PHASE II REPOSITORY SITE INVESTIGATION REPORT
NEW WORLD MINING DISTRICT
RESPONSE AND RESTORATION PROJECT

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RESPONSE AND RESTORATION PROJECT

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1.0 INTRODUCTION

This report was prepared for the U.S. Department of Agriculture Forest Service (USDA-FS) by Maxim Technologies, Inc. (Maxim) and presents the results of a Phase II investigation conducted at potential repository sites in the New World Mining District (District). A mine waste repository is needed in the District to dispose of mine wastes that are currently located at disperse sites throughout the District.

The Phase II investigation was conducted in accordance with recommendations forwarded in the Repository Site Evaluation Report (Maxim, 1999a) which was completed by Maxim in June 1999. About 27 potential repository sites were initially evaluated using existing information that was available from published sources and baseline information collected by Crown Butte Mines, Inc. (CBMI). The Repository Site Evaluation Report recommended that one area in particular, designated by CBMI as SB-4, exhibited the most favorable characteristics for mine waste disposal of the 30 sites studied, and that this area be evaluated in greater detail.

For purposes of this report, the SB-4 area is defined as glacial deposits in close proximity to the SB-4A and SB-4B sites described in the Repository Siting Evaluation Report. As the Phase II investigation proceeded, it became evident that numerous distinct sites were present within the SB-4 area, and that these sites were distinct from those shown in the Repository Siting Evaluation Report. So as not to confuse the reader with terminology between this report and the Repository Siting Evaluation Report, specific sites within the SB-4 area have new letter designations and the former -4A and -4B sites are redefined herein.

1.1 OBJECTIVES

The goal of the Phase II investigation was to characterize the geologic and hydrogeologic characteristics of the SB-4 area to the extent that definitive recommendations could be made on the suitability of the area for siting a mine waste repository. Criteria used to select the most favorable locations in the SB-4 area were the same criteria used in the Repository Site Evaluation Report (Maxim, 1999a). These criteria included size of the site as well as various physical, geologic, and hydrogeoleogic features. The combination of features that define a most favorable site would result in a facility with the following characteristics: a large area (ideally greater than 15 to 20 acres); gently sloping topography; hidden from direct view; no nearby springs or surface water; and, underlain by relatively thick deposits of low permeability material. Using these favorable features, investigation activities performed in the SB-4 area were designed to evaluate physical and chemical properties of geologic materials and hydrogeologic conditions.

- Specific objectives of the investigation were to:
    - Locate a suitable site or sites for long term storage of mine wastes.
    - Characterize geologic setting and physical/chemical properties of geologic materials.
    - Characterize hydrogeologic conditions, and
    - Provide technical information needed to prepare an engineering design of a repository.

1.2 INVESTIGATION ACTIVITIES

Activities which were completed during the evaluation of the SB-4 area to meet the Phase II objectives included the following tasks:

- ***Compilation and Analysis of Available Data*** - Additional analysis and evaluation of available data and aerial photography were performed to select potential repository sites in the SB-4 area.

- ***On-Site Inspections*** - On-site inspections of identified sites were completed to evaluate surface geologic and hydrologic features and to select locations for more detailed analysis.

- ***Geophysical Exploration*** - Seismic refraction data were collected at three sites to allow preliminary determination of unconsolidated material thickness, stratigraphy, and bedrock topography. This information was used to delineate specific repository sites for detailed investigations of subsurface material and hydrogeologic conditions.

- ***Subsurface Material Evaluation*** - Geotechnical boreholes were drilled and backhoe test pits excavated to establish the thickness of colluvial and glacial till overburden, characterize engineering and chemical properties of glacial till and bedrock, and to identify potential sources of borrow materials. These activities were performed at two selected sites.

- ***Groundwater Characterization*** - Groundwater monitoring wells were installed in two of the potential sites in the SB-4 area to document groundwater conditions, groundwater levels, and groundwater flow characteristics. Groundwater samples were collected and analyzed for standard water quality parameters to establish background groundwater conditions at the two sites. Of particular importance for this activity was to investigate groundwater interaction between glacial till and bedrock. Completion of multi-depth monitoring wells in the till was done to characterize three-dimensional groundwater movement. Aquifer and slug tests were performed to measure the hydraulic conductivity of glacial till and bedrock, and to monitor groundwater interaction between the two water-bearing units.

- ***Dye Tracer Study*** - Fluorescent dyes were used at two of the potential sites in the SB-4 area to provide data on groundwater flow direction and velocity in the bedrock and till water-bearing units. The dye tracer study will be completed in July 2000. Results of dye detections to date are included in this report.

- ***Topographic Map*** – Topographic maps with ½-meter contours of two sites in the SB-4 area were prepared using standard engineering survey methods.

This report presents results of the Phase II investigation as of December 24, 1999. Because water level and dye tracer data will continue to be collected over the next six months, this report will be updated with the any new information in the form of an addendum.

