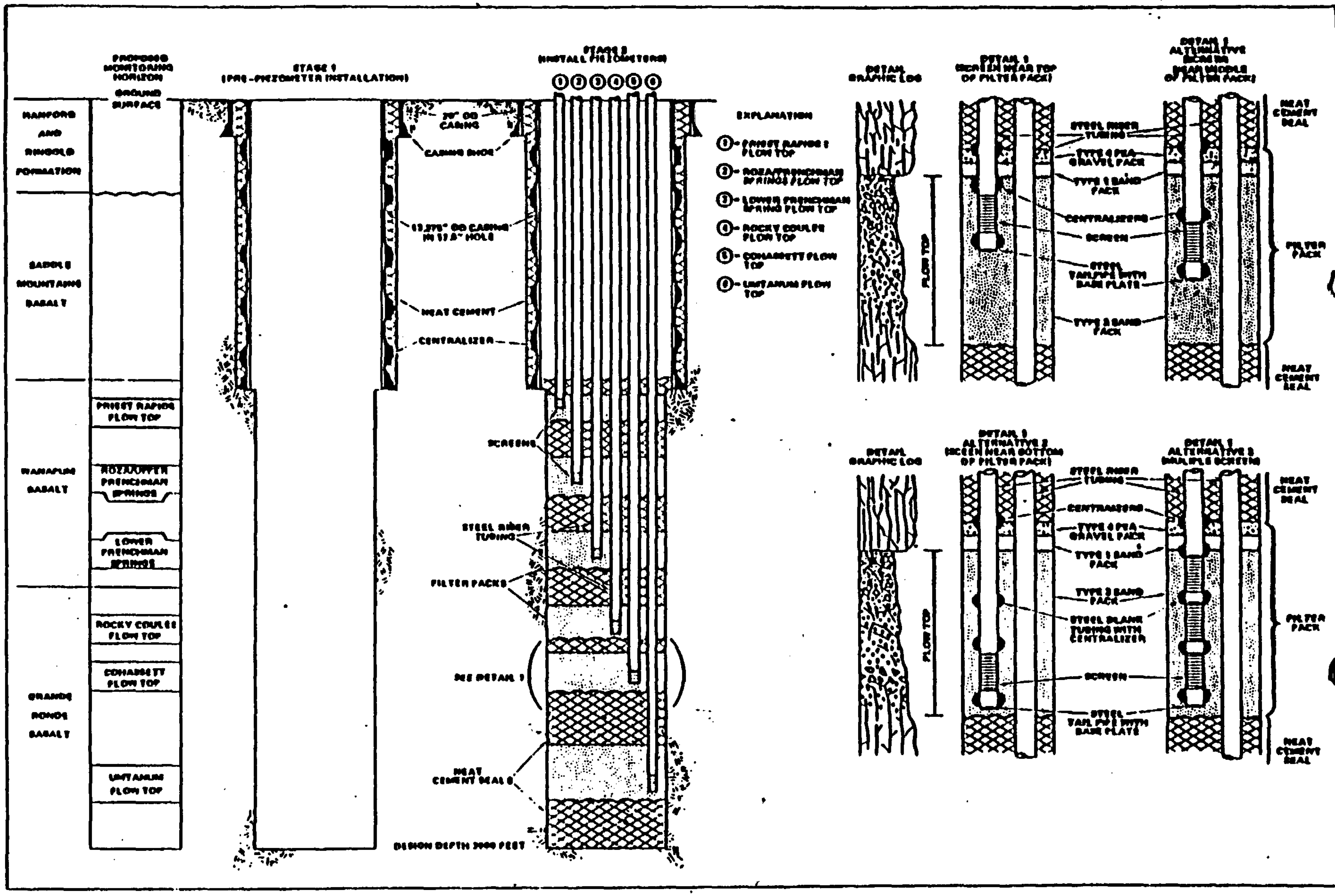


FIGURE 2. Configuration and Design Details of "C"-Series Multi-Level Piezometer Nests.

