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CONSTRAINING LOCAL 3-D MODELS OF THE SATURATED-ZONE, YUCCA MOUNTAIN, NEVADA

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ABSTRACT

A qualitative three-dimensional analysis of the saturated zone flow system was performed for a 8 km x 8 km region including the potential Yucca Mountain repository site. Certain recognized geologic features of unknown hydraulic properties were introduced to assess the general response of the flow field to these features. Two of these features, the Solitario Canyon fault and the proposed fault in Drill Hole Wash, appear to constrain flow and allow calibration.

I. INTRODUCTION

The saturated zone underlying Yucca Mountain is a significant part of the pathway for radionuclides traveling from the repository horizon out to the regulatory boundaries of the system. Understanding of the saturated zone has increased since models were developed for use in prior performance-assessment analyses.[1] The analyses recently completed for TSPA-93[2] contain a more sophisticated representation of the saturated zone based on current information developed by the U.S. Geological Survey (USGS).[3] For example, a high hydraulic gradient is known to exist to the northwest of the potential repository site. Both of the two alternate conceptual models for the existence of the high-gradient region appear to require three dimensions to adequately represent the local flow system.[2,4,6]

The two interpretations have led to two models that are thought to best fit the available information: the diversionary model and the nondiversionary model. For the nondiversionary model, all fluid flowing within the tuffaceous units northwest of the high gradient continue within the tuffs as the fluid flows to the southeast. In the diversionary model, part of the fluid in the saturated tuffs flows abruptly downward, coincident with the high gradient region, continuing to the southeast in the Paleozoic carbonate aquifer underlying the tuffs.

This analysis attempts to determine if it is possible to develop site characterization data that could ultimately allow differentiation between the two models. Numerical experiments were used to determine the effects on the flow system induced by four geologic features whose associated hydraulic properties are currently unknown.

II. THREE-DIMENSIONAL MODEL

The saturated zone is modeled here as an 8 km x 8 km confined system. The modeled region extends far enough laterally to include the region of a large hydraulic gradient and to include the 5 km limit for the accessible environment, down gradient. The three-dimensional block is divided into four layers, each 50 meters thick. The block thickness was fixed at 200 meters for several reasons; computational time becomes excessive for a thicker model, and USGS tracer injection tests[3] show considerable inhomogeneity over tested depths suggesting 200 meters is a reasonable mixing depth. The region of the model is shown in Figure 1.

Superimposed on the block is a representation of where the geologic units are expected to intersect the

