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APPENDIX B

SUMMARIES OF SITE GEOLOGIC, HYDROGEOLOGIC AND GEOCHEMICAL INFORMATION

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APPENDIX B.1

GEOLOGIC SETTING, STRUCTURE AND PIEZOMETER SURFACES

CHESTER ENGINEERS

Technical Memorandum

Date: August 12, 2013

Subject: **Geologic Setting, Structure and Piezometric Surfaces**

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Reviewed By: Mark Jancin, Ph.D., P.G.

Regional Geologic Setting

The UNC Church Rock Site (Site) lies near the southern margin of the San Juan structural and hydrologic basin. The San Juan Basin extends north into Colorado where it encompasses the surface drainage basin of the San Juan River. The Site straddles a portion of the southernmost area of Gallup Sandstone outcrop. The top of the Gallup Sandstone descends over 5500 ft in elevation over approximately 60 miles north from the Site to its northernmost extent, which corresponds to a regional dip (slope angle) of about 1 degree. The Gallup Sandstone comprises two of the three transmissive hydrostratigraphic zones defined at the Site (unconsolidated deposits comprise the third).

Local Geologic Setting

Figure 1 is a geologic map and stratigraphic legend showing hydrostratigraphic units in the area of the Site. The map shows where these units outcrop or subcrop (beneath unconsolidated materials). Five rock hydrostratigraphic units are represented in the map. From upper to lower these are the Dilco Coal (member of the Cravasse Canyon Fm.), Zone 3 (comprising the Torrivo Sandstone of the Cravasse Canyon Fm. and the uppermost sandstone of the Upper Gallup Sandstone), Zone 2 (a coal and shale unit of the Upper Gallup Sandstone), and Zone 1 (the lower sandstone of the Upper Gallup Sandstone). Beneath Zone 1 is the D-Cross Tongue of the Mancos Shale, which locally divides the Gallup Sandstone into upper and lower units.

The transmissive hydrostratigraphic units are the unconsolidated materials (principally alluvium), Zone 3, and Zone 1. The Dilco Coal and Zone 2 are aquatards, as is the Mancos Shale.

The remainder of this section describes the structural elevations and thicknesses of the transmissive hydrostratigraphic units at the Site: the unconsolidated materials (alluvium and tailings), Zone 3, and Zone 1. Bases for these estimates include geologic logs of wells and borings and previous Site reports (Canonie, 1987; US Filter, 2004). The extent of unconsolidated material is based on mapping by Canonie (1987) with extrapolations based on interpretation of aerial photography. The unconsolidated material mapped in Figure 1 represents alluvium outside of the tailings cells and undifferentiated alluvium, tailings, and cover material inside the tailings cells. The locations of data sources (e.g. wells and borings) are shown in the map views, for example by diamond symbols in Figure 1, and listed in tables (provided in the file posting files.xls). A geostatistical method (kriging) was used to estimate elevations of the structural surfaces over the map view extents. The kriged surfaces correspond to known elevations at points such as wells and take into account the spatial variability of the known elevations. Where data are sparse or spatially more variable the certainty of interpolated elevations is reduced. The Golden Software program Surfer (ver. 10) was used to make the estimates and generate the maps and cross sections.

The geologic map shown in Figure 1 was derived by intersecting the estimated structure surfaces with an estimate of the top of rock surface, which is shown in Figure 2. The geologic contacts are covered by unconsolidated material in most locations and have not been verified by field mapping. Therefore, they are inferred.

Tailings

Tailings are confined to the area of the reclaimed tailings cells (Figure 3). With the exception of limited areas, the easternmost part of the north cell and portions of the central cell and the two former borrow pits, the tailings are underlain by alluvium (Canonie, 1987; US Filter, 2004). Figure 3 shows estimated elevations of the base of tailings and Figure 4 the estimated vertical thickness of tailings and cover material. Figures 3 and 4 also show locations of wells and borings whose logs were the primary bases for the thickness and elevation estimates. Information from 1978 and 1985 topographic maps (US Filter, 2004) and cross sections from Canonie (1987) were used to supplement data from the wells and borings. Figure 5 shows the thickness of alluvium and dike material (primarily reworked alluvium) beneath the area of the tailings cells. The thickness of alluvium was calculated by subtracting elevations of the top of rock (Figure 2) from elevations of the base of tailings (Figure 3).

Zone 3

Figures 6 and 7 show estimated structural elevations (structure contours) on the top of and bottom of Zone 3. Figure 8 shows its estimated vertical thickness (isochores). Figures 6 and 7 also show locations of wells and borings whose logs were the primary bases for the elevation estimates. Figure 8 was derived by subtracting the elevations in Figure 7 from those shown in Figure 6. The structure contours terminate along the margins of Pipeline Canyon and higher elevations in the southern portion of the map. The loci of these termination points are the zero thickness isochores, which were estimated by intersecting the estimated base of Zone 3 with the estimated top of rock

(Figure 2). Areas where the vertical thickness is between 0 and approximately 30 feet correspond roughly to areas where Zone 3 outcrops at the surface or subcrops beneath unconsolidated material (see Figure 1 for a more precise delineation). Zone 3 is interpreted to have been removed by erosion to the south of these areas.

Zone 1

Figures 9 and 10 show estimated structural elevations (structure contours) on the top of and bottom of Zone 3. Figure 11 shows its estimated vertical thickness (isochores). Figures 9 and 10 also show locations of wells and borings whose logs were the primary bases for the elevation estimates. Figure 11 was derived from Figures 9 and 10. Areas of Zone 1 outcrop, subcrop, and absence due to erosion (Figures 1, 9 and 10) were estimated by methods analogous to that described above for Zone 3.

Piezometric Surfaces and Hydraulic Gradients

Piezometric surfaces were estimated for two time periods selected to illustrate the historic high stand of groundwater levels in early 1986 and a modern low stand of October 2011. For each time period estimates were made of the alluvium water table, and the Zone 3 and Zone 1 piezometric surfaces.

Discharge of mine water to the Pipeline Arroyo ceased in February 1986 (Chester Engineers, 2012). This was also a time when tailings were still being discharged to the central pond and borrow pits 1 and 2 (Chester Engineers, 2012). Subsequent to this time, groundwater levels in the vicinity of the tailings ponds (later tailings cells) began to decline in each of the hydrostratigraphic units, a process that continues to date.

Figures 12 through 14 show estimated early-1986 water table elevations for the alluvium and piezometric surface elevations for Zone 3 and Zone 1. Arrows on each of the maps indicate the directions of hydraulic gradient. Well water levels used to estimate the surfaces are plotted on each of the maps. These water levels are averages derived from measurements made during the first quarter of 1986. These averages were supplemented with averages derived from measurements made in the EPA-series wells in the second quarter of 1986. The purpose of using averages was to expand the extent of data on which the surface estimates were based. During this time period only portions of the well network were typically measured at a time and the EPA-series wells were not measured until the second quarter of 1986. The data used to estimate the maps are also listed in the file well water levels.xls.

Figures 15 through 17 show estimated October 2011 water table elevations for the alluvium and piezometric surface elevations for Zone 3 and Zone 1. Arrows on each of the maps indicate the directions of hydraulic gradient. Well water levels used to estimate the surfaces are plotted on each of the maps and listed in the file water levels.xls. The estimated piezometric surfaces for Zone 3 (Figure 16) and Zone 1 (Figure 17) were estimated by two different methods. A portion of each estimated surface was based directly on well water levels measured in October 2011. This was supplemented by piezometric elevations estimated for the same time by a groundwater flow model (Chester Engineers, 2012). The addition of the flow model estimates expands the depiction of piezometric surfaces beyond the distribution of existing wells.

Figure 15 shows water table contour lines and hydraulic gradient arrows over only a portion of the zone of saturation in the alluvium. The reason for this is that upgradient portions of the zone of saturation are interpreted to have become isolated (hydraulically disconnected) within depressions in the bedrock surface and no longer exhibit appreciable horizontal flow (Chester Engineers, 2013). Such hydraulic isolation occurs as the groundwater elevations continue to decline.

Cross Sections

Figures 18 and 19 are cross sections along alignment 1 (Figure 1). Both figures depict in vertical section the various geologic structures described above and shown in the map figures. The two figures differ in that Figure 16 shows estimated piezometric surfaces for early 1986 and Figure 17 shows estimated piezometric surfaces for October 2011.

Similarly, Figures 20 and 21 show geologic structures and piezometric surface estimates along the cross section 2 alignment (Figure 1). Figures 22 and 23 do the same for the cross section 3 alignment (Figure 1).

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FIGURES

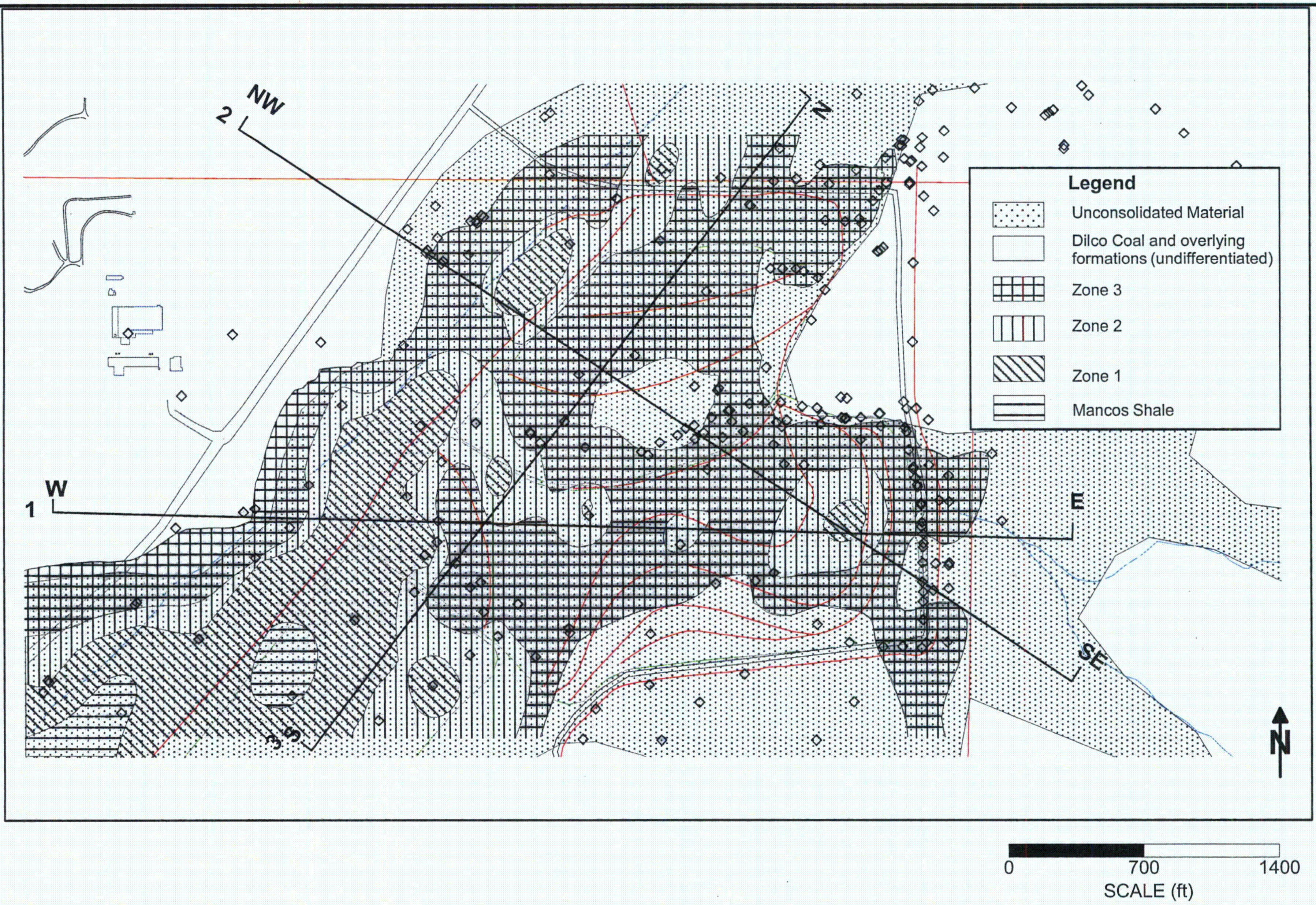

FIGURE 1
Geologic map showing site-defined hydrostratigraphic units and contiguous geologic units. Unconsolidated material represents alluvium outside of tailings cells and undifferentiated alluvium, tailings and cover inside tailings cells. Alignments are shown for cross sections 1, 2, and 3.

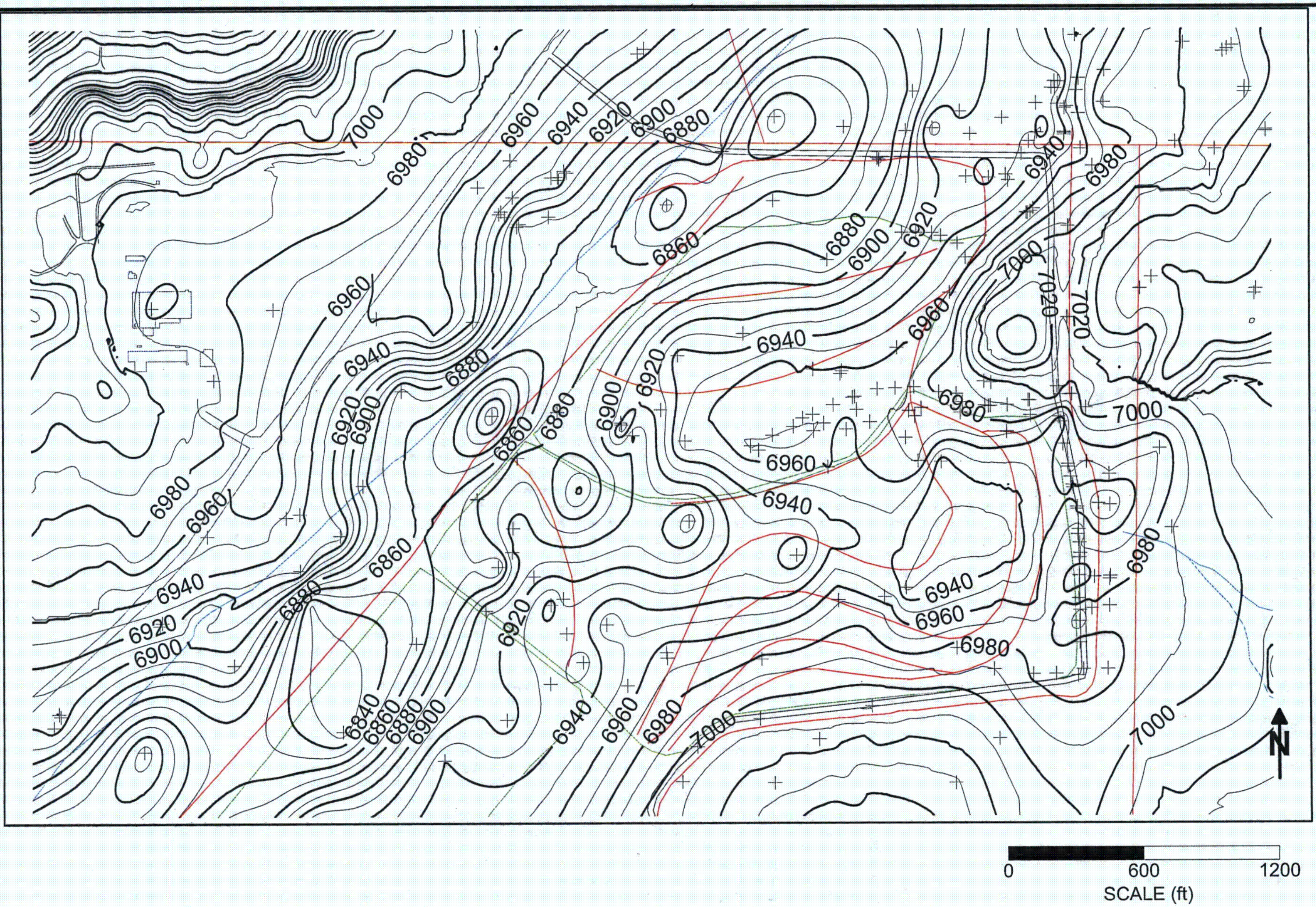

FIGURE 2
Elevations on the top of rock (ft amsl)