(from RHO - document SD-BWI-TC-016)

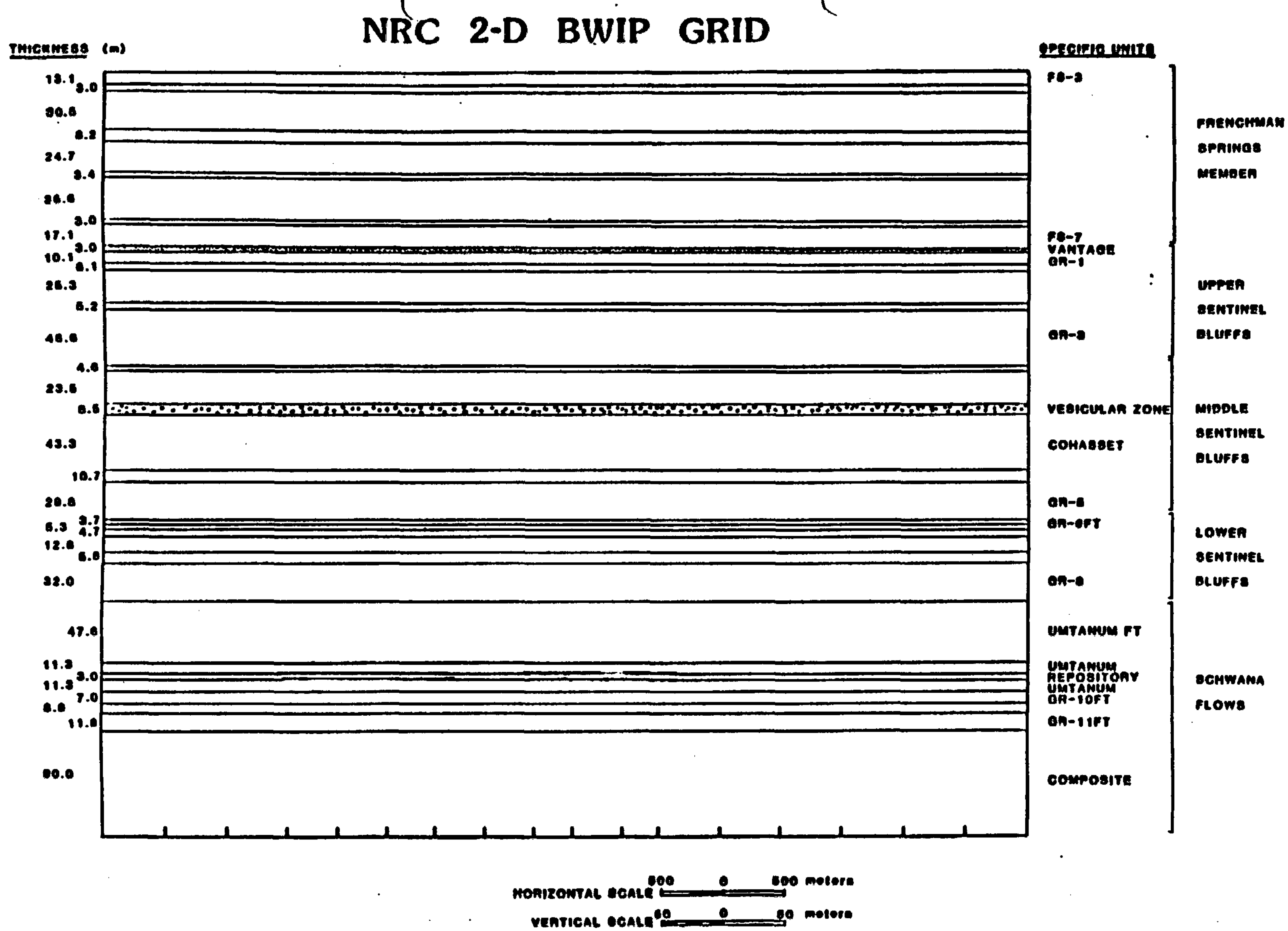


Figure 3. Simplified NRC 2-D BWIP grid showing hydrostratigraphic unit thicknesses and nomenclature. X-direction grid block spacings are marked along the bottom boundary of the grid.