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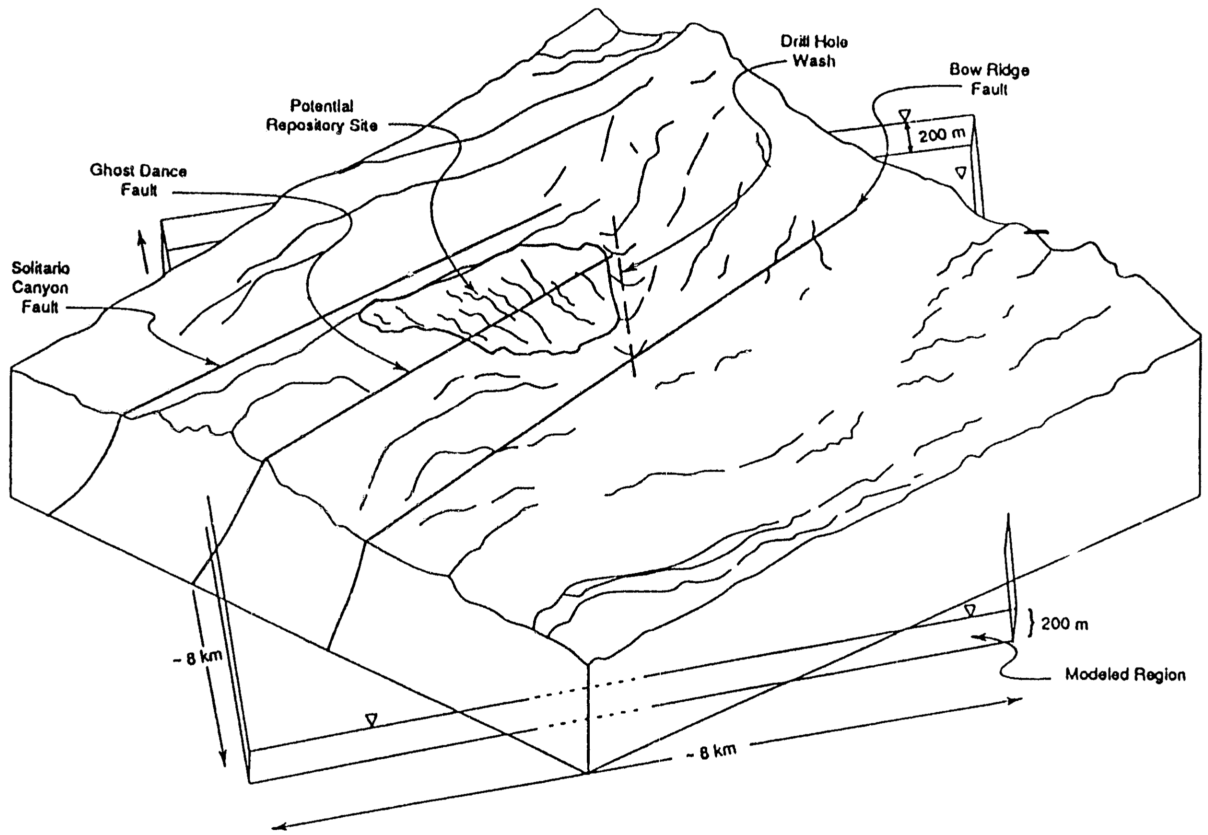

Figure 1. A general view of the region and features included in the 3-dimensional model. Solitario Canyon, Drill Hole Wash, Ghost Dance fault, and the potential repository appear in their approximate locations

water table.[2] Due to the 5-6 °ESE dip of the Cenozoic units underlying Yucca Mountain, five stratigraphic units are known to intersect the water table at various locations within the block.[2] These five units are the Topopah Spring Member of the Paintbrush Tuff, the Calico Hills, and the Prow Pass, Bullfrog, and Tram Members of the Crater Flat Tuff. Each successive vertical layer of the model was generated by translating the locations of these five units at the water table about 590 meters eastward for each additional 50 meters in depth. These features are the Solitario Canyon Fault (SCF) which bounds the site on the west; the Ghost Dance Fault (GDF) which crosses the site north to south; the proposed fault in Drill Hole Wash (DHW),[8] which forms a north boundary; and the proposed "drain" north of Drill Hole Wash, coupling the saturated tuffs and the carbonate aquifers.[2] The hydraulic conductivities associated with these features were varied individually over wide ranges to assess how they might influence calibration to the head data. The results of the attempts at calibration for these variations are discussed here.

The three-dimensional finite-element code, STAFF3D,[9] was used to construct flow models for equivalent porous media for both the diversionary and nondiversionary models. The complete listing of wells and locations from which head data were extracted appears in Table 1. Three of these wells; WT-11,G-2, and WT-6 occur on the boundary of the modeled region.

III. CALIBRATION OF NONDIVERSIONARY MODEL

For the nondiversionary models, calibration was first attempted with none of the features of concern included. Values for the hydraulic conductivity, K, were systematically varied in the five geologic units. A typical match to field data is shown in Table 2, column 1 (res1) and the corresponding head contours

Table 1
Well designations, the well locations in Nevada State plane coordinates (in meters) and the measured values of heads in those wells.[7]