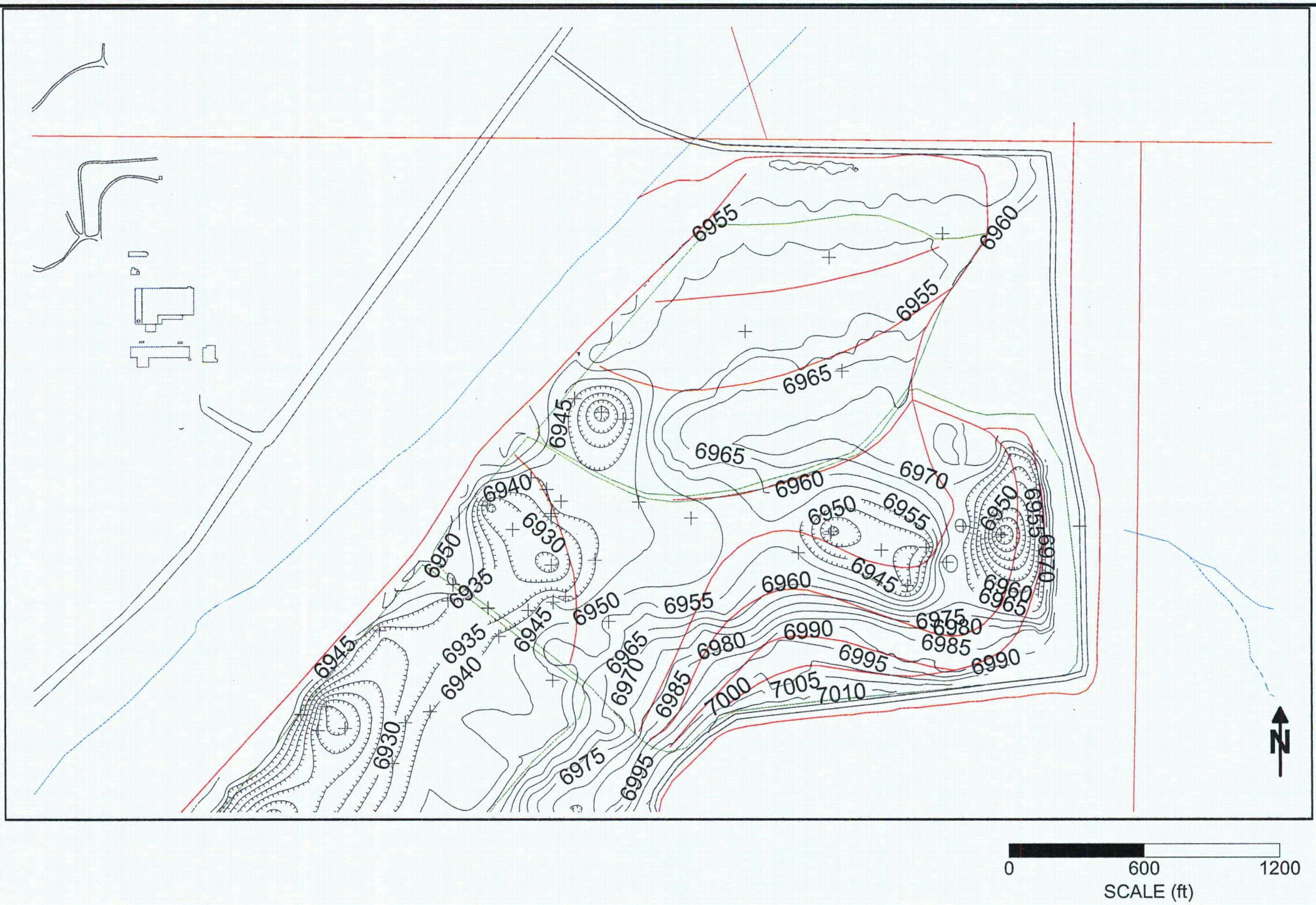

FIGURE 3
Elevation contours on the base of tailings (ft amsl)

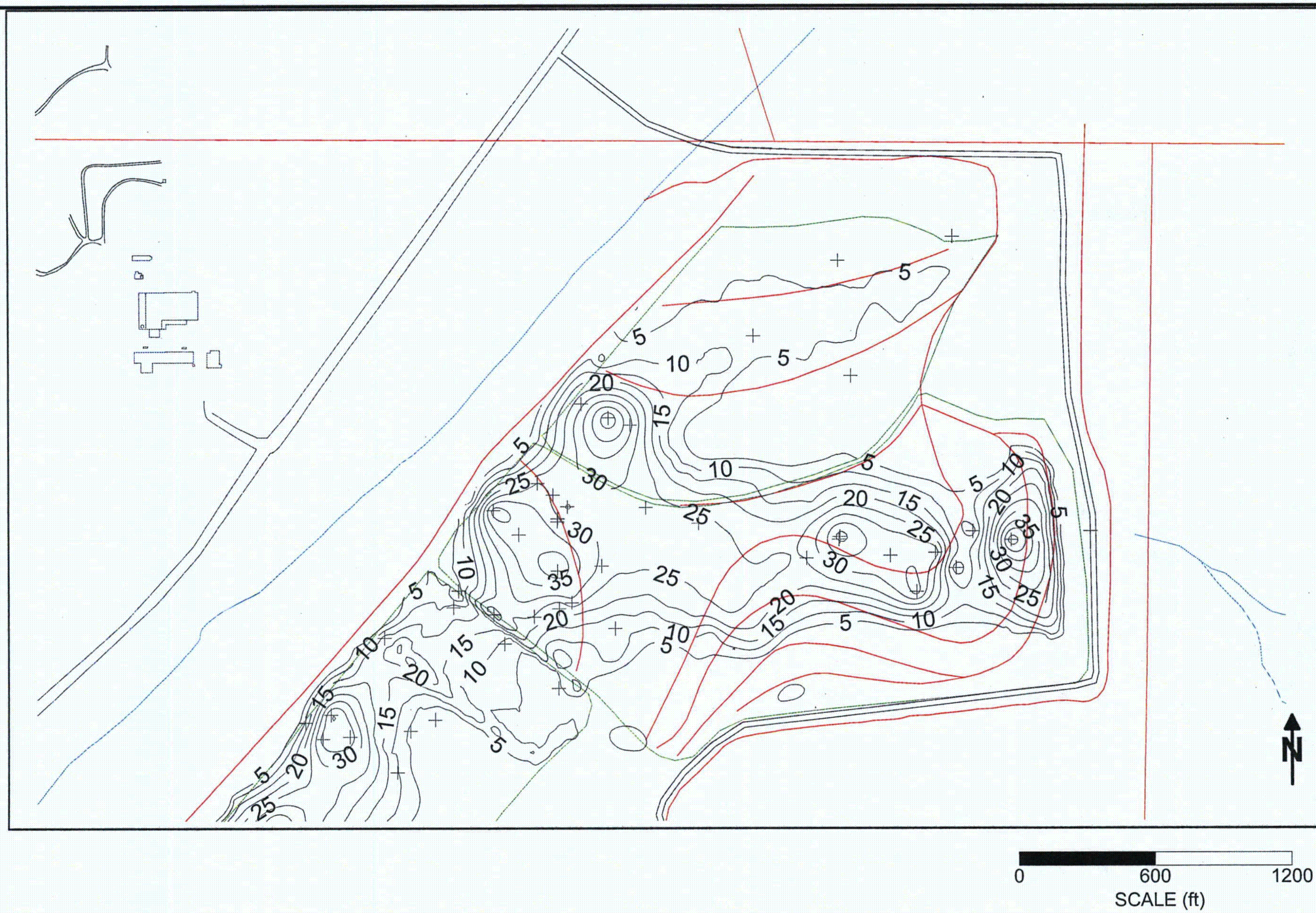

FIGURE 4
Depth to the base of tailings (ft)

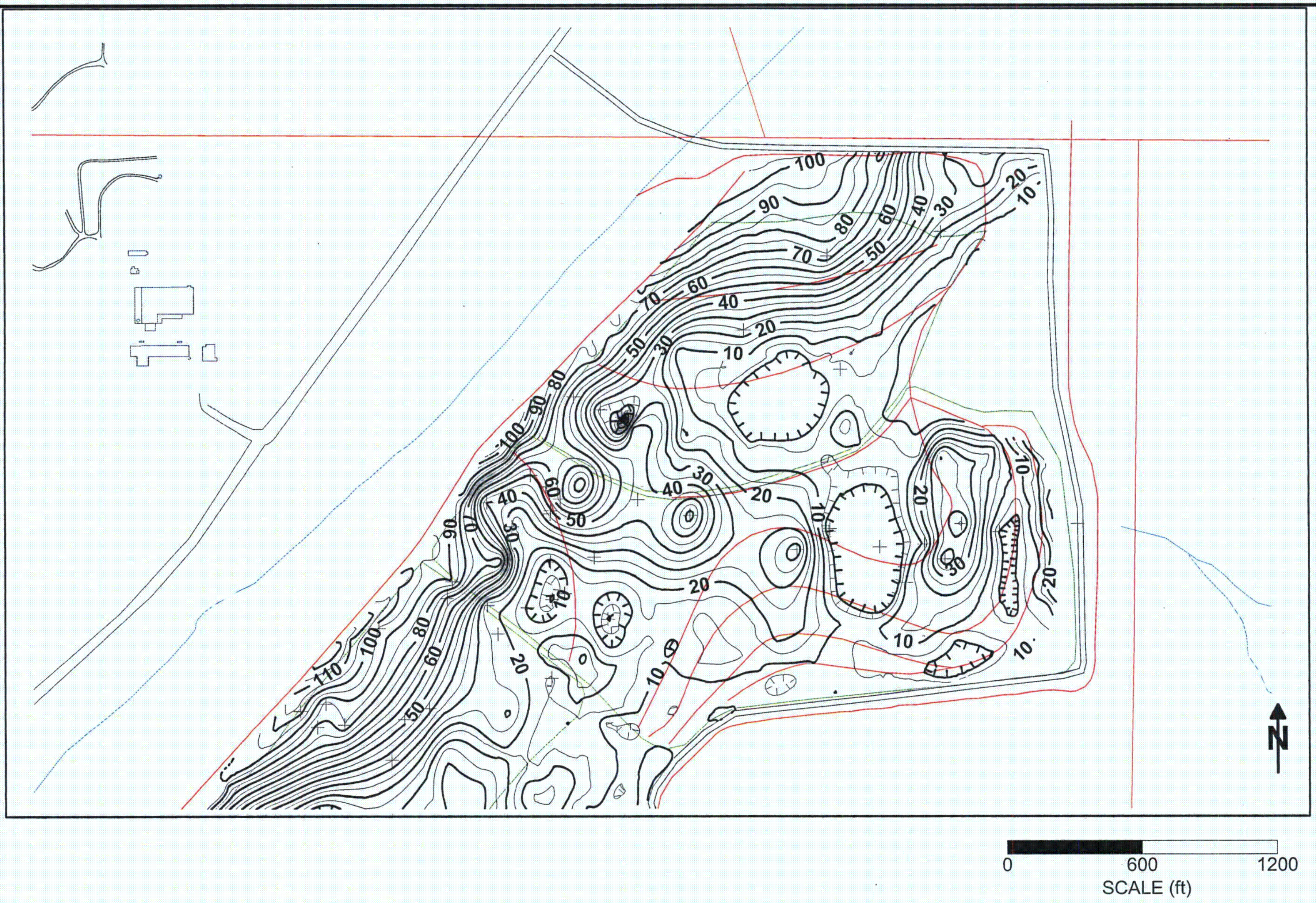

FIGURE 5
Estimated thickness (ft) of alluvium and dike material beneath the tailings cells

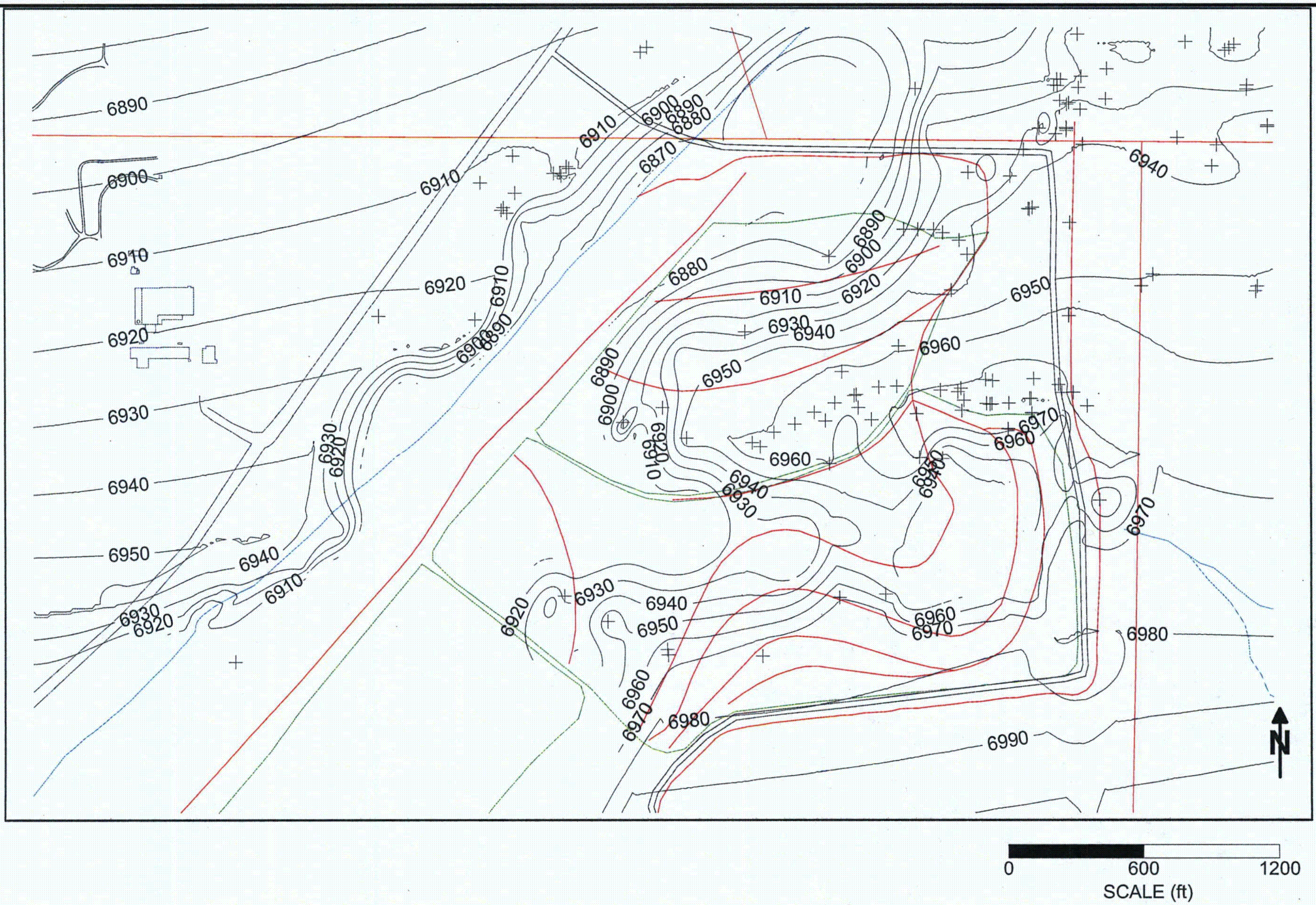

FIGURE 6
Structure contours on the top of Zone 3 (ft amsl)