2.0 METHODS AND RESULTS

This section presents methods and procedures of the Phase II investigation along with a summary of results. Standard operating procedures (SOPs) and investigation methods are briefly described in each of the result sections presented below. Except for two of the major investigation activities, methods and procedures followed to conduct the Phase II investigation are described in detail in the Site-Wide Sampling and Analysis Plan (Site-Wide SAP). The Site-Wide SAP was prepared as part of the Overall Work Plan and is included as Appendix B of that plan (Maxim, 1999b). The geophysical investigation and dye tracer study were performed according to separate sampling and analysis plans that are included in Appendix A of this report.

2.1 EVALUATION AND ON-SITE INSPECTION

Evaluation of the SB-4 area was performed during May and June 1999. Nine potential sites were delineated in the area using aerial photography, geologic maps, vegetation/wetland maps, and other existing information. The letters A through I are used to designate the nine potential repository sites (Figure 1). Maxim personnel performed a field inspection of the nine sites on June 22, 1999. General information on each of the sites is shown in Table 1. Brief descriptions of observations made at each location are provided below.

TABLE 1
GENERAL REPOSITORY SITE CHARACTERISTICS
Phase II Repository Site Investigation
New World Mining District - Response and Restoration Project

Site Attribute	Repository Site Name							
	SB-4A	**SB-4B**	**SB-4C**	**SB-4D**	**SB-4F**	**SB-4G**	**SB-4H**	**SB-4I**
Size (acres)	20	8	30	20	9	9	9	11
Drainage Basin (1)	SB/FC	SB	SB	SB	SB	SB/FC	SB	SB
Elevation (feet)	8400	8360	8400	8440	8800	8760	8760	8240
Slope (%)	0-15	7-30	7-30	7-15	15-30	<7	7-30	7->30
Visual Compatibility	Good	Good	Fair	Fair	Good	Good	Good	Good
Estimated Depth of Glacial Till	5-10	10-25	0-5	0-5	0-5	0-15	1-10	20-50
Surficial Material (2)	Qg	Qg	Qg/Gn	Qg/Pz	Qg/Gn	Qg/Gn	Qg	Qg
Type of Bedrock (2)	Gn	Gn	Gn	Pz	Gn	Gn	Gn	Gn

Notes: 1 - Drainage Basin - SB = Soda Butte, FC = Fisher Creek
2 - Surficial Material/Bedrock – Qg = glacial till, Gn = Granite/gneiss, Pz = Paleozoic

- **SB-4A -** This site surrounds the Rommel tailings deposit. It is located in both the Fisher Creek and Soda Butte Creek drainages. The site generally slopes to the south and east, and a small lake is present at the east edge of the area. In general, this site has some dry areas, but portions of the site were wet and appeared to be groundwater discharge areas. Several likely ephemeral streams were also present. Thickness of glacial till in the area was difficult to determine due to the gentle topography but was estimated to range from five to 10 feet. While it may be possible to locate a repository entirely in the Fisher Creek drainage, a detailed topographic survey would be needed to determine the configuration and capacity of a repository that would fall solely in this drainage.

The Rommel tailings site is reportedly controlled by unpatented claims. Claim information obtained from the Bureau of Land Management indicates that two unpatented claims, the 10-acre Old Miner and 20 acre Seven Dee, are located in the area (Figure 1). These claims do not appear to affect the siting of a repository in the area.

- **SB-4B -** This site includes an area located north of a prominent ridge formed by a glacial moraine (Figure 1). The southern boundary is a mapped wetland area and the north boundary is bedrock outcrop. The east and west boundaries are small creeks, the west being ephemeral and the east likely perennial. In general, the site consists of about 12 acres of meadowland and burned forest on a gently sloping southern exposure. No springs or wetland areas were observed within the boundaries of the site during our field visit, and none have been mapped previously by CBMI investigators. The site drains to Soda Butte Creek. It is generally not visible from Highway 212 or private property to the east although it may be visible from private property to the west. The thickness of glacial till is estimated to be approximately 10 to 25 feet.

- **SB-4C -** This site slopes to the south and southeast and is relatively dry. The thickness of unconsolidated glacial deposits is estimated to be five feet or less over most of the site. A small ephemeral creek drains to the west and bedrock is exposed to the north. The site lies in burned forest. It is visible from Highway 212 as well as several private residences to the northwest and southeast.

- **SB-4D -** This site is located in burned forest between two small drainages in which likely ephemeral streams were flowing. Bedrock is exposed in several areas and is estimated to lie less than five feet below unconsolidated glacial deposits over the remaining area of the site. The site drains to Soda Butte Creek, is relatively dry, and has a southern exposure. It is visible from Highway 212 and several local residences.

- **SB-4E -** This site was found to be on private land, so it was eliminated from further consideration.

- **SB-4F -** This forested site is located in the Soda Butte drainage. Numerous seeps and wet areas were found during the field visit. Thickness of unconsolidated glacial till appeared to be generally less than three feet with several areas of exposed bedrock noted immediately to the north.