Well	x	y	Head
WT-11	170193.2	225268.7	730.72
WT-10	168646.5	228225.4	775.92
WT-7	168826.1	230297.7	775.70
G-3	170225.65	229447.3	730.56
WT-12	172824.9	225468.5	729.52
H-3	170216.1	230594.0	731.72
H-6	168882.0	232653.5	775.96
WT-1	171827.7	229801.1	730.4
WT-17	172581.4	228118.3	729.64
WT-2	171274.3	231849.3	730.71
H-5	170335.6	233670.13	775.47
WT-3	174767.56	227379.3	729.57
H-4	171880.1	232148.98	730.33
C-3	173600.3	230706.1	730.10
C-2	173624.2	230687.5	729.95
P-1	174188.5	230481.0	730.00
J-13	176677.6	228358.9	728.45
B-1	172643.7	233246.2	730.66
H-1	171415.8	234733.4	730.95
WT-13	176405.0	230646.7	728.98
WT-4	173138.7	234242.4	730.70
WT-14	175324.0	232151.1	729.71
G-2	170841.6	237385.6	1029.00
WT-16	173856.4	236043.1	738.32
WT-6	172066.9	237919.5	1035.10
WT-15	176724.8	233512.3	729.24

appear in Figure 2. No variations of K values that were tried were able to significantly improve this alibration.

The calibration in column 1, Table 1, is rather poor. The first two features added to the model were SCF and DHWF (Figure 1 and Figure 3). Addition of either feature caused a partial correction to the calibration. The SCF affected primarily those heads to the west of the fault and DHW those east and north of the wash. Experiments were performed assigning K values to each feature that were either more conductive and less conductive than the surrounding rock. When these features were represented as zones of low transmissivity compared to the surrounding rock, it was possible to manipulate K to obtain a much closer calibration. All attempts at calibration to well H-5 resulted in head values that were too low. Upwelling was added at the bottom of the model at nodes below H-5 to compensate for the low calculated values. Although there is no specific information concerning upwelling at well H-5, the presence of elevated temperature measurements at the water table along the southern portion of the SCF have been interpreted as resulting from upwelling.[10] H-5 is believed to be located along a splay of the SCF,[7] therefore, there is some justification for introducing the effect of upwelling at this location. This fit is shown in column 2 (res2), Table 2, and the corresponding potentiometric surface appears in Figure 4.

The next case added only the GDF into the model (Figure 3). Variation of hydraulic conductivity for the GDF over extreme ranges from very conductive (K= 1.E-3m/sec) to quite nonconductive (K=6E-8m/sec), did not dramatically improve calibration. The potentiometric plot for small K is shown in Figure 5 and the calibration appears in column 3 (res3), Table 2. For large K, the potentiometric plot is shown in Figure 6 and the calibration appears in column 4 (res4), Table 2. The two potentiometric plots are sufficiently different that they are distinguishable from each other and from the field data. The GDF is believed to be a scissors fault with its hinge to the north of the potential repository and its offset increasing to the south. It apparently does not support substantial head differences at the south end where the throw is thought to be largest.

IV. CALIBRATION OF DIVERSIONARY MODELS

For the diversionary "drain" case, which represents an alternative conceptual model of the saturated-zone flow system, similar circumstances were obtain. This fit is no better than the fit which produced column 1, Table 2. When, however, SCF and DHWF are added to the model, the fit to data is as good as for the nondiversionary model with those faults added. The fit is shown in column 5 (res5), Table 2 and the corresponding potentiometric surface appears in Figure 7.

Table 2
Residual values (calculated values of head minus measured values of head, labeled resN) for each of the five models examined here.
The values indicated by "-" are exact.
These wells are on the boundary of the modeled region.