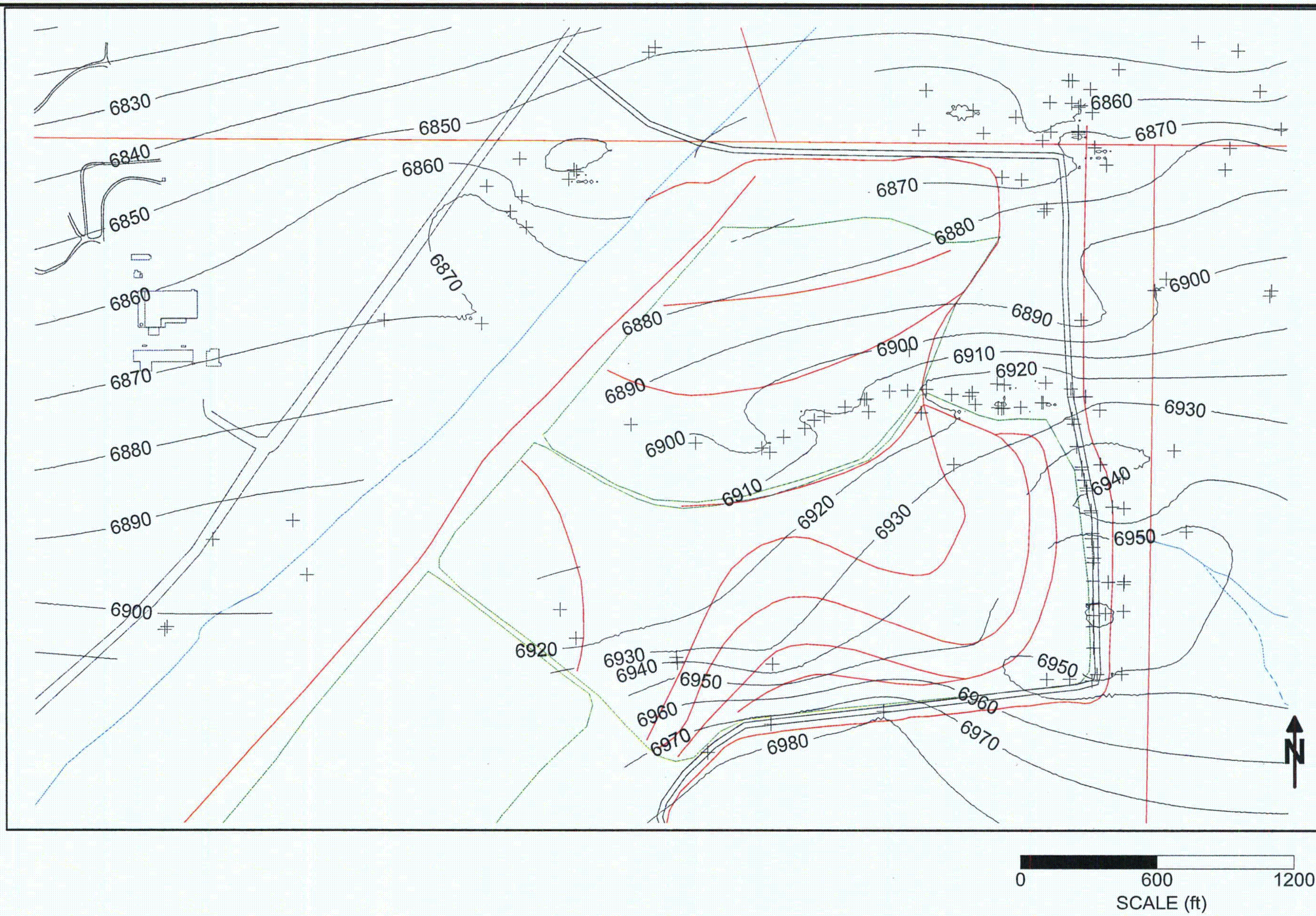

FIGURE 7
Structure contours on the bottom of Zone 3 (ft amsl)

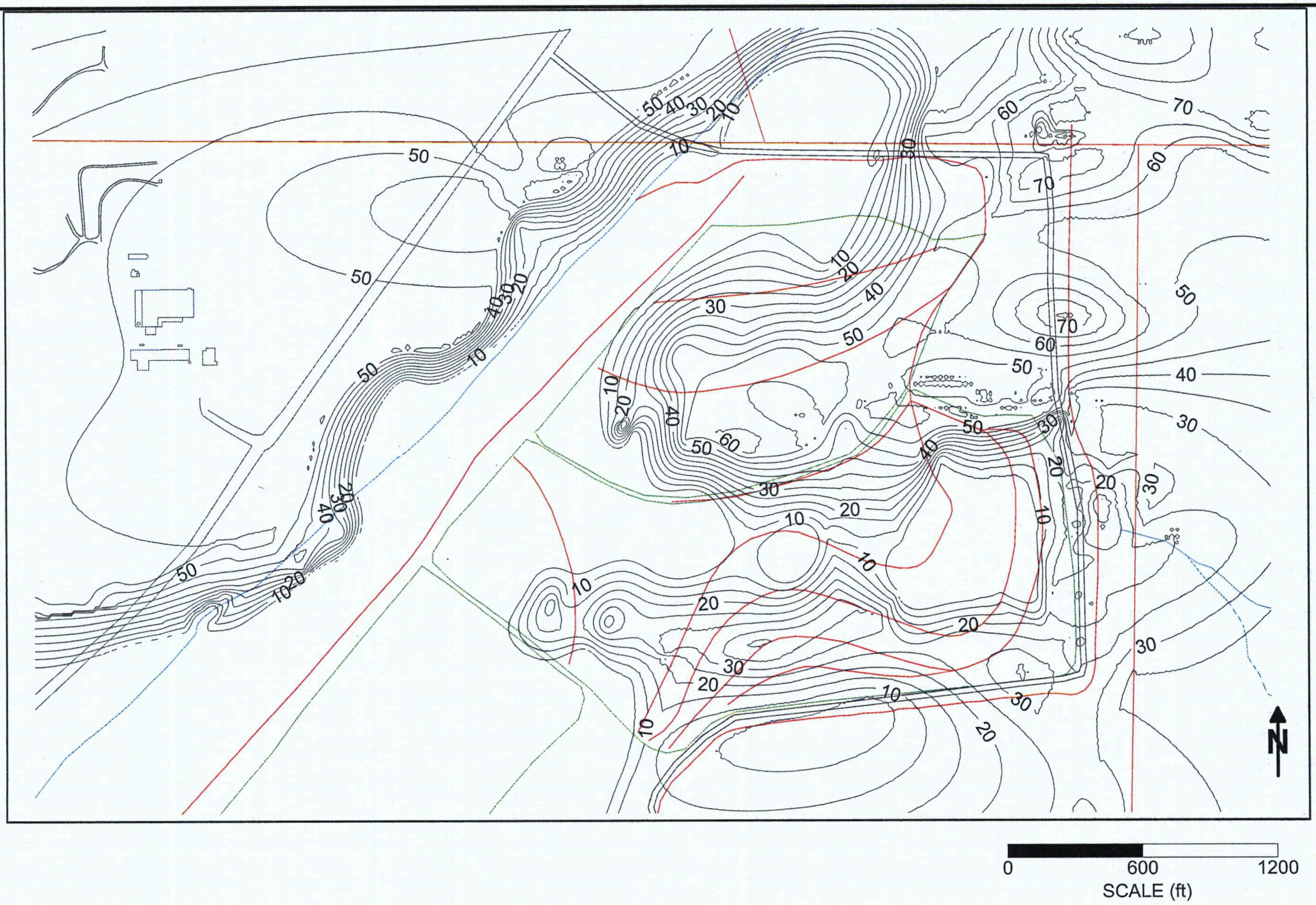

FIGURE 8
Isochore contours for Zone 3 (ft)

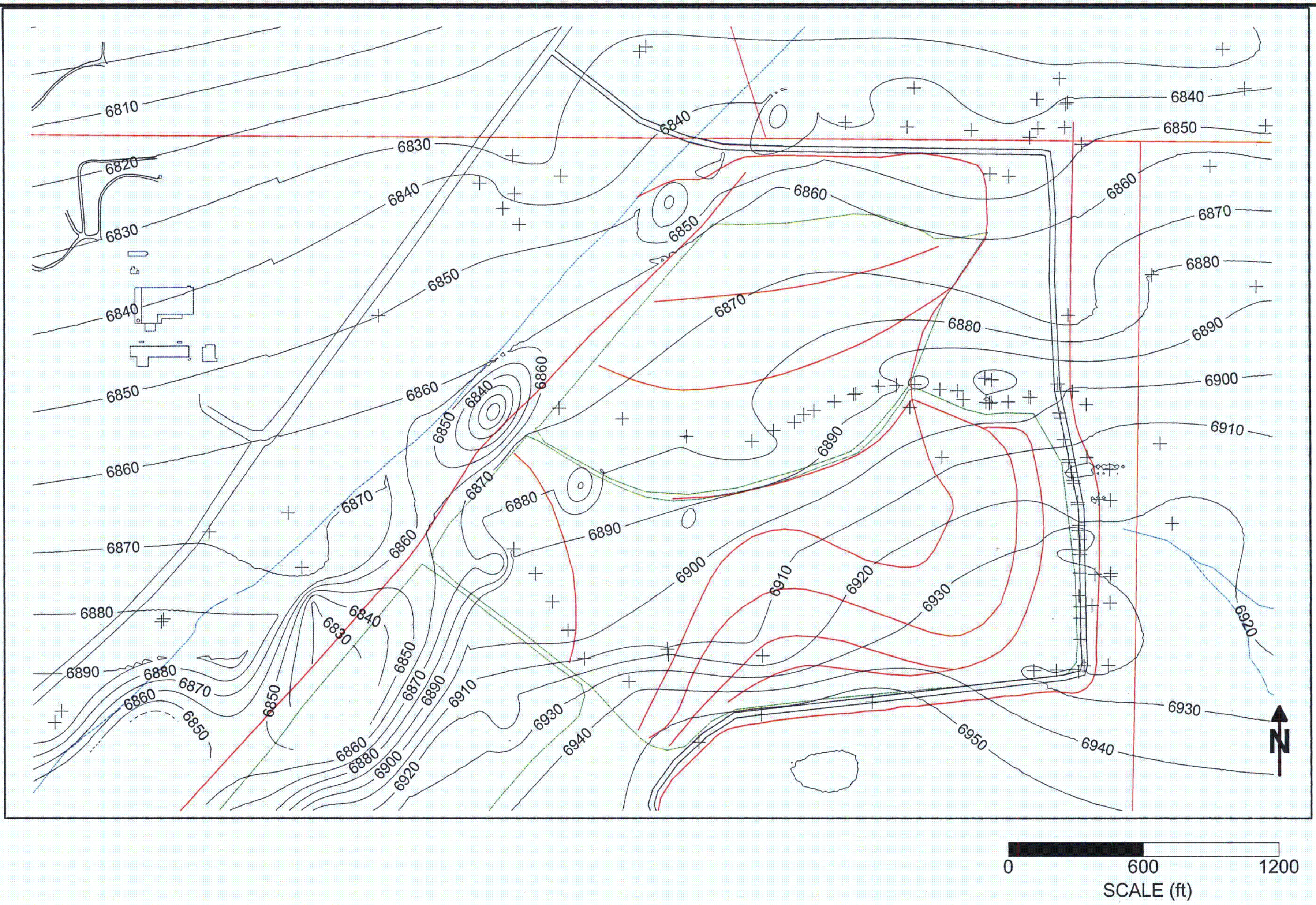

FIGURE 9
Structure contours on the top of Zone 1 (ft amsl)