- **SB-4G -** This site is located on a relatively flat area near the divide between Fisher Creek and Soda Butte Creek. The site was snow covered during the field visit. Although depth to bedrock was difficult to determine because of the gentle topography and snow cover, thickness of unconsolidated glacial till is estimated to be five to 15 feet over portions of the site. The site is partially forested, and wetlands are located to the west along the road and to the south. The eastern portion of the site may be large enough for a repository, although a bedrock knoll near the center of the site may constrain the available suitable area. The eastern portion of the site likely drains to Fisher Creek.

Figure 1 - Location Map

Figure 1 - back page

- **SB-4H -** This site is located west of a small ephemeral drainage and drains to Soda Butte Creek. A groundwater discharge area is located to the south, limiting the size of a repository that could be constructed on this location. The area of the site suitable for a repository is approximately nine acres. Thickness of unconsolidated glacial till is estimated to range from less than five to 10 feet.

- **SB-4I -** This 11-acre site is located on the south side of a moraine just north of the Lulu Pass road and drains to Soda Butte Creek. The site is relatively dry, slopes to the southeast, and is vegetated with grass. Thickness of glacial till in the area varies from 24 to 50 feet. The site would be visible from Highway 212 and several residences. The slope of the site is steep in some areas.

Each of the nine sites was evaluated with respect to criteria listed in Table 1 of the Repository Site Evaluation Report (Maxim, 1999a). During this evaluation, an emphasis was placed on selecting a site that contained relatively thick deposits of glacial till, was relatively dry, and where surface water drainage would not be a concern. Because glacial till is a relatively low permeable material that also has the capacity to retard and attenuate potential leachate generated from a mine waste repository, this criterion was one of the major factors in site selection.

Based on the results of the field evaluation, sites SB-4A, SB-4B, and SB-4I were identified as having the most favorable characteristics for a potential repository in the SB-4 area. Additional investigation activities were performed at these sites to further characterize geologic and hydrogeologic properties.

2.2 GEOPHYSICAL EVALUATION

A seismic refraction survey was performed at each of the three potential mine waste repository sites selected for additional investigation to determine the thickness of glacial till. Measurement of seismic refraction involves laying electrical line(s) across the site that contains receivers (geophones) at regularly spaced intervals. A sledgehammer is dropped on a plate near the line to create a source of refraction waves that can be measured with a receiver. The resulting sound waves travel through soil and rock, eventually being reflected back to the surface where the waves are detected by the geophones. Refraction data was calibrated to the known depth of different geologic materials at monitoring wells SB-22 and SB-24 and then interpreted to map the top of the bedrock surface along each seismic line. A computer program was then used to map the depth to bedrock. The surveys were performed by Glacier Engineering, Inc. during the period of July 5 through July 7, 1999. A copy of the Glacier Engineering report and contour maps is contained in Appendix A-1. A brief description of the geophysical survey results is provided below.

- **SB-4A -** One seismic line was completed at this site. The seismic line began near the small lake north of the Rommel tailings deposit and trended to the northwest for a distance of 520 feet. Depth to bedrock generally ranged from four to eight feet, thinning towards the northwest. Due to the shallow depth to bedrock, additional seismic lines were not run at this site.

- **SB-4B -** Four seismic lines, three laid parallel to each other and the fourth perpendicular to the other three, were completed across this site. The longest seismic line was 600 feet. The thickness of unconsolidated glacial till was greatest near the west side of the site at about 24 feet and thinned toward the east to about eight feet. The usable area of the site was estimated by using a thickness of overburden greater than eight feet. Using this guideline, the potential area of the repository would be about 7.4 acres.

- **SB-4I -** Five seismic lines were completed over this area. Three lines were run parallel to each other and the other two were run perpendicular to the three. The longest line was about 600 feet.

Thickness of glacial till ranged from 30 to 50 feet over most of the area surveyed. The usable area of this location for a repository is estimated at 11 acres.

Evaluation of the geophysics data indicated that the SB-4B and SB-4I sites exhibited an adequate thickness of glacial till to be suitable for a mine waste repository. The SB-4A site contained relatively thin deposits of glacial till and was the wettest of the three sites. For these reasons, no further Phase II investigation activities were conducted at the SB-4A site.

2.3 SUBSURFACE MATERIAL INVESTIGATION

A subsurface investigation was completed at the SB-4B and SB-4I sites by excavating 12 backhoe test pits and drilling 23 boreholes. Boreholes were advanced using a variety of methods, including hollowstem auger, ODEX, and core drilling. The following subsections describe methods and procedures used to collect samples and present the results of physical and chemical tests performed.

2.3.1 Test Pits

Backhoe test pits were excavated at the sites to evaluate subsurface conditions and to collect samples of subsurface materials for laboratory analyses. Ten test pits were excavated at the SB-4I site and two test pits were excavated at the SB-4B site (Figures 2 and 3) during July 19 to 21, 1999.

Soil lithology exposed in the test pits was logged by a field scientist and samples were collected from selected intervals following SOP-22 in the Site-Wide SAP. Samples were submitted to Northern Analytical Laboratories in Billings for analytical chemistry and Maxim's Helena and Billings material testing facilities for engineering and physical property tests. Methods used for laboratory analysis are shown in Tables 4-7 and 4-9 of the Site-Wide SAP. Test pit logs are provided in Appendix B.