SC & DHW Faults		Ghost Dance Fault		Diversionary drain	Well
res1	res2	res3	res4	res5	
-.7	-	-	-	-	WT-11
-4.32	-2.79	-10.32	-10.72	-3.3	WT-10
-6.44	-1.2	-14.79	-16.62	-2.9	WT-7
+14.41	+1.2	+8.57	+6.53	+1.5	G-3
+2.42	+1.47	+2.25	+2.66	+0.9	WT-12
+15.59	+0.63	+10.99	+6.38	+0.83	H-3
-14.81	+1.23	-7.45	-13.14	-2.5	H-6
+7.58	+0.85	+3.31	+5.27	+1.3	WT-1
+5.07	+1.28	+3.51	+4.67	+1.7	WT-17
+11.13	+1.83	+15.82	+6.56	+2.7	WT-2
-30.94	-1.17	-23.54	-32.36	-2.0	H-5
-1.95	+0.48	+0.85	+0.99	+0.3	WT-3
-10.52	-2.35	-3.22	+6.85	+2.85	H-4
+5.71	+0.81	+2.13	+4.1	+1.3	C-3
+3.64	+0.47	+1.09	+2.0	+0.47	P-1
+1.83	+0.72	+0.76	+0.69	+0.72	J-13
+10.26	+2.95	-3.74	+6.75	+4.2	B-1
+11.56	+6.91	+12.87	+8.22	+5.9	H-1
+11.21	+0.15	-0.01	+0.82	+0.3	WT-13
+10.79	+3.37	+6.56	+6.48	+3.6	WT-4
+4.87	-0.87	-0.23	+0.87	+0.02	WT-14
--	--	--	--	--	G-2
-2.36	-3.4	-2.03	-2.69	-3.4	WT-16
--	--	--	--	--	WT-6
+1.89	+0.22	+0.53	+0.62	+0.5	WT-15

V. CONCLUSION

The purpose here was to examine the qualitative behavior of the saturated-zone flow system. It was observed in the course of the study that the hydraulic properties assumed for the geologic features discussed above have profound effects on calibration of the models. The SCF and DHWF allow reasonable calibration of both models when treated as zones of low transmissivity. The GDF appears to exercise no constraints on the flow field. The diversionary model also requires SCF and DHWF to reproduce the known heads.

Reasonable values have presumably been assumed for the hydraulic conductivity along the various geologic features. The geologic features which were introduced have plausible effects and their properties are testable. However, the values must be verified with experimental data collected from the specific features in question. If future site testing shows that these features do not exhibit these properties, then additional work will be necessary to explain the flow system.

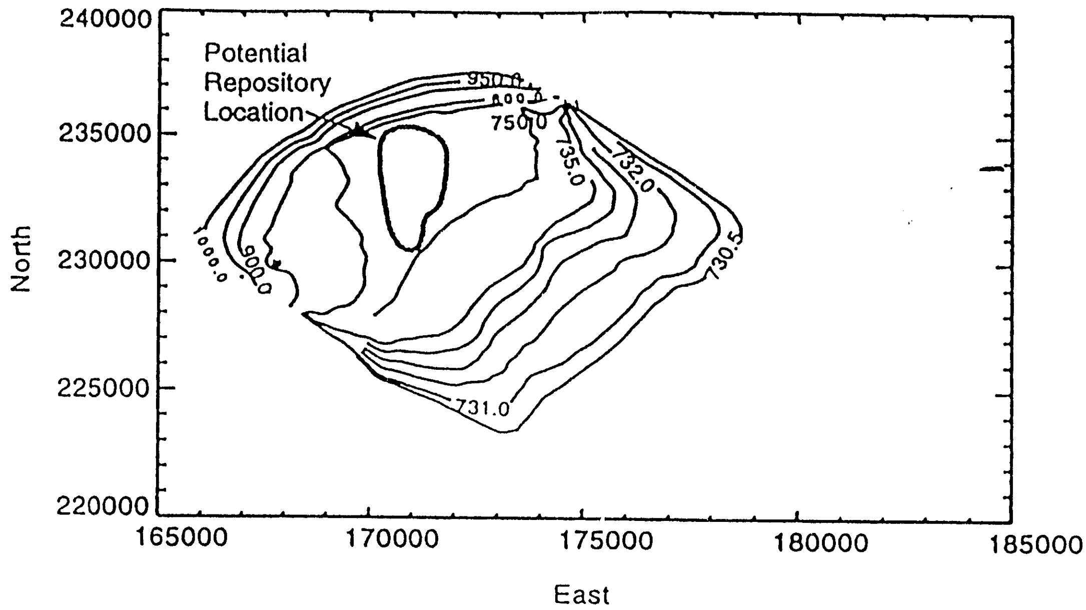

Figure 2. Heads (in meters calibrated by variation fo hydraulic conductivity, for the case of no special geologic features being considered. Coordinates are Nevada State plane coordinates (in meters).