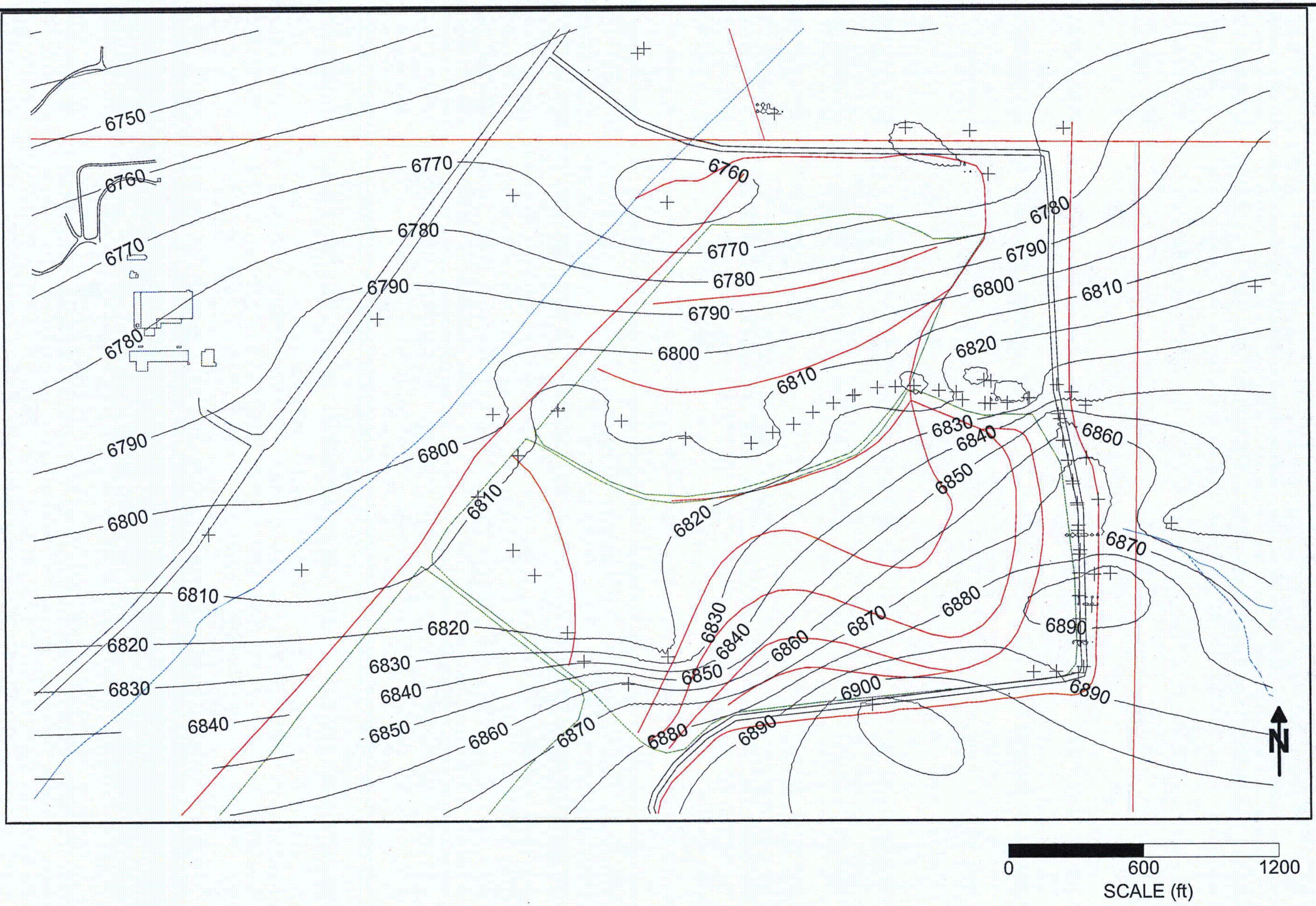

FIGURE 10
Structure contours on the bottom of Zone 1 (ft amsl)

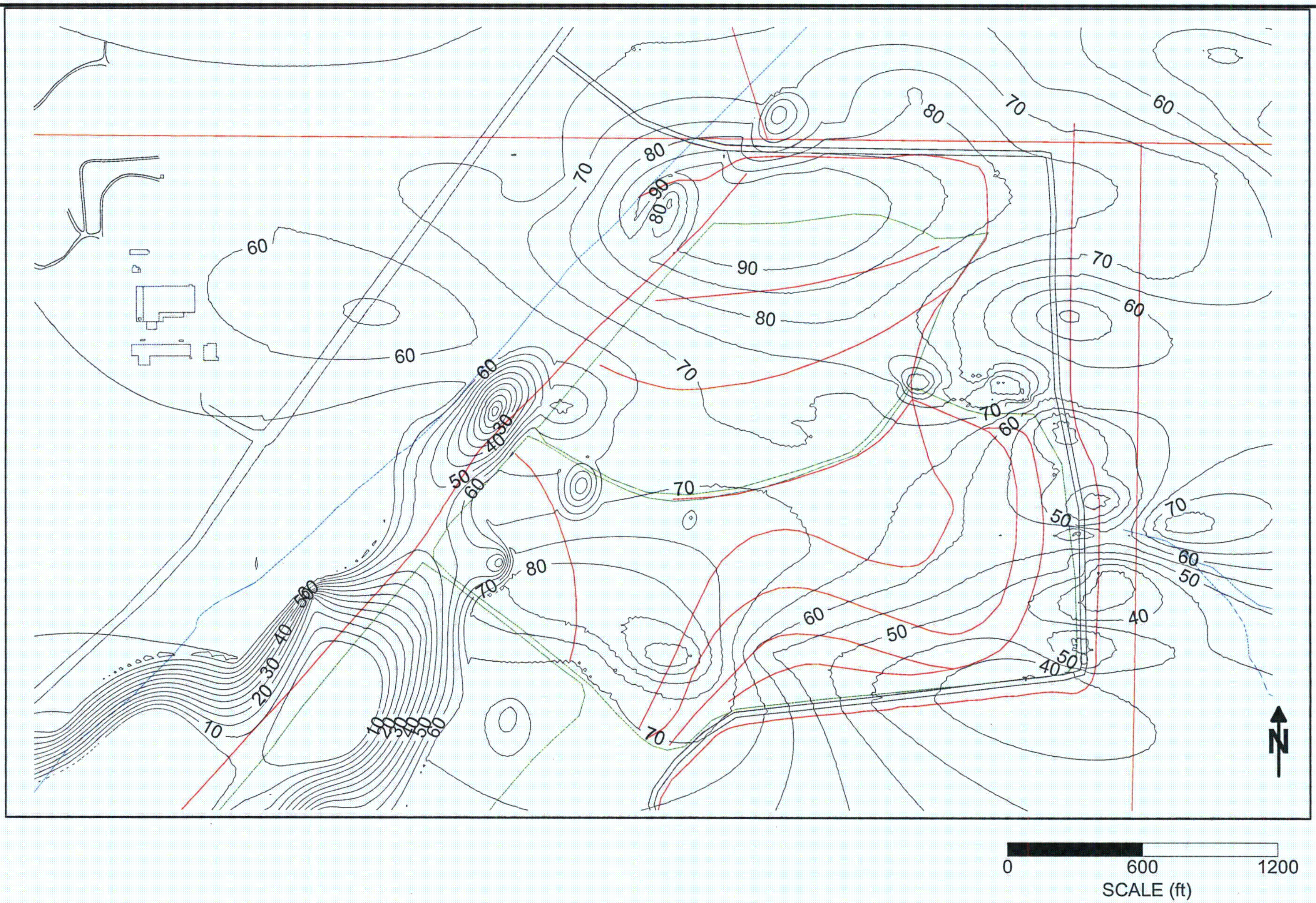

FIGURE 11
Isochore contours for Zone 1 (ft)

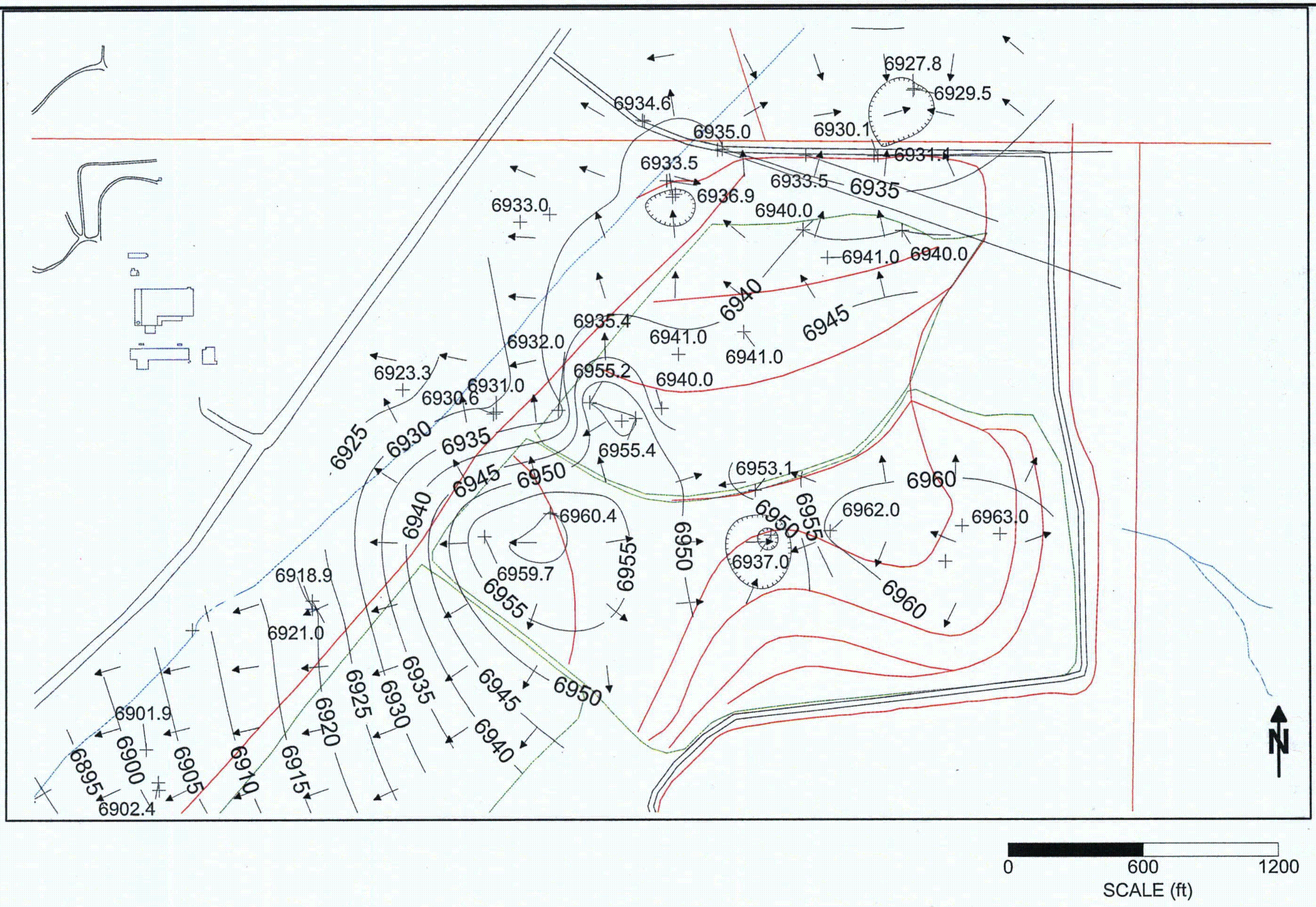

FIGURE 12
1st Qtr. 1986 Alluvium water table elevation contours (ft amsl)
Directions of hydraulic gradient indicated by arrows.

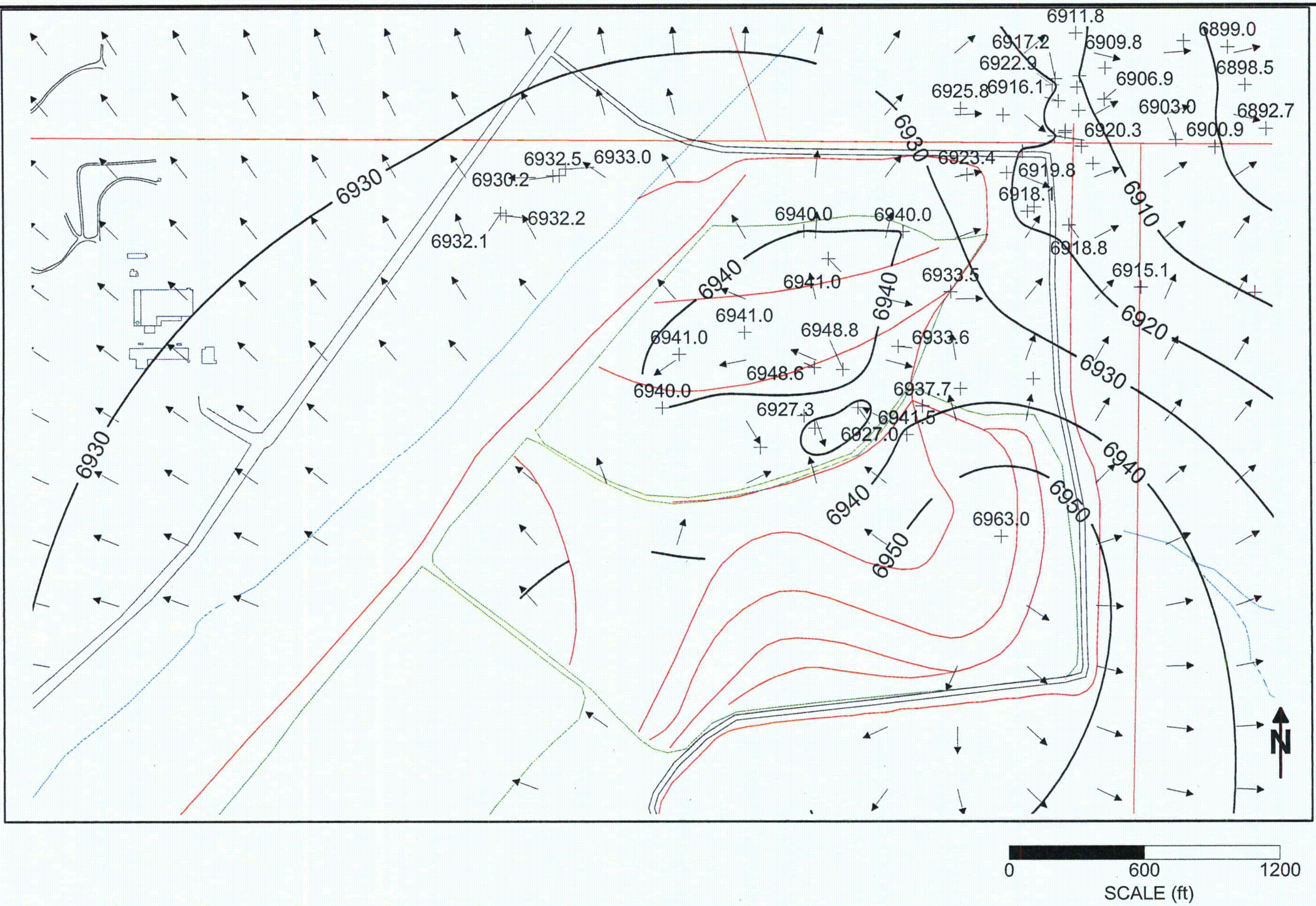

FIGURE 13
First qtr. 1986 zone 3 piezometric surface elevation contours (ft amsl)
Directions of hydraulic gradient indicated by arrows.