Test pits were excavated to a depth of four to 11 feet below ground surface. Material encountered in the test pits was glacial till and generally consisted of heterogeneous mixtures of sand and gravel with silt, clay, and cobbles. Small seeps of water were observed infiltrating into several of the test pits at various depths at the SB-4I site. In one case, the water was flowing from a sandy zone approximately one-inch thick. Three of the test pits were left open overnight, resulting in the accumulation of ½ to 2.0 feet of water in the bottom of the pits.

2.3.2 Boreholes

Boreholes were drilled at each of the two repository locations. Material samples were collected according to SOP-22 in the Site-Wide SAP. Sample types collected included split spoon, California, core, and return cuttings from auger and downhole air hammer drilling. Borehole logs indicate the methods used to advance each borehole (Appendix C).

Geologic materials encountered at the SB-4B and SB-4I sites consisted of glacial till overlying granitic-gneiss bedrock. Glacial till thickness varied from 24 to 83 feet at the SB-4I site and from 15 to 33 feet at the SB-4B site. Total depth of each borehole, thickness of glacial till encountered, and the locations and elevations of the boreholes are shown in Table 2. Figure 4 is a map of the potentiometric surface and shows the locations of boreholes at the two sites. Figure 5 is a generalized geologic cross-section through the SB-4 area.

Figure 2 - Site Map - SB-4B

Figure 2 - back page

Figure 3 - Site Map - SB-4I

Figure 3 - back page

Figure 4 - Potentiometric Surface Map - SB-4 Area

Figure 4- back page

Figure 5 - Generalized Geologic Cross-Section - SB-4 Area

Figure 5 - back page

2.3.3 Engineering Properties

Engineering properties of the glacial till were determined by performing a variety of physical tests on the samples collected. Methods used for the materials tested are shown in Tables 4-7 and 4-9 of the Site-Wide SAP. Testing included sieve analyses, Atterberg limits, moisture density, permeability, and trixial shear tests. Results of the tests are summarized in Table 3. Laboratory data sheets for these tests are contained in Appendix D. General characteristics of the glacial till include the following:

Soil Classification
GC-GM, SM, SC-SM, GM
Silty Sand w/ Gravel to Silty Clayey Gravel w/ Sand

Grain Size
33-40 % Gravel/Cobbles (retained on #4 sieve)
29-42% Sand (#4 to #200 sieve)
25-29% Silt/Clay (passing #200 sieve)

Atterberg Limits
Liquid Limit = 19-26
Plastic Limit = 15-19
Plastic Index = 3-10

Shear Strength
Coefficient of Cohesion ranges from 0.11 kilopounds per square foot (ksf) to 3.23 ksf
Friction Angle ranges from 34.4 to 55 degrees

2.3.4 Chemical Properties

Chemical properties of glacial till samples were evaluated by analyzing samples in the laboratory for acid potential, neutralization potential, electrical conductivity (saturated paste), pH (saturated paste), sulfur fractionation, and lime requirement. Methods used for the parameters tested are shown in Tables 4-7 and 4-9 of the Site-Wide SAP. Table 4 summarizes results of these analyses. Laboratory data sheets are contained in Appendix E.

General chemical characteristics of the glacial till are:

Acid Potential -	0 tons/1000 tons
Neutralization Potential -	118 to 271 tons/1000 tons
Total Sulfur -	<0.1 to 0.07 percent
Electrical Conductivity (saturated paste) -	0.21 to 0.32 mmhos/cm
pH (saturated paste) -	6.8 to 7.8

TABLE 2
BOREHOLE AND WELL INFORMATION
Phase II Repository Site Investigation
New World Mining District - Response And Restoration Project