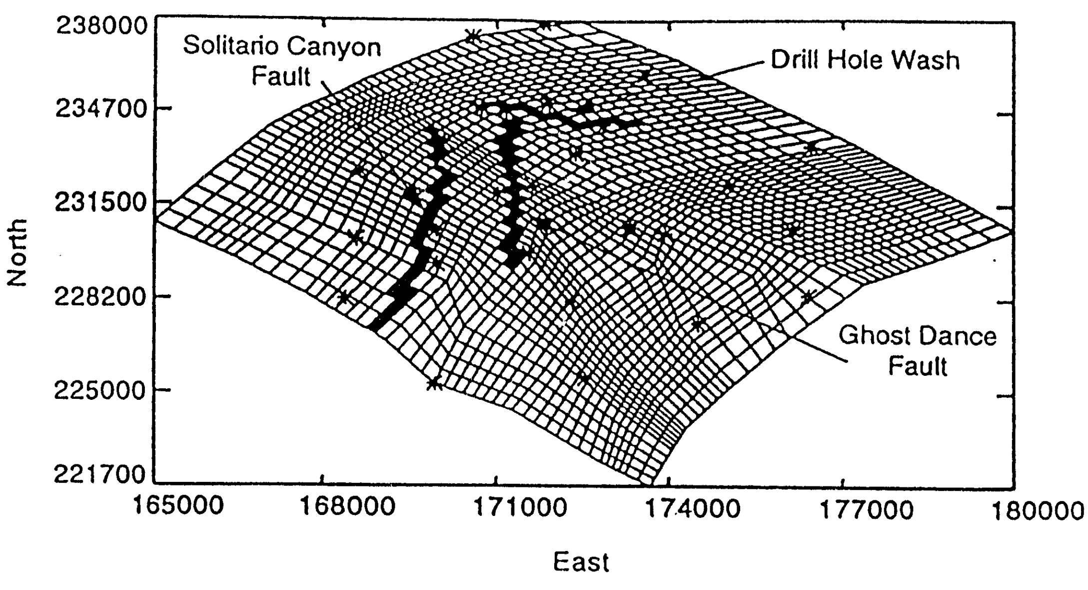

Figure 3. The calculational grid at the water table with the well locations indicated by asterisks and the locations of the Solitario Canyon fault, Ghost Dance fault, and the possible fault in Drill Hole Wash indicated by black elements. Coordinates are Nevada State plane coordinates (in meters).