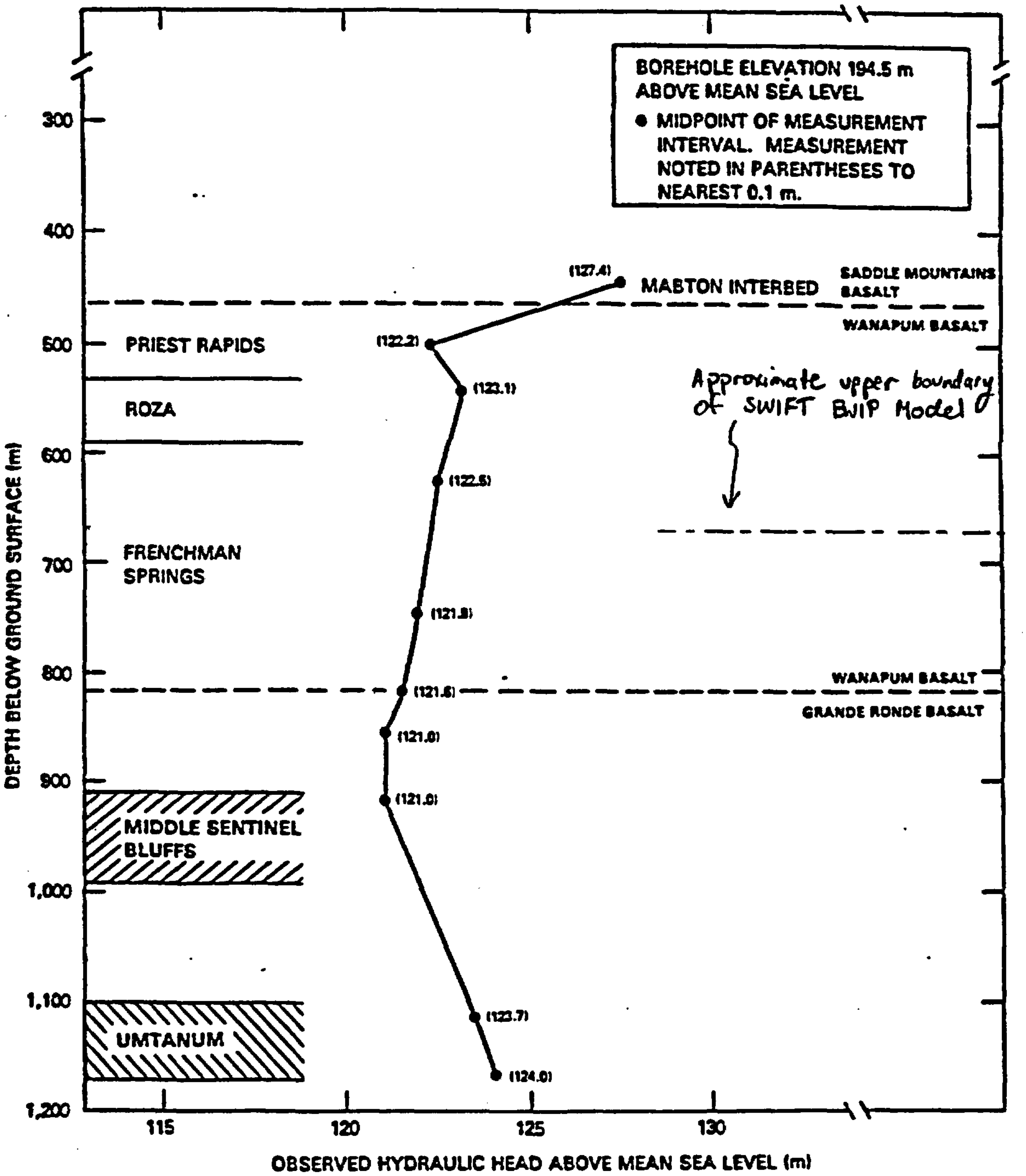


Figure 4. Hydraulic head measurements in Borehole RRL-2 (BWIP, Figure 5-41, SCR, 1982, p. 5.1-72)