WELL	Northing (meters)	Easting (meters)	Ground Elevation (meters)	Ground Elevation (feet)	Meas. Point Elevation (meters)	Meas. Point Elevation (feet)	Stickup (feet)	Total Depth (feet)	Screen (feet)	Filter Pack (feet)	Depth to Bedrock (feet)	Bedrock Elevation (approx., feet)
101	87164.7862	567849.1789	2536.4672	8322.15	2537.1442	8324.37	2.22	103	92-102	91-103	83	8239
101TS	87160.0794	567843.4401	2536.6800	8322.85	2537.5200	8325.60	1.85	23	19-22	17-23	-	-
101TD	87163.3731	567844.0073	2537.0200	8323.96	2537.5500	8325.70	2.54	35	28-33	27-35	-	-
101TDD	87161.8165	567849.0346	2536.3379	8321.72	2536.9422	8323.71	1.98	78	73.5-76.5	72.5-78	-	-
102	87015.8329	567878.3260	2502.4500	8210.54	2503.0000	8212.34	1.8	30	19.5-29.5	16-30	13.4	8197
102T	87019.7306	567884.6349	2502.6270	8211.12	2503.3800	8213.59	2.35	11	5-10	3.5-11	-	-
103	87069.2003	568180.7927	2488.8189	8165.81	2489.3730	8167.63	1.87	50	40-50	38-50	34	8132
103TS	87068.4567	568173.2884	2489.3538	8167.57	2490.1740	8170.26	1.85	14	10-13	8-14	-	-
103TD	87070.3269	568176.4902	2489.3624	8167.60	2489.9710	8169.59	2.54	22	18-21	15-22	-	-
SB-22	87040.3180	568049.4952	2492.2500	8177.07	2493.0060	8179.55	2.7	70	58.3-67.9	56-70	49.6	8127
SB-22TS	87038.2658	568044.3602	2492.0787	8176.51	2492.8163	8178.93	2.42	24	20.5-23.5	19-24	-	-
SB-22TD	87042.0317	568057.4276	2492.1242	8176.66	2492.9483	8179.36	2.70	40	36-39	34-40	-	-
SB-23	87232.8052	568090.1740	2517.2628	8259.14	2518.1430	8262.03	2.8	70.5	50.7-70.3	46.5-70.5	28	8231
SB-23TS	87225.7796	568092.3518	2517.2512	8259.10	2517.8400	8261.03	1.97	10	6-9	4-10	-	-
SB-23TD	87228.6375	568090.4857	2517.3823	8259.53	2518.1890	8262.18	2.54	20	16-19	14-20	-	-
SB-24	86986.7690	568131.1882	2486.1071	8156.92	2486.7502	8159.03	1.9	70	50-69.6	47.5-70	24.2	8133
SB-24T	86988.5467	568125.3697	2486.3698	8157.78	2487.1675	8160.40	2.3	10	6-9	4-10	-	-
SB-104	87450.9	567661.0	2569.8	8431.5	2564.1	8429.3	2.18	42	30.5-40.5	30-42	26	-
SB-105	87495.2	567637.3	2574.65	8447.43	2575.17	8449.13	1.70	35	29-34	28-35	24	8425
SB-105T	87495.8	567640.9	2574.54	8447.08	2575.21	8449.26	2.18	17	12-15	11-17	-	-
SB-106	87476.1304	567798.3231	2561.3737	8403.87	2562.0052	8405.94	2.07	45	39.0-44.0	38.0-45.0	33	8371
SB-106T	87479.8296	567795.7523	2561.6866	8404.89	2562.1528	8406.42	1.53	18	14.0-17.0	13.0-18.1	-	-
SB-107	87363.3819	567864.4682	2542.7535	8342.77	2543.2919	8344.54	1.77	30	24.5-29.5	23.5-30.0	15	8328
SB-107T	87363.5100	567861.8563	2542.9264	8343.34	2543.3954	8344.88	1.54	10	7.0-10.0	6.0-10.0	-	-
SB-108	87339.9838	567685.0283	2548.6436	8362.10	2549.3385	8364.38	2.28	35	26.0-31.0	25.0-32.0	19	8343
SB-108T	87340.3585	567688.0768	2548.5913	8361.93	2549.1753	8363.84	1.92	14.75	10.0-13.0	9.0-14.75	-	-

TABLE 3
ENGINEERING PROPERTIES - GLACIAL TILL
SB-4I Site
Evaluation of Potential Repository Sites
New World Response and Restoration Project
Gallatin National Forest, Montana

SAMPLE ID	RRSO-01	RRSO-04	RRSO-06	RRSO-09	RRSO-10
DEPTH	6.0' - 11.0'	6.0' - 10.3'	3.0' - 11.0'	3.2' - 10.0'	2.8' - 10.0'
USCS Classification (1)	SM	GM	GM	SM	SM
Description	Silty,Clayey Sand w/ Gravel	Silty Clayey Gravel w/ Sand	Silty, Clayey Gravel w/ Sand	Silty Clayey Sand w/ Gravel	Silty Sand w/ Gravel
Sieve Data (percent passing)					
5"					
4"			100	100	
3"		100	96	93	100
2"	100	96	79	90	90
1 1/2"	94	93	75	87	84
1"	85	89	70	82	82
3/4"	82	85	67	79	79
1/2"	77	78	64	75	75
3/8"	73	72	61	72	73
No. 4	67	61	55	65	66
No. 10	60	52	50	58	58
No. 20	51	45	44	51	51
No. 40	42	38	39	44	44
No. 80	32	32	32	36	36
No. 200	25	26	26	29	29
Hydrometer Analysis					
0.050 mm			25	27	26
0.037 mm			22	26	23
0.0225 mm			19	23	20
0.019 mm			17	20	17
0.012 mm			15	16	15
0.009 mm			14	14	13
0.005 mm			9.7	9.9	10
0.002 mm			3.7	3.3	1.8
Atterberg Limits					
Liquid Limit	18	19	23	21	19
Plastic Limit	15	15	17	17	16
Plastic Index	3	4	6	4	3
Moisture Density					
Maxium Density (PCF) (2)	-	-	139	136.5	136
Moisture Content (%)	-	-	6.0	7.0	7.0
Dry Density					
Undisturbed Sample (PCF) (2)	-	-	125.2	122.9	
Hydraulic Conductivity (cm/sec)(3)					
Remolded Sample, 90% Maxium	-	-	9.3E-07	2.4E-06	-