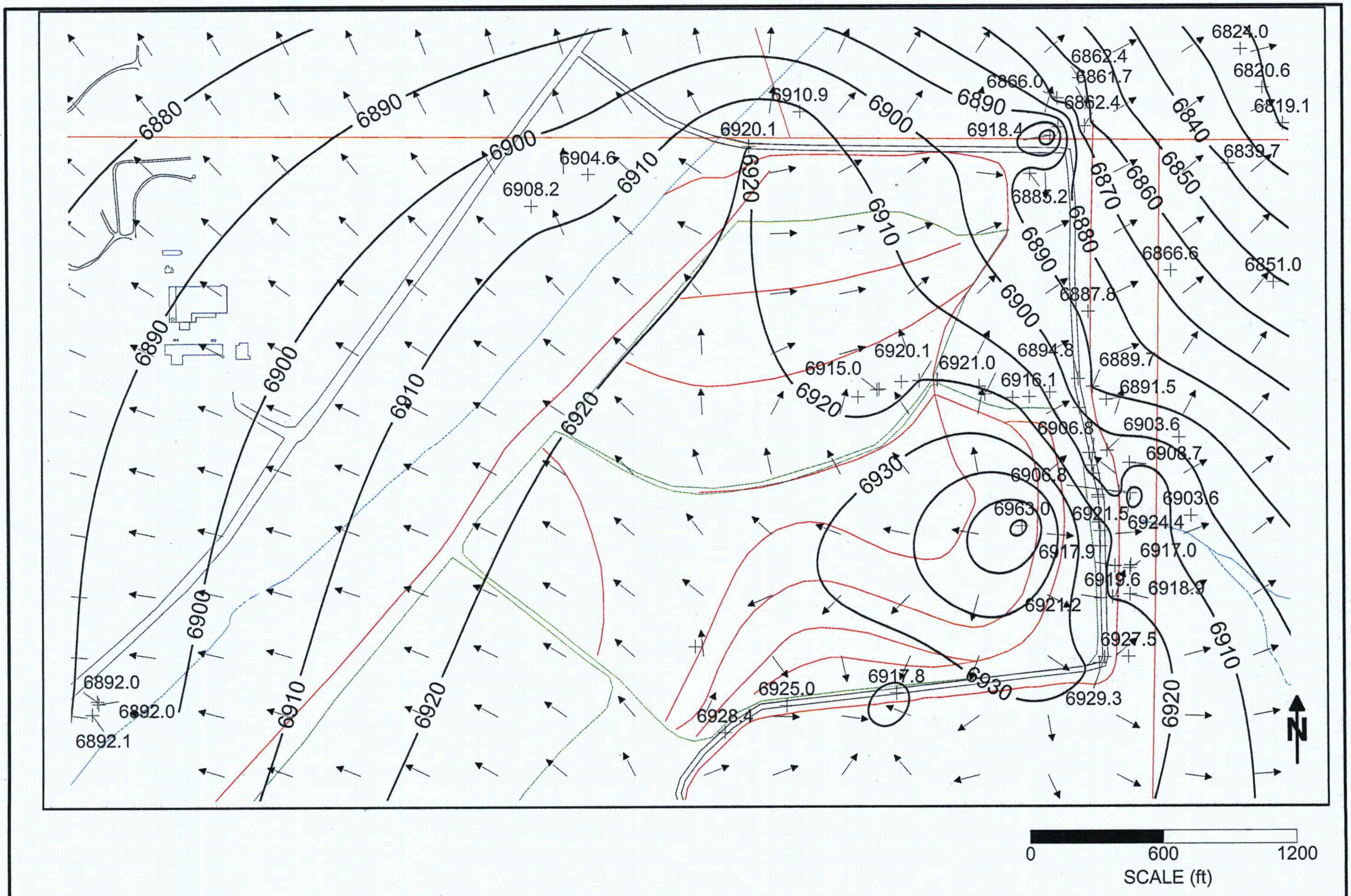

FIGURE 14

First qtr. 1986 zone 1 piezometric surface elevation contours (ft amsl)
Directions of hydraulic gradient indicated by arrows.

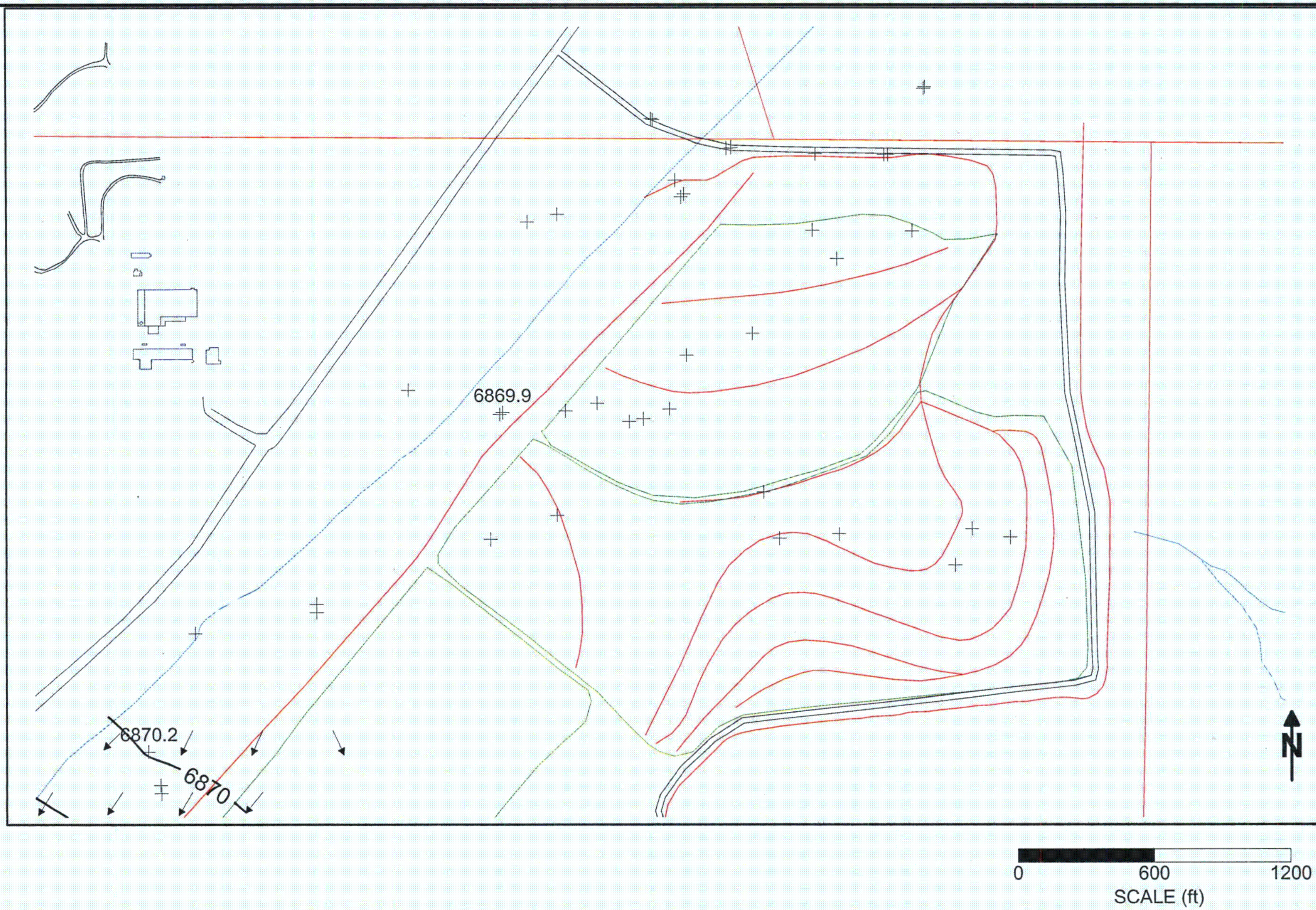

FIGURE 15
October 2011 Alluvium water table elevation contours (ft amsl)
Directions of hydraulic gradient indicated by arrows.

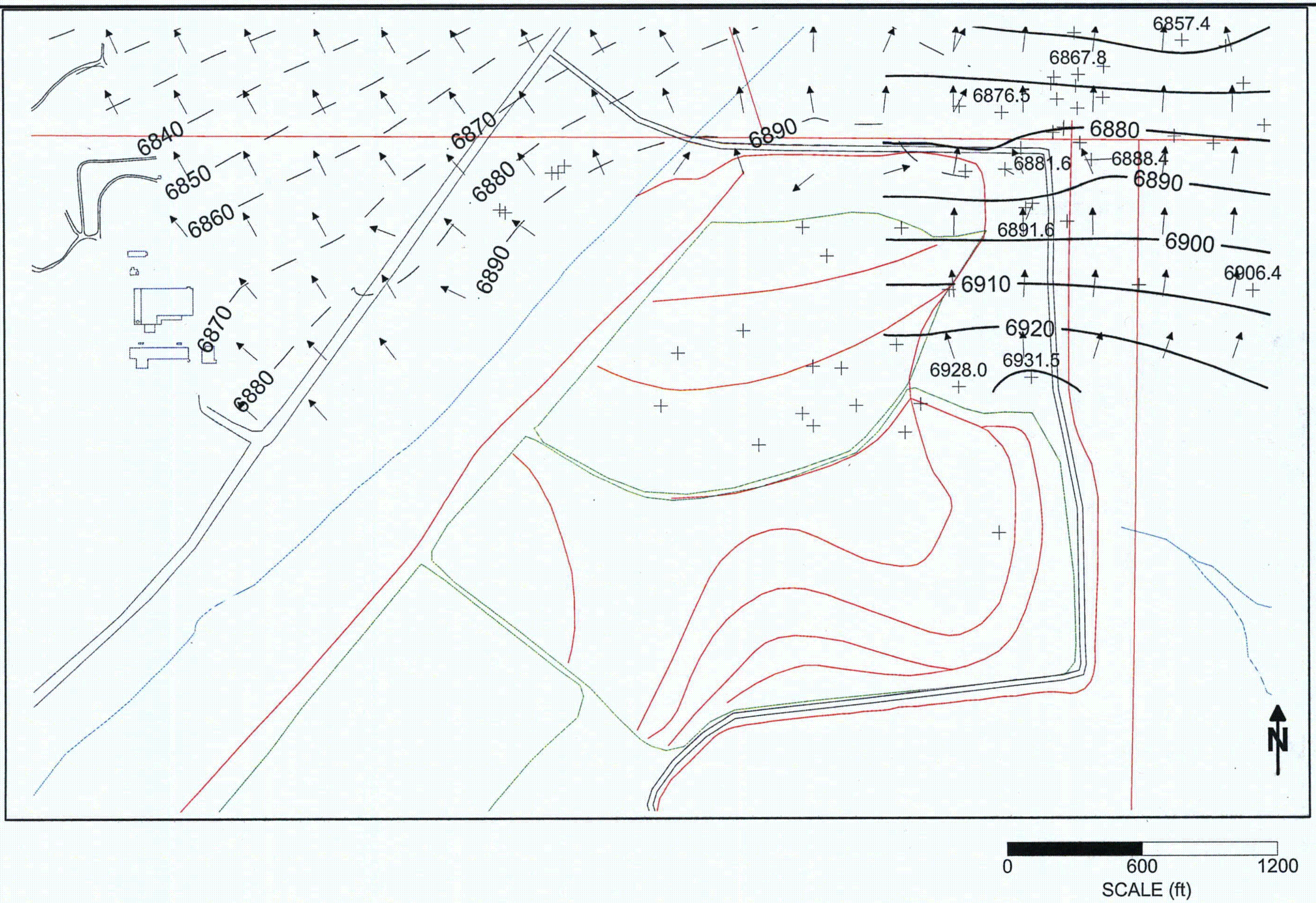

FIGURE 16
October 2011 Zone 3 piezometric surface elevation contours (ft amsl) dashed where based on flow model estimates. Directions of hydraulic gradient indicated by arrows.

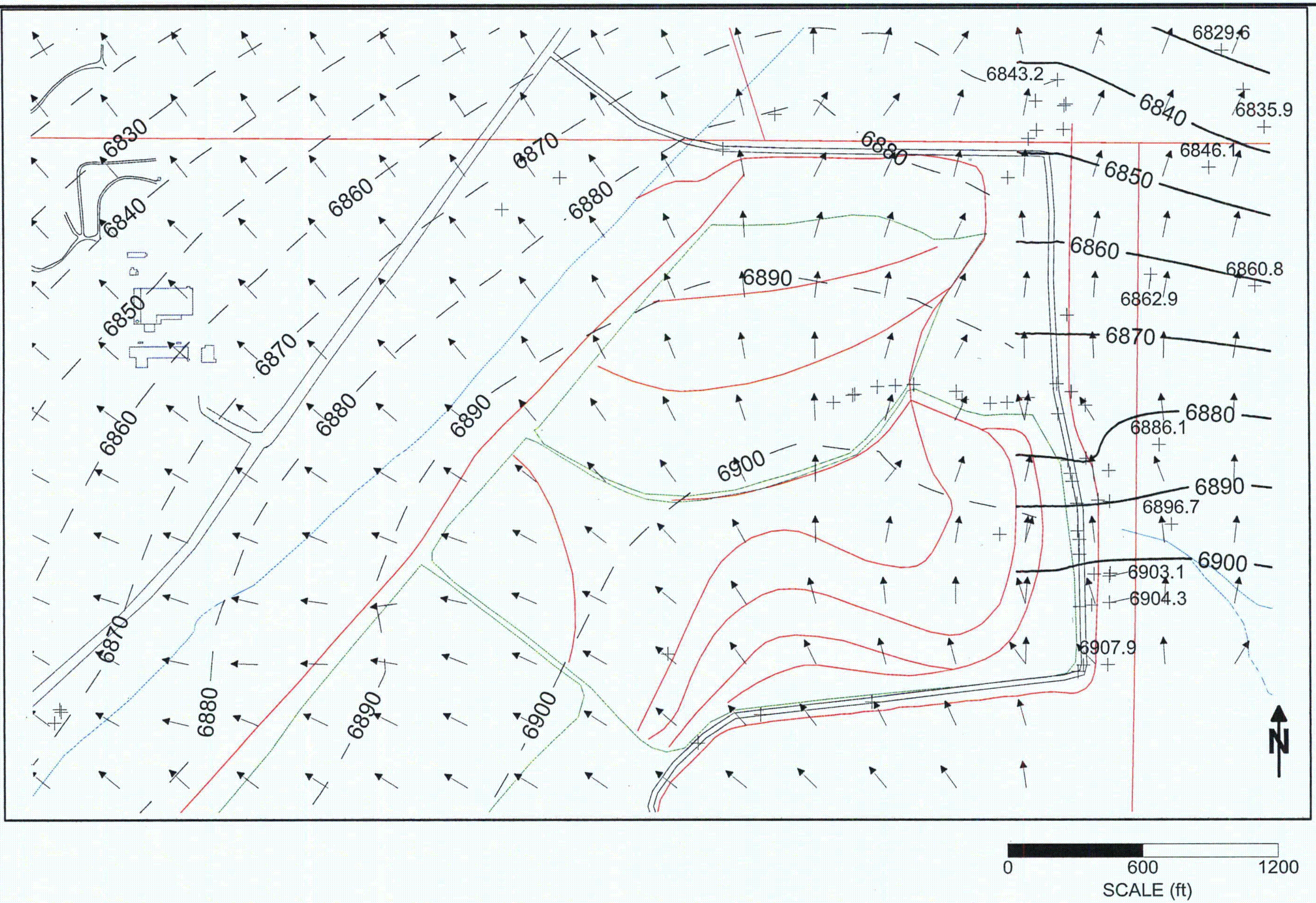

FIGURE 17
October 2011 Zone 1 piezometric surface elevation contours (ft amsl)
dashed where based on flow model estimates. Directions of hydraulic gradient indicated by arrows.