ORIGINAL
GORO028
June 26

LEGEND
Head Contour Map

Head Range (meters)			Map Character
0.	-	116.0	
116.0	-	116.5	1
116.5	-	117.0	
117.0	-	117.5	2
117.5	-	117.9	
117.9	-	118.4	3
118.4	-	118.9	
118.9	-	119.3	4
119.3	-	119.8	
119.8	-	120.3	5
120.3	-	120.7	
120.7	-	121.2	6
121.2	-	121.7	
121.7	-	122.2	7
122.2	-	122.7	
122.7	-	123.1	8
123.1	-	123.6	
123.6	-	124.0	9
124.0	-	124.5	
124.5	-	125.0	0

Figure 5. Head distribution across grid calculated with "undisturbed model".

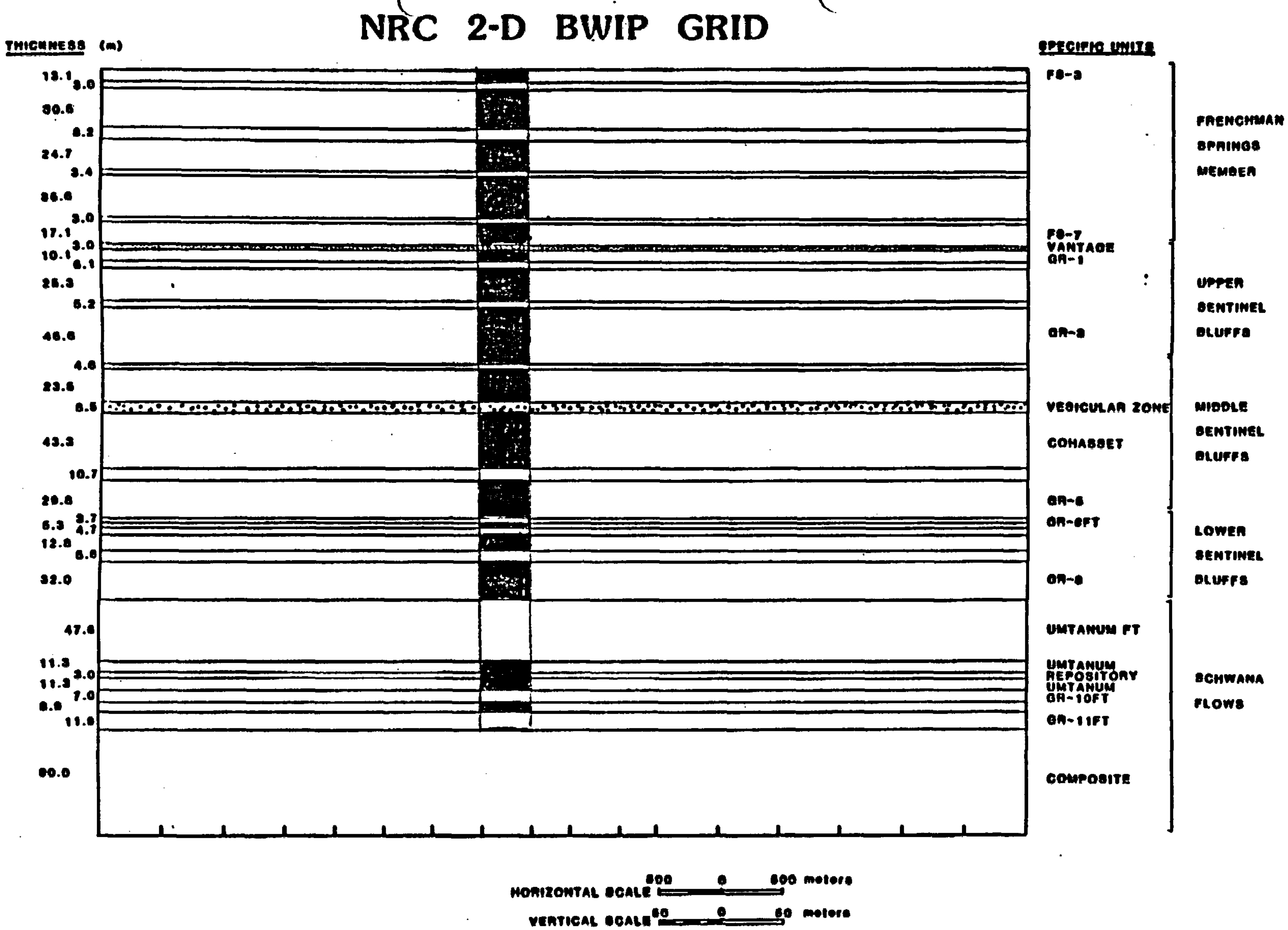
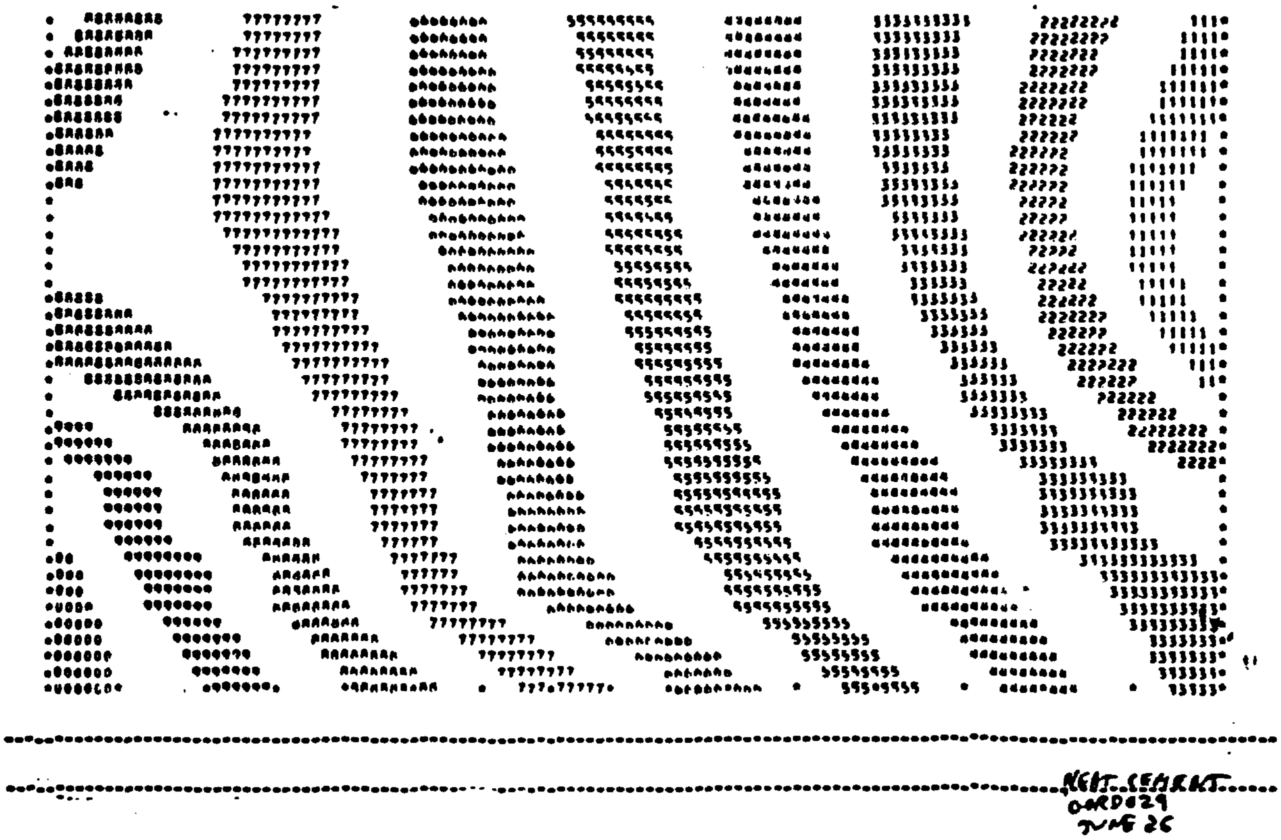


Figure 6. Simplified NRC 2-D BWIP grid showing hydrostratigraphic unit thicknesses, "borehole" location, and nomenclature. Cement zones have been darkened. X-direction grid block spacings are marked along the bottom boundary of the grid.