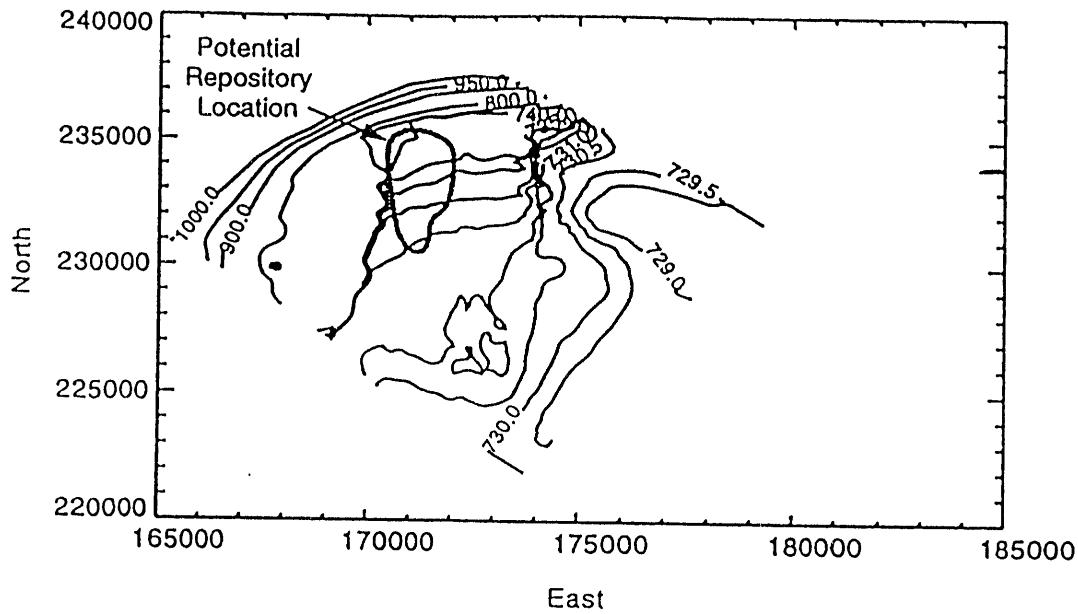

Figure 4. The potentiometric surface map based on calculated values of head for the case with Solitario Canyon fault and Drill Hole Wash fault. Contour labels are meters above mean sea level. Coordinates are Nevada State plane coordinates (in meters).

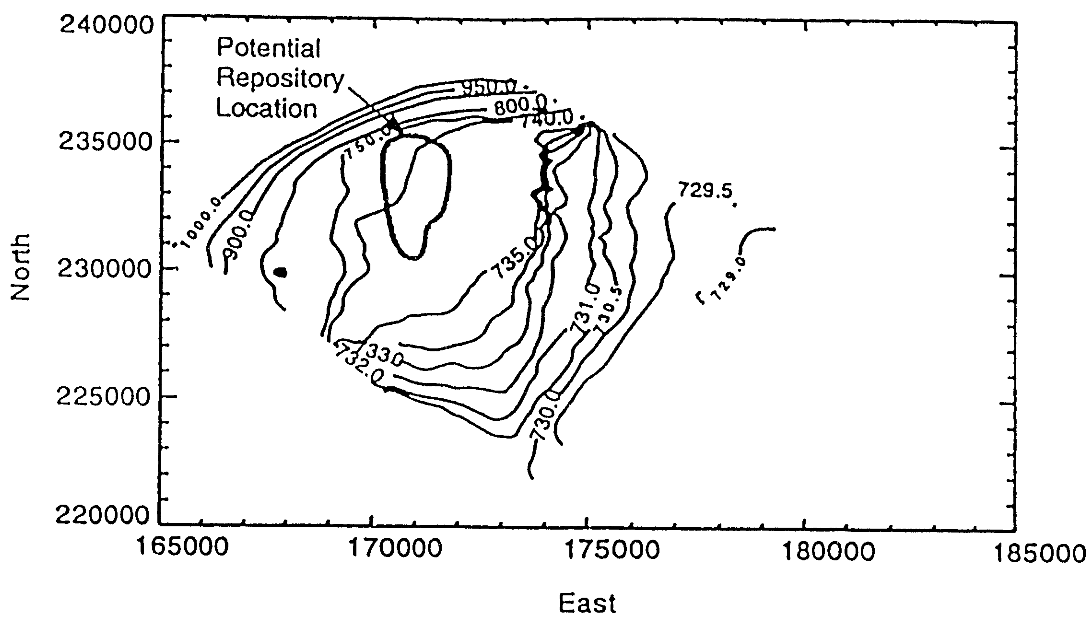

Figure 5. The potentiometric surface map based on calculated values of head for the case with Ghost Dance fault (K=1E-3 m/sec) as the feature added. Contour labels are meters above mean sea level. Coordinates are Nevada State plane coordinates (in meters).