Notes:
(1) Unified Soil Classification System
(2) PCF = Pounds per Cubic Foot
(3) Test conducted on sample remolded to 90% of maxium density, cm/sec = centimeters per second
- = Not Analyzed

TABLE 3 (continued)
ENGINEERING PROPERTIES - GLACIAL TILL
SB-4I Site

Evaluation of Potential Repository Sites
New World Response and Restoration Project
Gallatin National Forest, Montana

SAMPLE ID	SB-23TS	SB-24 TS	SB-101	SB-101	SB-101
DEPTH	10.4' - 10.9'	11.0' - 11.5'	15.5' - 16.0'	30.0' - 30.5'	40.5' - 41.0'
USCS Classification (1)	SM	SM	GM	SC	GM
Description	Silty Clayey Sand w/ Gravel	Silty Clayey Sand w/ Gravel	Silty Clayey Gravel w/ Sand	Clayey Sand w/Gravel	Silty Clayey Gravel w/Sand
Sieve Data (percent passing)					
5"					
4"					
3"					
2"					
1 1/2"		100	100		100
1"	100	94	77	100	89
3/4"	92	84	72	95	81
1/2"	82	78	57	90	76
3/8"	77	74	51	85	72
No. 4	69	68	45	77	64
No. 10	60	63	40	70	57
No. 20	50	55	33	64	50
No. 40	44	49	29	57	45
No. 80	37	42	24	50	40
No. 200	30	35	19	42	34
Hydrometer Analysis					
0.040 mm	26	31	16	39	31
0.020 mm	22	25	13	34	26
0.010 mm	17	21	10	29	21
0.008 mm	15.5	16.8	8.7	26.4	16.6
0.006 mm	13.4	14	7.4	22.2	14.2
0.004 mm	11.2	11.7	6.4	19.2	11.7
0.002 mm	6.2	6.8	4.7	15.4	9.2
Atterberg Limits					
Liquid Limit	18.5	18.7	18.5	22.9	18.0
Plastic Limit	12.5	13.5	14.0	12.8	12.8
Plastic Index	6.0	5.2	4.5	10.1	5.2
In Situ Moisture					
Moisture Content (%)	8.1	9.9	7.8	6.1	-
Dry Density					
Undisturbed Sample (PCF) (2)	135.6	129.0	132.9	126.1	-
Hydraulic Conductivity					
Undisturbed Sample (cm/sec) (3)	-	3.4E-08	-	2.1E-07	-

Notes:
(1) Unified Soil Classification System
(2) PCF = Pounds per Cubic Foot
(3) Test conducted on Shelby tube sample, cm/sec = centimeters per second
- = Not Analyzed

TABLE 3 (continued)
ENGINEERING PROPERTIES - GLACIAL TILL

SB-4B Site

Evaluation of Potential Repository Sites
New World Response and Restoration Project
Gallatin National Forest, Montana

SAMPLE ID	RRSO-11	RRSO-12	SB-105T	SB-108T	
DEPTH	10.4' - 10.9'	11.0' - 11.5'	15.5' - 16.0'	30.0' - 30.5'	
USCS Classification (1)	SM	SM	GM	SC	
Description	Clayey Gravel w/ Sand	Silty Clayey Sand w/ Gravel	Silty Clayey Gravel w/ Sand	Clayey Sand w/Gravel	
Sieve Data (percent passing)					
5"					
4"					
3"	100				
2"	92				
1 1/2"	85	100	100		
1"	79	89	97	100	
3/4"	79	77	94	99	
1/2"	73	72	89	90	
3/8"	69	69	83	87	
No. 4	61	60	72	79	
No. 10	55	53	63	70	
No. 20	48	46	55	61	
No. 40	42	40	47	54	
No. 80	34	32	34	46	
No. 200	27	25	25	39	
Hydrometer Analysis					
0.050 mm	26	25	24	38	
0.037 mm	24	24	24	35	
0.0225 mm	21	20	23	31	
0.019 mm	20	19	23	29	
0.012 mm	18	16	19	27	
0.009 mm	16	15	18	24	
0.005 mm	13	13	14	20	
0.002 mm	7.1	7.5	8.5	13	
Atterberg Limits					
Liquid Limit	24.0	26.0	22.0	-	
Plastic Limit	15.0	16.0	15.0	-	
Plastic Index	9.0	10.0	7.0	-	
Moisture Density					
Maxium Density (PCF) (2)	136.5	-	-	-	-
Moisture Content (%)	7	-	-	-	-
Hydraulic Conductivity					
Remolded, 90% max density	3.1E-07	-	-	-	

Notes:
(1) Unified Soil Classification System
(2) PCF = Pounds per Cubic Foot
(3) Test conducted on Shelby tube sample, cm/sec = centimeters per second
- = Not Analyzed

TABLE 4
CHEMICAL TEST RESULTS - GLACIAL TILL
SB-4 Area
Phase II Repository Site Investigation
New World Mining District - Response and Restoration Project