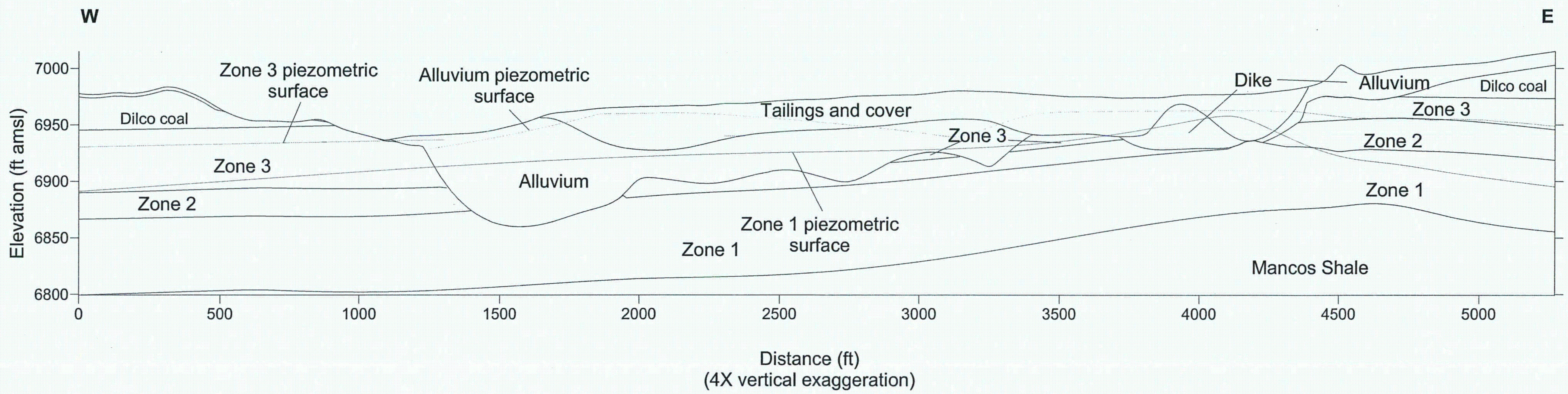

FIGURE 18
Cross Section 1, showing tailings cells and geologic formations,
and estimated piezometric surfaces for the alluvium, Zone 3, and Zone 1
based on 1st Qtr. 1986 well water level measurements.

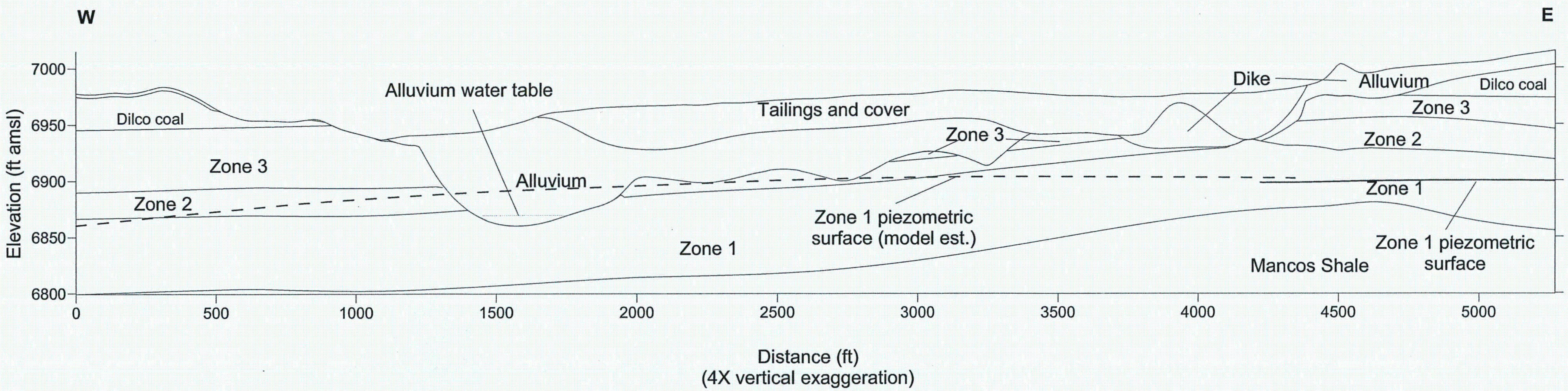

FIGURE 19
Cross Section 1, showing tailings cells and geologic formations, and estimated piezometric surfaces for the alluvium, and Zone 1 based on Oct. 2011 well water level measurements. A portion of the Zone 1 piezometric surface (dashed line) was estimated using the groundwater flow model (Chester Engineers, Oct. 2012). Zone 3 is dry in the area of view.

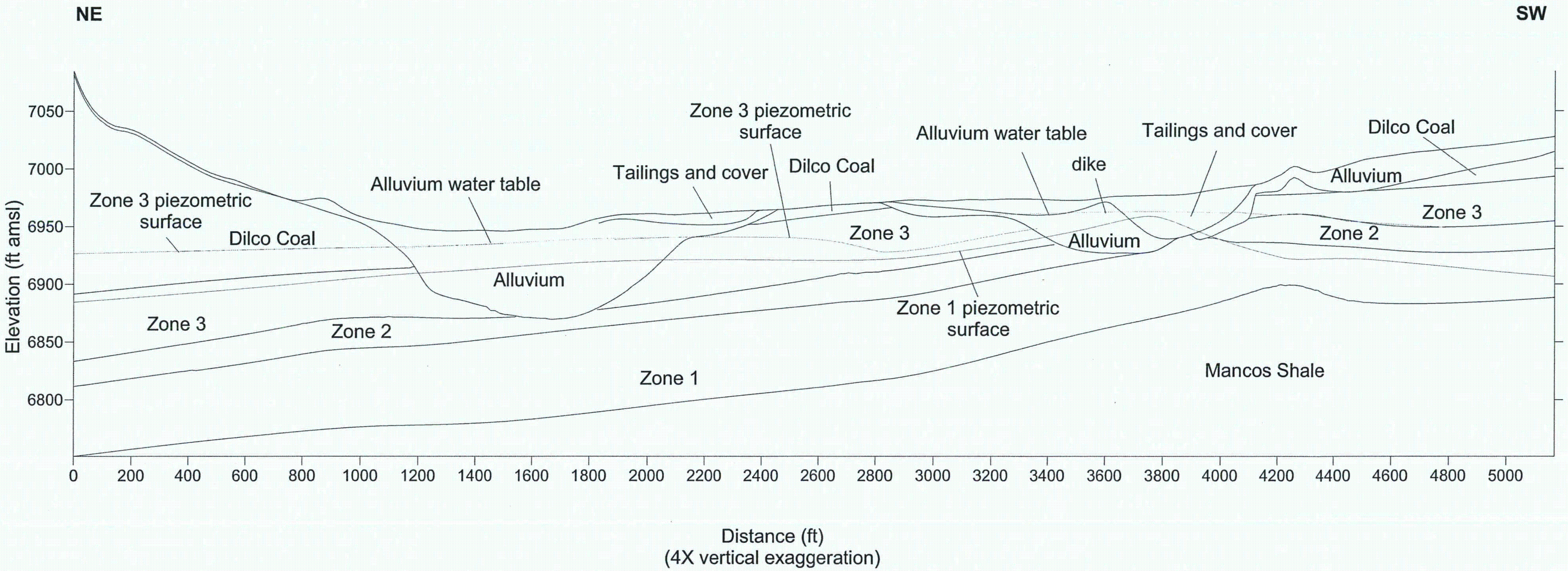

FIGURE 20
Cross Section 2, showing tailings cells and geologic formations,
and estimated piezometric surfaces for the alluvium, Zone 3, and Zone 1
based on 1st Qtr. 1986 well water level measurements.

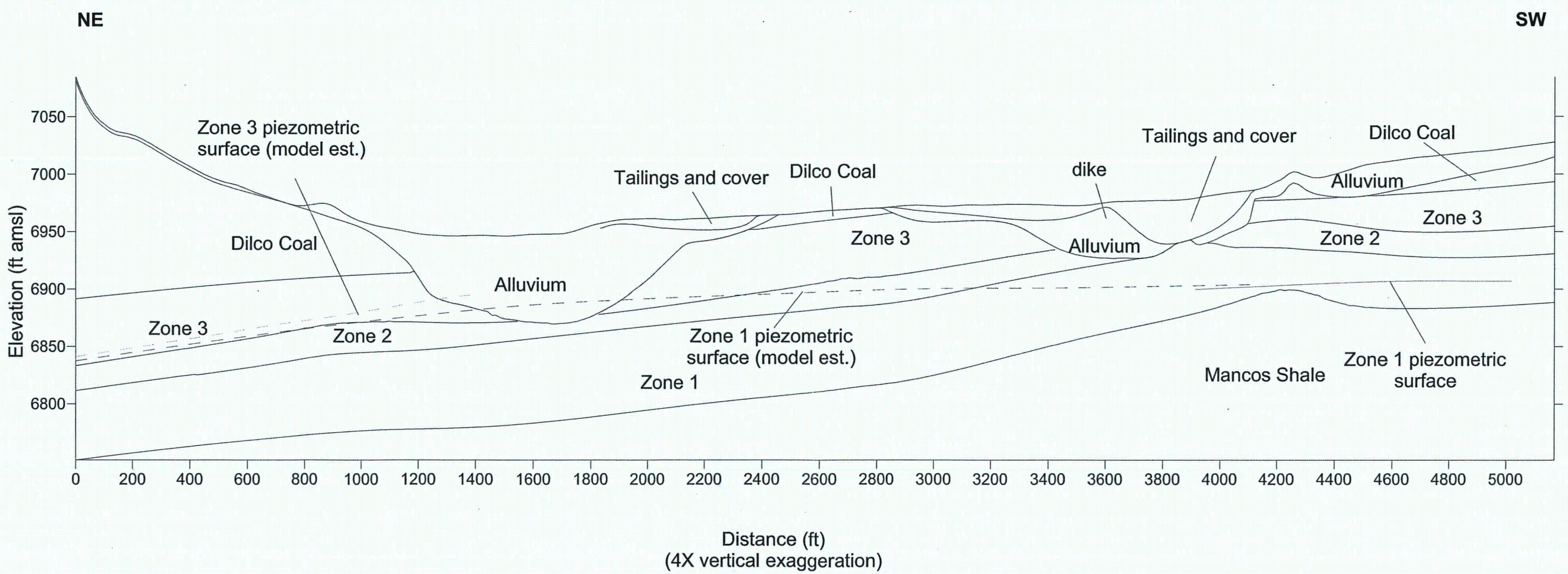

FIGURE 21
Cross Section 2, showing tailings cells and geologic formations, and estimated piezometric surfaces for Zone 3 and Zone 1 based on Oct. 2011 well water level measurements. A portion of the Zone 3 and Zone 1 piezometric surfaces (dashed lines) were estimated using the groundwater flow model (Chester Engineers, Oct. 2012). The alluvium is dry in the area of view.

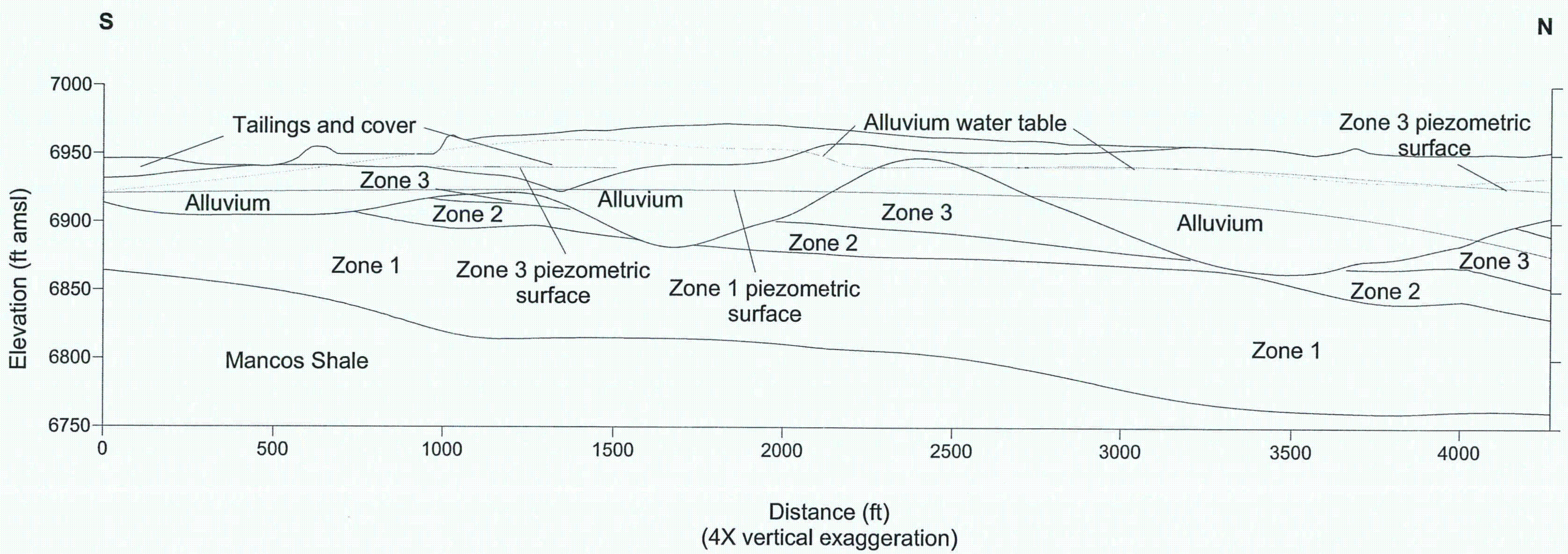

FIGURE 22
Cross Section 3, showing tailings cells and geologic formations,
and estimated piezometric surfaces for the alluvium, Zone 3, and Zone 1
based on 1st Qtr. 1986 well water level measurements.

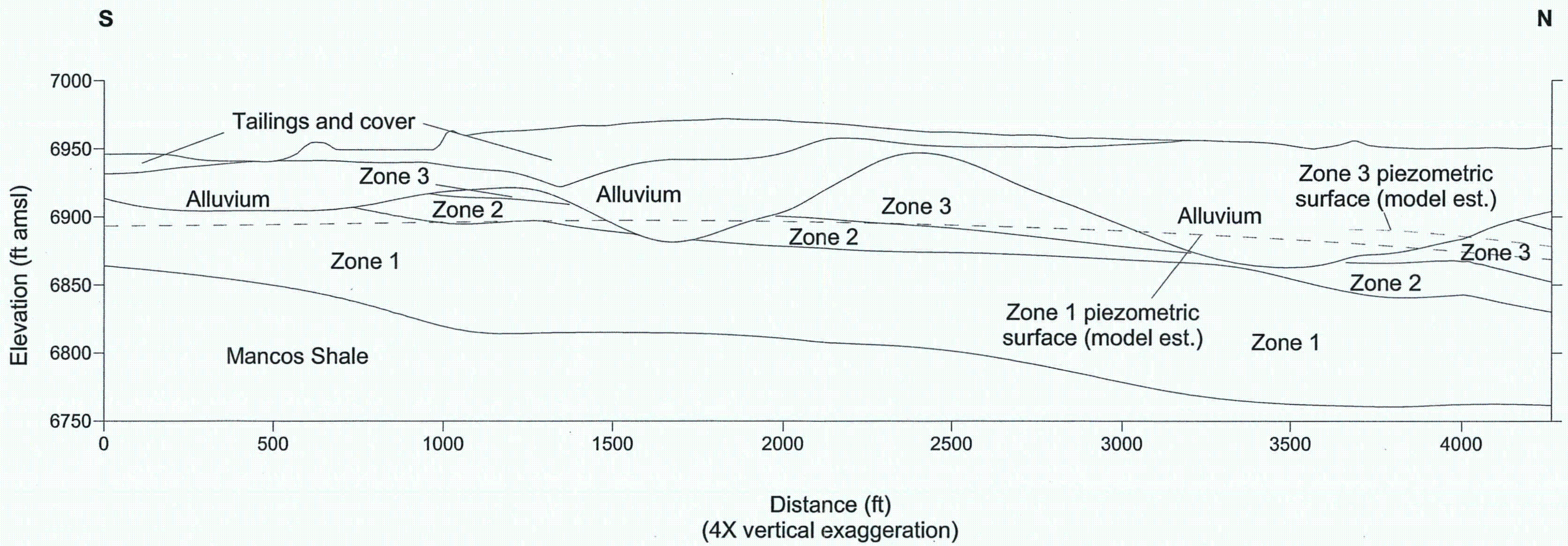

FIGURE 23
Cross Section 3, showing tailings cells and geologic formations, and estimated piezometric surfaces for Oct. 2011. The Zone 3 and Zone 1 piezometric surfaces (dashed lines) were estimated using the groundwater flow model (Chester Engineers, Oct. 2012). The alluvium is dry in the area of view.