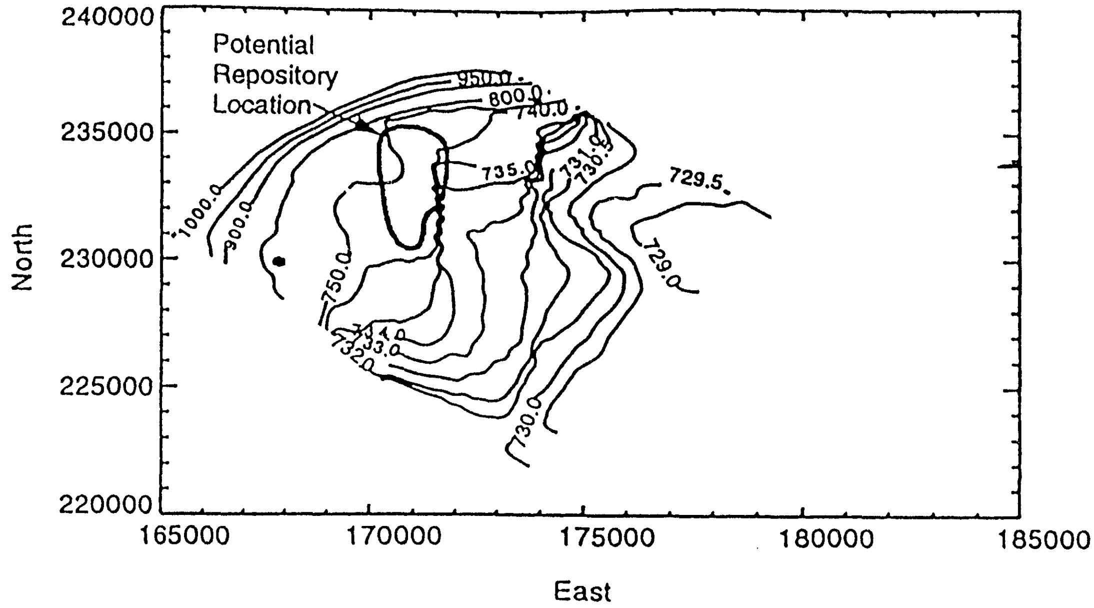

Figure 6. The potentiometric surface map based on calculated values of head for the case with Ghost Dance fault (K=6E-8 m/sec) as the feature added. Contour labels are meters above mean sea level. Coordinates are Nevada State plane coordinates (in meters).

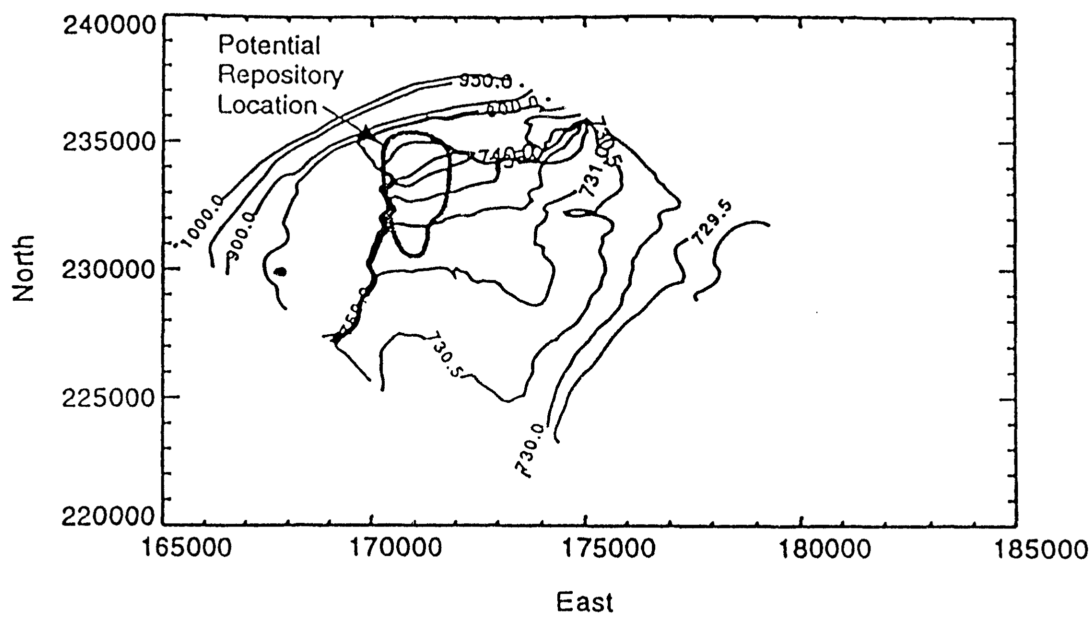

Figure 7. The potentiometric surface map based on calculated values of head for the case of the drain and Solitario Canyon fault and Drill Hole Wash fault. Contour labels are meters above mean sea level. Coordinates are Nevada State plane coordinates (in meters).

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