Parameter	Sample ID				
	RRSO-01	RRSO-09	RRSO-10	RRSO-11	RRSO-12
Depth (feet)	6.0 - 11.0	3.2 - 10	2.8 - 11.0	2.5 - 11.0	3.0 - 9.5
Sample Date	7/19/99	7/21/99	7/21/99	7/21/99	7/21/99
Acid Potential (tons/1000 tons)	< 1	< 1	< 1	< 1	< 1
Acid/Base Potential (tons/1000 tons)	271	118	195	193	154
Neutralization Potential (tons/1000 tons)	271	118	195	193	154
Electrical Conductivity (mmhos/cm)	0.32	0.24	0.21	0.28	0.28
pH (standard units)	7.5	7.6	7.8	6.9	6.8
Sulfur - HCl Extractable (%)	<0.1	<0.1	<0.1	<0.1	<0.1
Sulfur, HNO_3 Extractable (%)	<0.1	<0.1	<0.1	<0.1	<0.1
Sulfur - Residual (%)	<0.1	<0.1	<0.1	<0.1	<0.1
Sulfur - H_2O Extractable (%)	<0.1	<0.1	<0.1	<0.1	<0.1
Sulfur - Total (%)	0.04	0.07	0.03	<0.1	<0.1
Lime Requirement (tons/1000 tons)	0	0	0	0	0

2.3.5 Site Capacity

Using preliminary estimates for the footprint of a full build-out at the two potential repository sites, an estimate of the total storage capacity of mine waste was made. Full build-out assumed a final slope configuration of 4:1 slopes for the face and sides of a repository and a top liner thickness of four feet. To maximize the thickness of glacial till between the bottom of waste and bedrock, excavation into the till was assumed four feet. This amount of excavation allows for salvage of soil material that will be used to construct a soil cap at the repository sites. Under these assumptions, the calculated storage for the two sites is the following:

- SB-4B - 110,000 cubic yards
- SB-4I - 240,000 cubic yards

2.4 GROUNDWATER OCCURRENCE

Groundwater occurrence at the sites SB-4B and SB-4I were evaluated by installing monitoring wells in 23 boreholes (Figures 2, 3, and 4). Table 2 summarizes well location, completion depths, and measuring point information. Wells were generally installed in clusters, with one well installed in the bedrock at each location and one to three wells completed at shallower depths in the overlying glacial till. Figure 6 shows an example of the well cluster at SB-101.

Monitoring wells were installed and developed using SOPs 16 and 17 that are included in the Site-Wide SAP. Wells were competed using 2-inch diameter PVC casing with a three to 10 foot section of 0.020-inch factory slotted pipe in the completion zone. Filter pack installed in the slotted section was 10-20 silica sand. Boreholes were backfilled using neat cement and bentonite pellets. Measuring points were established for each well and the measuring point elevations were determined by surveying methods. Three bedrock monitoring wells, installed by CBMI in the SB-4 area, were also used in the monitoring well network (SB-22, SB-23, and SB-24). Borehole and completion logs for wells installed during this investigation and for wells SB-22, -23, and -24 are included in Appendix C.

2.4.1 Groundwater Movement

Groundwater movement was evaluated by measuring water levels in the completed wells. Water levels measured during the period July 27 to October 4, 1999 are included in Appendix F. Figure 7 shows water level graphs for wells near the SB-4I site. Water levels in wells in the SB-4B site had not stabilized before commencement of the dye tracer study so only a few water levels were measured during the same period. Figures 2, 3, and 4 show water level information along with the bedrock potentiometric surface.

The following general observations were made from examination of water level data collected at the two sites:

- Glacial till confines groundwater in the underlying granitic bedrock, resulting in artesian conditions in bedrock wells.

- Groundwater flow in bedrock is toward the southeast within the Soda Butte drainage at a gradient which ranges from 25% in the northwest to 12% near the southeast corner of the SB-4I site (Figure 3).

- Water levels in bedrock and glacial till wells (Figure 2) indicate there is an upward hydraulic gradient from bedrock to glacial till over most of the SB-4I site. The upward gradient ranges from 23% at SB-102T to 1% at SB-23T. The average upward gradient is 13% across the site. The upward gradient at the SB-101 well cluster decreases as the distance from the bedrock/till contact increases (Figure 7). A downward gradient from till to bedrock of 1% is present in SB-23TD near the northeast corner of the site.

- Water levels in glacial till wells indicate that, within glacial till, there are both upward and downward hydraulic gradients present at the site. The upward gradient in glacial till ranges from 7% to 10% in the SB-101 well cluster (Figure 7) to 26% at the SB-23 cluster. A downward hydraulic gradient of 18% was calculated between the shallow and deep glacial till wells at the SB-103 cluster. This cluster is located at the southeast corner of SB-4I. The top of the screened interval in the deeper till well in this cluster is located at the same elevation as the bottom of the screened interval in the upper till well. The water level in the upper well is about 1.2 feet higher than that in the lower well. One explanation for this variance from the general gradient characteristics measured in the other well clusters is the possibility that the downward gradient is due to surface recharge near SB-103. The downward gradient in the SB-103 cluster may also be due to the fact that water levels in the deeper till well have not yet stabilized.
- Groundwater levels in bedrock well SB-103 (Figure 7) and glacial till well SB-22TD had not stabilized after more than 55 days following completion and development.