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APPENDIX B.2

AQUIFER TESTING AND MATERIAL PROPERTIES

CHESTER ENGINEERS

Technical Memorandum

Date: July 19, 2013

Subject: **Aquifer Testing and Material Properties**

Prepared By: James Ewart, Ph.D., P.G.

Reviewed By: Mark Jancin, Ph.D., P.G.

Well Pumping Test Analyses

Hydraulic properties have been estimated for each of the three transmissive hydrostratigraphic zones at the UNC Church Rock Site (Site). These estimates were based on analyses of time-drawdown data collected from numerous wells during pumping tests. Figures 1 through 3 show the locations of wells where such data was obtained in the alluvium, Zone 3, and Zone 1. Tables 1 through 3 list estimates of hydraulic properties, pumping test types, analytical methods and citations for each of the well data-set analyses.

Field Permeability Test Analyses

Field permeability tests were made in 27 soil borings within and adjacent to the area of the tailings cells. Figure 4 shows the locations of borings where these tests were made. With one exception the borings were made prior to the construction of the former tailings ponds (Sergent, Hauskins & Beckwith, 1974, 1976). The exception was at boring DH-3, which was made outside of the area of the former tailings ponds in 1980 (see Figure 4 for location). The field permeability tests made in soil borings took place in unsaturated alluvium. This contrasts with the well pumping tests referenced in the previous section, which were all made in the saturated portion of the various hydrostratigraphic zones.

The type of borehole infiltration test used to estimate field permeabilities employed a well permeameter to monitor infiltration rates while maintaining a constant water level in the boring. This procedure and method of analysis used was the US Bureau of Reclamation Test Procedure E-19 (Appendix Des E-19, US Bureau of Reclamation Earth Manual, 1974). The objective of the test is to derive a field permeability or saturated hydraulic conductivity. Flow is maintained for a sufficient time for a zone of saturation to develop around and below the bottom of the soil boring. Flow is both radial and downward. Therefore, the resulting estimate of field permeability or hydraulic conductivity is not strictly a horizontal or vertical component, but rather an effective (nondirectional) value. This contrasts with the estimated components of transmissivity or hydraulic conductivity estimates derived from well pumping tests, which typically are influenced by horizontal flow. Results of the field permeability analyses are listed in Table 4.

Representative Hydraulic Property Estimates

Representative hydraulic properties have been determined for each of the three hydrostratigraphic zones where tests have been made. Canonie (1987) derived such estimates based on a critical review of previous pumping test analyses (i.e. as listed in Tables 1 and 2). Their estimates of representative hydraulic properties appear at the bottom of Subtables 2.1, 2.2, and 2.3.

Other estimates of representative hydraulic properties are listed in Table 5. These estimates postdate the work of Canonie (1987), with the exception of the listed estimates for Zone 1 (replicated from Table 2.3) and the listed analysis from Sergent, Hauskins & Beckwith (1976) summarizing the results of their field permeability tests. One of the estimates for the alluvium (US Filter, 2004) was based on a comprehensive review of the logs and field permeability tests of soil borings and a reevalution of the estimates shown in Table 2.3.

Of particular note for Zone 3 are the references cited for the listed Zone 3 representative hydraulic properties (ARCADIS BBL, 2007 and N.A. Water Systems, 2008). Well test data from the In-Situ Alkalinity Stabilization Study (ARCADIS BBL, 2007) provided an estimate of the hydraulic conductivity (5 X 10-5 cm/s) in Zone 3 approximately 500 ft north of the north tailings cell. This value of hydraulic conductivity is less by an order of magnitude than that previously interpreted to be representative of Zone 3 materials. Investigation of the mineralogy of the local Zone 3 materials indicated pore clogging (by clay), which was interpreted to be a reaction product of tailings-derived acidity with native feldspar. This finding was important to the understanding that hydraulic conductivity in Zone 3 sandstones changed (reduced) over time as a result of the geochemical effects of acidity derived from tailing seepage.

N.A. Water Systems (2008) utilized information from the In-Situ Alkalinity Stabilization Study in an analysis to derive representative hydraulic properties for Zone 3. This analysis employed hydrographs from 26 Zone 3 wells covering the period from June 2000 through October 2007. During the portion of this period leading up to January 2005 Zone 3 was in a state of slow gravity-driven drainage, without influence from well pumping. During the remainder of this period Zone 3 was influenced by pumping from as many as eight wells. Extrapolations of the pre-pumping hydrograph trends were used to separate effects of pumping-induced drawdown from the post-pumping portions of the well hydrographs. The volume of aquifer drained by pumping was compared to the measured volume of water pumped to derive an effective porosity estimate of 6 percent.

Having a representative effective porosity estimate for Zone 3 made it possible to calculate the rate of groundwater loss from storage in Zone 3 from the well hydrographs from the pre-pumping period of gravity-driven drainage. Areal estimates of the rates of storage loss were used to estimate fluxes across three transects perpendicular to the hydraulic gradient in Zone 3 (all map locations are shown in N.A. Water Systems, 2008). Estimates of representative hydraulic conductivites along two of the transects (the estimated hydraulic conductivity at the southernmost transect was taken from the analysis of ARCADIS BBL (2007), see also Table 5) were made using the Darcy one-dimensional flow equation. This equation was solved for hydraulic conductivity by using the estimated effective porosity of 6 percent and the measured hydraulic gradients at the transects. An independent analysis of representative transmissivity was also made by aquifer test analysis of the time-drawdown data from separated from the well hydrographs from the period of pumping. The resulting estimate was consistent with the results of the estimates based on groundwater fluxes. The representative hydraulic properties listed for Zone 3 in Table 5 are the best available estimates of current conditions, because they are very broadly based in area and time on comprehensive field data.

Material Property Zones Derived from Model Calibration

Chester Engineers (2012) describes the development of a numerical groundwater flow model of the Site and surrounding area. Hydraulic properties such as those described in previous sections are integral to the construction of such a model. The representative hydraulic properties listed in Table 5 were the basis for initial estimates for the flow model. These estimates were assigned to material property zones that correspond with sub-areas of the hydrostratigraphic zones simulated in the model. The estimates were refined through a process of calibration whereby adjustments are made to improve the capacity of the model to replicate targets such as the well hydrographs described in the previous section. The results of this process are germane, because the material property zones and their assigned hydraulic properties were tested against documented behavior (e.g. historical well hydrographs) in a physics-based flow model.

Figures 5 through 9 are maps showing the material property zones developed for the groundwater flow model (Chester Engineers, 2012). The property zones are assigned to the Site hydrostratigraphic units and overlying geologic units (Dilco Coal). Zone 3 is subdivided into an upper and lower portion in the assignment of material property zones. The hydraulic properties assigned to each of the material property zones shown in Figures 5 through 9 are listed in Table 6.

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TABLES

TABLE 1 Historical Aquifer Test Analysis Results
UNC Church Rock Site, Church Rock, New Mexico

Well/Boring	Zone	Test Type	Analytical Method Identification	Transmissivity (gal/d/ft)	Storage Coefficient	Reference
606	1	SD	1	39	-	BAPA83
606	1	SD	2	31 - 86	-	BAPA83
606	1	SD	8	50	-	BAPA83
606	1	SD	9	89	-	BAPA83
607	1	SD	1	86	-	BAPA83
607	1	SD	2	36 - 100	-	BAPA83
607	1	SD	8	70	-	BAPA83
607	1	SD	9	88	-	BAPA83
608	3	SD	1	507	-	BAPA83
608	3	SD	2	270 - 630	-	BAPA83
608	3	SD	8	430	-	BAPA83
608	3	SD	9	500	-	BAPA83
609	3	SD	1	1020	-	BAPA83
609	3	SD	2	320 - 890	-	BAPA83
609	3	SD	8	850	-	BAPA83
609	3	SD	9	1000	-	BAPA83
610	3	SD	1	890	-	BAPA83
610	3	SD	2	640 - 1200	-	BAPA83
610	3	SD	8	800	-	BAPA83
610	3	SD	9	800	-	BAPA83
611	1	SD	1	132	-	BAPA83
611	1	SD	2	120 - 210	-	BAPA83
611	1	SD	8	140	-	BAPA83
611	1	`	9	180	-	BAPA83
612	1	SD	7	60 - 80	-	BAPA83
613	3	SD	1	2106	-	BAPA83
613	3	SD	2	2400 - 3800	-	BAPA83
613	3	SD	8	1700	-	BAPA83
613	3	SD	9	1900	-	BAPA83
505B	3	SD	7	1800	-	BAPA83
126	3	TC	-	2668	0.02	BAPA84
123**	3	TC	-	1220 - 4494	0.01 - 0.04	BAPA84
121	3	TC	-	1138	0.02	BAPA84
119***	Alluvium	TC	-	1138	0.03	BAPA84
505-B	3	TC	-	569 - 1708	4.2E-03 to 4.3E-03	BAPA84
518	3	TC	-	1220	0.03	BAPA84
517	3	TC	-	267 - 2108	0.01	BAPA84
8-D****	Alluvium	TC	-	1314	0.03	BAPA84
7-D†	Alluvium	TC	-	1067	0.03	BAPA84
105-A	Alluvium	TC	-	1004	0.03	BAPA84
601††	1	TC	-	833	0.15	BAPA84
10-D	3	TC	-	1314	0.12	BAPA84
9-D	3	TC	-	1313 - 1760	0.01 - 0.03	BAPA84
106-D†	3	TC	-	1067 - 1708	0.01	BAPA84
36-05/10	Composite*	TC	-	1220 - 2846	0.01 - 0.04	BAPA84
36-05/07	Composite*	TC	-	1067	0.05	BAPA84
609	3	TC	-	122 - 1626	3.1E-03 to 0.01	BAPA84
11-D†	3	TC	-	2339	1.7E-03	BAPA84
12-D†	3	TC	-	1067	1.3E-03	BAPA84
522†††	Composite*	TC	-	569	4.5E-04	BAPA84
125	3	TC	-	1004	3.7E-03	BAPA84
127	3	TC	-	2134	1.7E-03	BAPA84
109-A†	Alluvium	TC	-	1552	3.4E-03	BAPA84
118-D†	3	TC	-	1986	0.01	BAPA84
110-D	Composite*	TC	-	1552	0.04	BAPA84
506-A	1	TC	-	108	1.3E-04	BAPA84
448	1	TC	-	100	0.01	BAPA84
606	1	TC	-	39 - 87	0.01	BAPA84
612	1	TC	-	118	4.0E-03	BAPA84
505-A	1	TC	-	103	0.01	BAPA84
120	1	TC	-	53 - 134	0.01	BAPA84
Zone 1	1	LSR	-	68	0.0014	BAPA84
Zone 1	1	LSR	-	300	0.05	BA85
600	3	R	A	44.8	-	BA82b
600	3	TD	B	35.1	-	BA82b
600	3	TD	C	26.9	-	BA82b
600	3	TD	D	31.4	-	BA82b
517	3	TD	E	31.3	0.014	BA82b
517	3	TD	F	42.5	0.016	BA82b
604	1	TD	B	21.3	-	BA82b
604	1	TD	C	17.7	-	BA82b
604	1	TD	D	21.9	-	BA82b
519	1	TD	E	60.2	0.01	BA82b
519	1	TD	F	58.2	0.01	BA82b

TABLE 1 Historical Aquifer Test Analysis Results
UNC Church Rock Site, Church Rock, New Mexico

Well/Boring	Zone	Test Type	Analytical Method Identification	Transmissivity (gal/d/ft)	Storage Coefficient	Reference
603	1	TD	B	49.6	-	BA82b
603	1	TD	C	36	-	BA82b
603	1	TD	D	42	-	BA82b
432	3	Aquifer test at 402	G	942.5	0.015	NMEID81
404	3	Aquifer test at 402	G	822.8	0.0042	NMEID81
406	3	Aquifer test at 402	G	1236	0.02	NMEID81
433	3	Aquifer test at 402	G	1324	0.013	NMEID81
430	3	Aquifer test at 438	G	2135	0.037	NMEID81
431	3	Aquifer test at 438	G	2420	0.019	NMEID81
439	3	Aquifer test at 438	G	2233	0.034	NMEID81
437	3	Aquifer test at 438	G	1749	0.029	NMEID81
430	3	Aquifer test at 438	H	2071 (SAI), 1703 (NMEID)	0.047 (SAI), 0.050 (NMEID)	NMEID81
431	3	Aquifer test at 438	H	2505	0.018	NMEID81
439	3	Aquifer test at 438	H	2618	0.019	NMEID81
437	3	Aquifer test at 438	H	2505	0.032	NMEID81
322	1	Aquifer test at 323A	G	11000	0.013	NMEID81
323	1	Aquifer test at 323A	G	6812	0.01	NMEID81
324	1	Aquifer test at 323A	G	12571	0.05	NMEID81
304	Composite*	Aquifer test at 303	G	200	-	NMEID81
303	Composite*	Aquifer test at 303	G	185	-	NMEID81
304	Composite*	Aquifer test at 303	I	115	-	NMEID81
335	Composite*	Aquifer test at 335	G	532	-	NMEID81

Test Type

TD	Time-Drawdown
SD	Step-Drawdown
TC	Type Curve
LSR	Least Squares Regression
R	Recovery

Acronyms

SAI	Science Applications Incorporated
NMEID	New Mexico Environmental Improvement Division

Analysis Procedures

1	Transmissivity (Jacob Method)
2	Transmissivity (Cooper-Jacob Method)
7	Transmissivity/Storage Coefficient (Theis and Cooper-Jacob Method)
8	Transmissivity (Sternberg)
9	Transmissivity (Cooper-Jacob Method: Modified)
A	Theis Recovery (1936)
B	Papadopulos and Cooper (1967)
C	Cooper and Jacob (1946)
D	Jacob (1944)
E	Theis (1935)
F	Chow (1952)
G	Jacob-Cooper Approximation
H	Type-Curve Method
I	Recovery Method

References

BA82b Billings & Associates, Inc., 1982b. Results and Drilling and Testing of the 600 Series and Continuation of the 500 Series: Upper Gallup Formation and Alluvial Aquifer. Billings & Associates, Inc., Albuquerque, New Mexico, September 10, 1982

BA85 Billings & Associates, Inc., 1985. Final Evaluation of the Seepage Collection System: East - Zone 1, Phase I. Billings & Associates, Inc., Kimberling City, Missouri, August 1985.