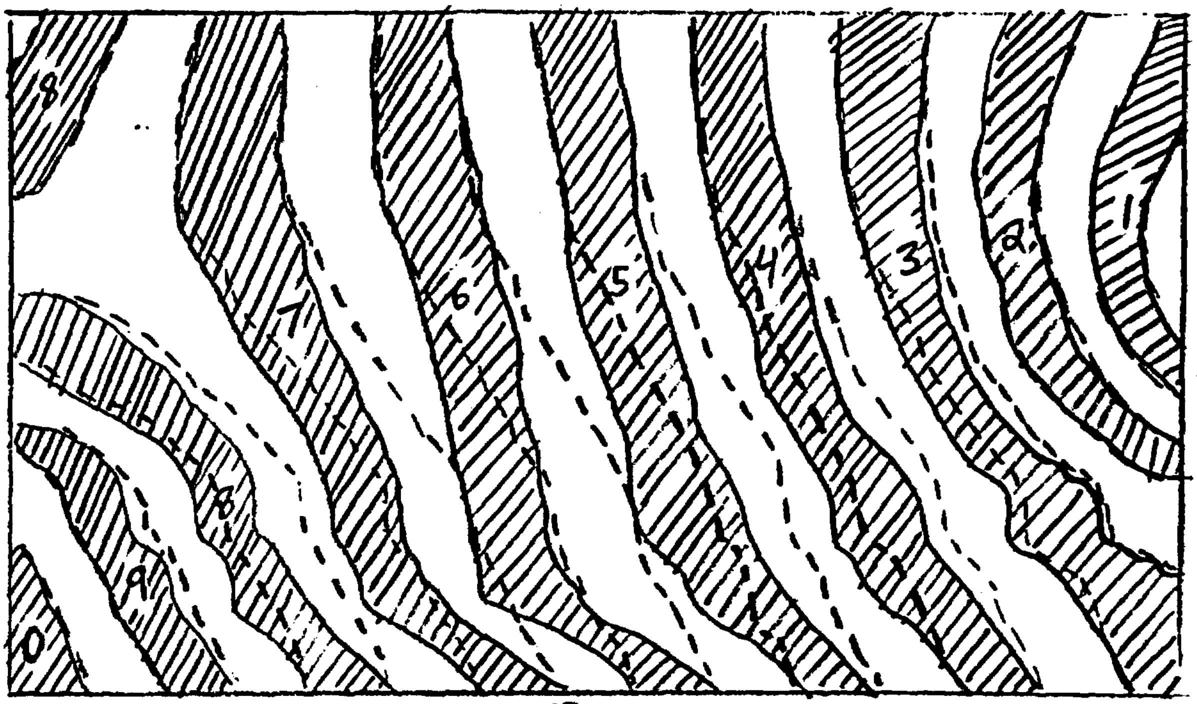
12



LEGEND
Head Contour Map

Head Range (meters)			Map Character
0.	-	116.0	
116.0	-	116.5	1
116.5	-	117.0	
117.0	-	117.5	2
117.5	-	117.9	
117.9	-	118.4	3
118.4	-	118.9	
118.9	-	119.3	4
119.3	-	119.8	
119.8	-	120.3	5
120.3	-	120.7	
120.7	-	121.2	6
121.2	-	121.7	
121.7	-	122.2	7
122.2	-	122.7	
122.7	-	123.1	8
123.1	-	123.6	
123.6	-	124.0	9
124.0	-	124.5	
124.5	-	125.0	0

Figure 7: Head distribution calculated with "neat cement" model.



LEGEND
Head Contour Map

Head Range (meters)			Map Character
0.	-	116.0	
116.0	-	116.5	1
116.5	-	117.0	
117.0	-	117.5	2
117.5	-	117.9	
117.9	-	118.4	3
118.4	-	118.9	
118.9	-	119.3	4
119.3	-	119.8	
119.8	-	120.3	5
120.3	-	120.7	
120.7	-	121.2	6
121.2	-	121.7	
121.7	-	122.2	7
122.2	-	122.7	
122.7	-	123.1	8
123.1	-	123.6	
123.6	-	124.0	9
124.0	-	124.5	
124.5	-	125.0	0

Figure 8a Impact of neat cement on head distribution across grid. Solid lines (cross-hatched) are calculations based on "neat cement" model; dashed lines are calculations based on "undisturbed" model.

CEMENT IMPACT ON HEAD PROFILE, COL. 8

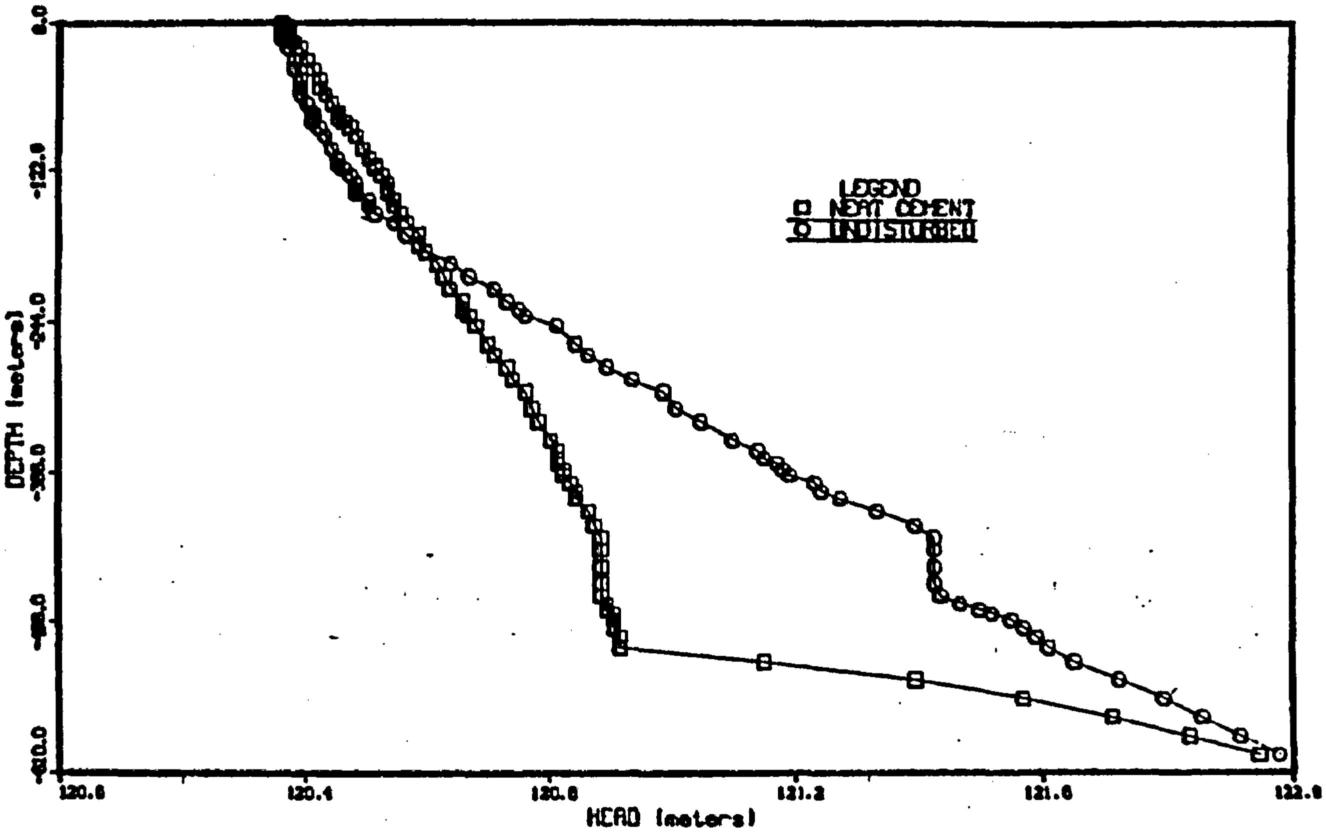


Fig. 8b: Impact of Neat Cement on head profile in "borehole" column.