BAPA83 Billings & Associates, Inc., and S. S. Papadopulos & Associates, 1983. Report of Drilling and Step Drawdown Testing fo the Seepage Cleanup System in The Vicinity of Wells TWQ-124 and 450-A. Billings & Associates, Inc., Kimberling City, Missouri, and S. S. Papadopulos & Associates, Rockville, Maryland, December 1983.

BAPA84 Billings & Associates, Inc., and S. S. Papadopulos & Associates, 1984. Evaluation of the Seepage Collection System: Northeast, Phase I. Billings & Associates, Inc., Kimberling City, Missouri, and S. S. Papadopulos & Associates, Rockville, Maryland, July 1984.

NMEID81 Letter from Richard R. Raymondi and Ron Conrad (NMEID) to Thomas M. Hill (UNC Mining and Milling), June 17, 1981.

*	Composite wells not identified on associated maps for specific hydrostratigraphic units
**	Well 123 reported to be an alluvial well in BAPA84, but is actually a Zone 3 well.
***	Well 119 not shown on maps because it is not listed in Canonie (1987) water level tabulations.
****	Identified as Well 8 (instead of 8-D) in reference document and as alluvial well, but the interval monitored is unknown.
†	Noted wells were identified incorrectly (missing the trailing letter designation) in reference document table.
††	Well 601 identified as a composite well in reference documents but is a Zone 1 well
†††	Well 522 identified as an alluvial well in the reference document but is a composite well

Table 2.1 (Canonie, 1987)
Summary of Pumping Test Data for Alluvium
UNC Church Rock Site, Church Rock, New Mexico

Well No.	Type of Test (1)	Transmissivity (gpd/ft)	Hydraulic Conductivity (cm/sec)	Storativity
625	P	500	1.2E-03	0.003
637	P	30	5.7E-05	-
642	P	8400	2.0E-02	0.02 - 0.15
EPA-21	P	6100	1.4E-02	-
EPA-23	P	6600	8.9E-03	0.1
EPA-28	P	1300	8.7E-04	0.03
Representative Properties (2)		7000	1.0E-02	0.05

(1) P = Pumping
(2) Representative properties determined from results for Wells 642, EPA-21, and EPA-23. These wells had the most reliable and complete data for both pumping and recovery phases of the tests. Also provides the most conservative estimate of hydraulic properties.

Reference

Canonie Environmental, 1987. Geohydrologic Report, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico., May 1987.

Table 2.2 (Canonie, 1987)
Summary of Pumping Test Data for Zone 3
UNC Church Rock Site, Church Rock, New Mexico

Well No.	Type of Test (1)	Transmissivity (gpd/ft)	Hydraulic Conductivity (cm/sec)	Storativity
402 (2)	P	900	1.0E-03	0.02
438 (5)	P	2400	2.3E-03	0.03
600 (3)	P	35	3.4E-05	0.01
608	S	500	5.9E-04	-
609	S	900	1.0E-03	0.004
610	S	900	1.0E-03	-
613	S	2000	1.9E-03	-
EPA-15	P	1500	1.4E-03	0.05
Representative Properties (4)	-	1000	1.0E-03	0.05

(1) P= Pumping, S = Step Drawdown
(2) No response in Well 409, which is screened in Zone 1 when when well 402 pumped. Indicates that there is no communication through Zone 2.
(3) Results from test in Well 600 questionable, possibly due to irregular discharge rates.
(4) Representative properties determined from tests and review of geophysical logs where available. Higher hydraulic properties believed related to well completion and possibly fracturing. For example, geophysical log for Well 613 indicates that this well is completed in the more porous`
(5) Note from file: Anisotropy ratio is 1.7 in the horizontal plane at well 438. The major direction is N27 degrees W. The ratio is not high enough to indicate strong directional properties caused by fractures or other such features.

Reference

Canonie Environmental, 1987. Geohydrologic Report, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico., May 1987.

Table 2.3 (Canonie, 1987)
Summary of Pumping Test Data for Zone 1
UNC Church Rock Site, Church Rock, New Mexico

Well No.	Type of Test (1)	Transmissivity (gpd/ft)	Hydraulic Conductivity (cm/sec)	Storativity
606	S	50	5.6E-05	-
607	S	80	8.4E-05	0.02
611	S	150	1.7E-04	-
604	P	50	6.6E-05	0.01
603	P	40	5.6E-05	-
East Seepage Collection System	Multiple Well	300	2.9E-04	0.05
Representative Properties (2)	-	150	1.0E-04	0.05

(1) P= Pumping, S = Step Drawdown
(2) Representative properties determined from high average of the tests. Higher hydraulic properties reported for East Seepage Collection System believed related to fracturing in the vicinity of Well 311.

Reference

Canonie Environmental, 1987. Geohydrologic Report, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico, May 1987.

TABLE 3 Aquifer Test Analysis Results Associated with SWA and Zone 3 Pumping System Design
UNC Church Rock Site, Church Rock, New Mexico

Well/Boring	Zone	Test Type	Analytical Method Identification	Transmissivity (ft2/day)	Storage Coefficient	Reference
804	Alluvium	Time-Drawdown	Transmissivity/Storage Coefficient (Theis and Cooper-Jacob Method)	3,200 - 4,300	0.0048 - 0.008	Canonie , 1989a
632	Alluvium	Time-Drawdown	Transmissivity/Storage Coefficient (Theis and Cooper-Jacob Method)	2,500 - 3,900	0.01 - 0.017	Canonie , 1989a

Well/Boring	Zone	Test Type	Specific Capacity (gpm/ft)	Well Efficiency (%)	Operational Q (gpm)	Predicted Operational Drawdown (ft)	Reference
708	3	Multi-well test	0.38	59.5	5	16.6	Canonie, 1989b
709	3	Multi-well test	0.17	65.3	5	33.2	Canonie, 1989b
710	3	Multi-well test	0.06	49.9	2	35.4	Canonie, 1989b
711	3	Multi-well test	0.45	55.6	5	21.6	Canonie, 1989b
712	3	Multi-well test	0.33	34	5	18.8	Canonie, 1989b
701	3	Multi-well test	0.4	No data	No data	No data	Canonie, 1989c
702	3	Multi-well test	No data	No data	No data	No data	Canonie, 1989c
703	3	Multi-well test	0.4	No data	No data	No data	Canonie, 1989c
705	3	Multi-well test	0.2	No data	No data	No data	Canonie, 1989c
706	3	Multi-well test	0.6	No data	No data	No data	Canonie, 1989c
707	3	Multi-well test	0.2	No data	No data	No data	Canonie, 1989c
713	3	Multi-well test	0.3	No data	No data	No data	Canonie, 1989c

References

Canonie, 1989a Canonie `

Canonie, 1989b Canonie Environmental - Table 1 of 6/27/1989 letter, proj. # 86-060-18 F2 - Evaluation of Zone 3 Aquifer Test, Pumping Rates

Canonie, 1989c Canonie Environmental - UNC - Zone 3 Calculations 9/6/1989, proj. # 86-060-18 F2 - Evaluation of Zone 3 Aquifer Test, Pumping Rates

TABLE 4 Historical Field Permeability Analysis Results
UNC Church Rock Site, Church Rock, New Mexico

Boring	State Plane (NAD83 E)	State Plane (NAD83 N)	Upper Depth	Lower Depth	Coefficient of Permeability (ft/year, unless noted)	Reference
SHB74-04	2524492.91	1691624.69	10	10	4.0	SHB74
SHB74-12	2523187.91	1690981.96	10	10	3.8	SHB74
SHB74-15	2523261.52	1690422.65	10	10	27.0	SHB74
SHB76-03	2523382.68	1690874.38	9	23.5	3.5	SHB76
SHB76-03	2523382.68	1690874.38	19	25	30.0	SHB76
SHB76-04	2523708.24	1691265.29	19	24	9.7	SHB76
SHB76-04	2523708.24	1691265.29	9	16.5	5.5	SHB76
SHB76-05	2524073.79	1691605.95	9	18.5	0.0	SHB76
SHB76-05	2524073.79	1691605.95	19	25	1.7	SHB76
SHB76-06	2524433.15	1691949.78	9	16.5	5.5	SHB76
SHB76-06	2524433.15	1691949.78	19	24.5	5.1	SHB76
SHB76-07	2524795.71	1692306.07	9	17.5	1.1	SHB76
SHB76-07	2524795.71	1692306.07	18.5	27.5	1.0	SHB76
SHB76-10	2525588.28	1692465.63	1.5	7.5	15.3	SHB76
SHB76-11	2524919.44	1691811.94	9	18	1.1	SHB76
SHB76-11	2524919.44	1691811.94	18.5	27.5	1.0	SHB76
SHB76-12	2525393.22	1691658.59	9	16	12.0	SHB76
SHB76-12	2525393.22	1691658.59	18.5	25	14.5	SHB76
SHB76-13	2525876.34	1691511.41	9	17.5	8.0	SHB76
SHB76-13	2525876.34	1691511.41	18.5	25	1.3	SHB76
SHB76-14	2524109.29	1690925.18	9	16	7.3	SHB76
SHB76-14	2524109.29	1690925.18	19.5	21.5	37.0	SHB76
SHB76-15	2523414.52		9	16	28.0	SHB76
SHB76-15	2523414.52	1690115.6	19	24	105.0	SHB76
SHB76-16	2523772.08	1689769.57	19	23.5	6.8	SHB76
SHB76-17	2523332.12	1689875.85	9	14.5	42.0	SHB76
SHB76-17	2523332.12	1689875.85	19	24	89.0	SHB76
DH-3	2526229.61	1690225.45	18	20	4.02E-04 cm/s	CSI80

Tests were performed in accordance with the Bureau of Reclamation's E-19 test procedure

References

SHB74 - Sergent, Hauskins & Beckwith, 1974. Preliminary Geotechnical Investigation Report, Tailings Dam, SHB Job E74-1072, October 26, 1974 (January 7, 1975, with Addedum No. 1).

SHB76 - Sergent, Hauskins & Beckwith, 1976. Geotechnical Investigation Report, United1976. Nuclear Corporation, Tailings Dam and Pond, SHB Job E76-1013. May 17,

CSI80 - Civil Systems, Inc., 1980. Final Design Report, Southeast Evaporation Ponds, August 1980.

TABLE 5 Additional Estimates of Hydraulic Conductivity
UNC Church Rock Site, Church Rock, NM

Hydrostratigraphic Unit	Horizontal Hydraulic Conductivity (cm/sec)	Vertical Hydraulic Conductivity (cm/sec)	Porosity	Information Source
Southwest Alluvium	2.00E-03			Recalculated from Canonie (1987) in USFilter (2004)
Southwest Alluvium	2.70E-05			SHB (May 1976) from 27 borehole tests
Southwest Alluvium	2.50E-03			Mean value based on groundwater flow model calibration (Chester Engineers, 2012)
Zone 1	1.00E-04		7-9%	Canonie (1987)
Zone 3 (Southern)	5.00E-05			Well testing by ARCADIS BBL (June 2007)
Zone 3 (Central)	2.16E-04		6-8%	Estimated fluxes and Darcy formula (N.A. Water Systems, April 2008)
Zone 3 (Northern)	2.95E-04		6-8%	Estimated fluxes and Darcy formula (N.A. Water Systems, April 2008)

References

ARCADIS BBL, 2007. In-Situ Alkalinity Stabilization Pilot Study Report. UNC Church Rock Site, Gallup, New Mexico. June 2007.

Canonie Environmental, 1987. Geohydrologic Report, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico., May 1987.

Chester Engineers, 2012. Groundwater Flow Model of the Church Rock Site and Local Area, Church Rock, New Mexico. United Nuclear Corporation Church Rock Tailings Site, Church Rock, New Mexico. October, 2012.

N.A. Water Systems, 2008. Letter Report from James Ewart (NAWS) to M. Purcell (USEPA) and M. Fliegel (USNRC) regarding Recommendations and Summary of Hydrogeologic Analysis Evaluation of Groundwater Flow in Zone 3 for the Design of a Pumping System to Intercept and Recover Impacted Groundwater United Nuclear Corporation's Church Rock Tailings Site, Gallup, New Mexico Administrative Order (Docket No. CERCLA 6-11-89) Materials License No. SUA-1475. April 25, 2008.

Sergent, Hauskins & Beckwith, 1976. Geotechnical Investigation Report, United Nuclear Corporation, Tailings Dam and Pond, SHB Job E76-1013. May 17, 1976.

USFilter, 2004. Rationale and Field Investigation Work Plan to Evaluate Recharge and Potential Cell Sourcing to the Zone 3 Plume, Church Rock Site, Gallup, New Mexico, January 1994.

Table 6
Summary of Model Parameters for Material Property Zones

	Units	Layer 1	Layer 2 (Dilco Coal)		Layers 3 and 4 (Zone 3)						Layer 5 (Zone 2)		Layer 6 (Zone 1)	
		Alluvium	Dilco_M1	Dilco_M2	Z3_M1	Z3_M2	Z3_M3	Z3_M4	Z3_M5	Z3_M6	Z2_M1	Z2_M2	Z1_M1	Z1_M2
Kh(max)[1]	(ft/d)	7.125	0.01	0.1	0.836	2.38	0.418	1.19	0.377	0.142	0.01	0.015	0.425	0.637
Kh(min)	(ft/d)	7.125	0.01	0.067	0.836	1.19	0.418	0.797	0.377	0.142	0.01	0.010	0.425	0.427
Kv	(ft/d)	2.375	0.0005	0.01	0.042	0.238	0.021	0.119	0.0189	0.007	0.0005	0.00075	0.035	0.064
Ss[2]		0.001	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0016	0.0016
Sy		0.25	0.18	0.18	0.12	0.12	0.06	0.12	0.06	0.06	0.12	0.12	0.06	0.06
Porosity		0.25	0.18	0.18	0.12	0.1	0.06	0.08	0.06	0.06	0.06	0.06	0.1	0.1

Notes

1. Hydraulic conductivity is designated by three directional components: Kh(max) is column-wise (northeast), Kh(min) is row-wise (northwest), Kv is vertical.
2. Two storage parameters are designated: Ss is specific storage (for confined conditions) and Sy is specific yield (for unconfined conditions).
3. Porosity influences groundwater velocities used for particle tracking, but does not affect Flow Model estimates of head.
4. See Figures 15a through 15f for maps of material property zones