Table 1. Hydrostratigraphic Units of the SWIFT 2-D Models

Member of Sequence	Layer	Thickness (m)@	K_H	K_V
Frenchman Springs	FS-3	13.1	1E-11	1E-10
Frenchman Springs	FS-4FT	3.0	1E-7	1E-7
Frenchman Springs	FS-4	30.5	1E-11	1E-10
Frenchman Springs	FS-5FT	8.2	1E-7	1E-7
Frenchman Springs	FS-5	24.7	1E-11	1E-10
Frenchman Springs	FS-6FT	3.4	1E-7	1E-7
Frenchman Springs	FS-6	35.6	1E-11	1E-10
Frenchman Springs	FS-7FT	3.0	1E-7	1E-7
Frenchman Springs	FS-7	17.1	1E-11	1E-10
Vantage	V-1	3.0	3E-7	3E-7
Upper Sentinel Bluffs	GR-1	10.1	1E-11	1E-10
Upper Sentinel Bluffs	GR-2FT	6.1	1E-7	1E-7
Upper Sentinel Bluffs	GR-2	25.3	1E-11	1E-10
Upper Sentinel Bluffs	GR-3FT	5.2	1E-7	1E-7
Upper Sentinel Bluffs	GR-3	46.6	1E-11	1E-10
Middle Sentinel Bluffs	GR-4FT	4.6	1E-7	1E-7
Middle Sentinel Bluffs	GR-4	23.5	1E-11	1E-10
Middle Sentinel Bluffs	Vesicular Zone	8.5	1E-8	1E-8
Middle Sentinel Bluffs	GR-4	43.3	1E-11	1E-10
Middle Sentinel Bluffs	GR-5FT	10.7	1E-7	1E-7
Middle Sentinel Bluffs	GR-5	29.8	1E-11	1E-10
Lower Sentinel Bluffs	GR-6FT	3.7	1E-7	1E-7
Lower Sentinel Bluffs	GR-6	5.3	1E-11	1E-10
Lower Sentinel Bluffs	GR-7FT	4.7	1E-7	1E-7
Lower Sentinel Bluffs	GR-7	12.8	1E-11	1E-10
Lower Sentinel Bluffs	GR-8FT	5.8	1E-7	1E-7
Lower Sentinel Bluffs	GR-8	32.0	1E-11	1E-10
Schwana	Umtanum FT	47.6	1E-7	1E-7
Schwana	Umtanum	25.6	1E-11	1E-10
Schwana	GR-10FT	7.0	1E-7	1E-7
Schwana	GR-10	8.9	1E-11	1E-10
Schwana	GR-11FT	11.9	1E-7	1E-7
Schwana	Composite Base	90.0	1E-7	1E-10

@ 3.0 m is asssumed as a minimal thickness where hydrostratigraphic units may be less than 3.0 m in thickness.

Simplified stratigraphy, layer designations, and thicknesses are from Chapter 12 of the BWIP SCR, 1982 , especially Table 12-14.

Table 2. Hydraulic Properties Assigned to "Neat Cement" Model

Member of Sequence	K_h	K_v
Neat Cement- substituted for all zones in grid column 8 except flow tops (FT), Cohassett vesicular zone, Vantage interbed, and composite base	1E-8	1E-8
Flow tops, Cohassett vesicular zone, Vantage interbed, and composite base in grid column 8	As in "undisturbed" model; See Table 1.	
All zones in all columns other than column 8	As in "undisturbed" model; See Table 1.	

All unit thicknesses are as in "undisturbed" model; See Table 1.