- Diurnal pressure variations of 0.01 to 0.02 foot are present in bedrock well SB-24 (Figure 8). This information supports other data indicating the bedrock aquifer is a confined system. Diurnal pressure variations indicate an evapotranspiration, lunar, or barometric effect on the confined bedrock aquifer.

Groundwater gradients measured in the near surface glacial till at both potential repository sites generally follow surface topography. Gradients indicate that groundwater flow is to the south-southeast in the glacial till. Groundwater discharge areas are present downgradient of the two sites. At SB-4B, a groundwater discharge zone is located in the drainage south of the site. This discharge area is a wetland with surface drainage from the west side of the site flowing across the area to the southeast (Figure 4). Groundwater discharge in this area likely comes from near-surface groundwater flow through the glacial till. A small swale located south of SB-4I may be a groundwater discharge area for near-surface groundwater discharging from the till.

Potentiometric heads in the till indicate that, over the majority of the SB-4I site, an upward gradient is present between bedrock and till. This would preclude downward migration of leachate that may be produced by mine wastes disposed in a repository at this site.

2.4.2 Groundwater Quality

Groundwater quality was evaluated by collecting groundwater samples at 10 wells in the repository area. Six bedrock wells and four glacial till wells were sampled. Laboratory analytical results are summarized in Table 5. Appendix G contains laboratory data sheets for groundwater samples.

Data in Table 5 indicate that, in general, groundwater in both till and bedrock is of relatively good quality. That is, groundwater in the SB-4 area has relatively low or non-detect concentrations of trace metals and exhibits relatively low total dissolved solids and hardness. In reflecting the type of rock it is contained in, groundwater is alkaline, with lab pH measurements ranging from 7.6 to 8.4 and total alkalinity ranging from 118 to 210 milligrams per liter (mg/L).

One water sample collected from one of the bedrock wells at the SB-4B site (SBGW-106) is an exception to the above statements. Groundwater from this well contained high iron and aluminum concentrations, and the water was described as orange-brown and cloudy. Water level data indicates well SBGW-106 did not recover after sampling (Appendix G), and therefore the sample collected from this well may not be representative of groundwater conditions.

One other sample collected from SBGW-108 exhibited an extremely high pH (11.7). This high pH may be due to neat cement contaminating the water sample. Neat cement was used during well completion to backfill the annulus above a four-foot thickness of bentonite that was placed above the filter pack.

2.4.3 Aquifer Testing

Both static and dynamic aquifer tests were conducted in selected wells at the two Phase II repository sites to determine hydraulic conductivities of bedrock and till water-bearing units. A discussion of the results of aquifer testing is presented in the following subsections.

Figure 6 - SB-101 Well Cluster Cross-section

Figure 6 - back page

Figure 7 - Static Water Level Plots

Figure 7 - back page

Figure 8 - Potentiometric Heads in Flowing Artesian Wells

Figure 8 - back page

TABLE 5
GROUNDWATER QUALITY DATA - SB-4 AREA
Phase II Repository Site Investigation
New World Mining District - Response and Restoration Project

Parameter (units in mg/L unless otherwise noted)	Well Designation									
	SB-22	SB-23	SB-24	SBGW-101	SBGW-101-TD	SBGW-101-TDD	SBGW-101-TS	SBGW-103-TD	SBGW-106	SBGW-108
Date	7/26/99	7/26/99	7/26/99	9/24/99	9/24/99	9/24/99	9/24/99	9/24/99	9/24/99	9/24/99
Time	8:40	9:45	8:00	800	735	745	1300	940	1230	1150
Depth to Water (ft)		6.65		2.32	11.96	5.31	12.23	6.74	15.38	13.28
Oxidation/reduction potential	+ 508	+ 283	+ 530	- 110	+ 93	- 26	+ 101	+ 65	- 97	+ 96
Field pH (standard units)	7.19	7.47	6.94	9.01	8.22	8.64	6.78	8.16	9.61	11.83
Lab pH (standard units)	7.8	7.9	7.6	8.6	7.9	8.1	7.8	7.8	8.4	11.7
Specific Conductance (millimhos - lab)	330	291	355	237	542	324	531	473	307	570
Specific Conductance (millimhos - field)	370	349	424	148	370	220	420	350	240	750
Total Dissolved Solids	198	168	218	153	316	187	342	291	208	180
Temperature (°C)	10.8	14.8	7.9	6.8	7	7	6.5	7	7.5	7.5
Hardness as CaCO3	163	147	175	109	252	152	260	225	83	142
Calcium	39	34	42	24	48	33	66	49	25	57
Magnesium	16	15	17	12	32	17	23	25	5	1
Sodium	12	7	13	5	10	6	9	10	32	8
Potassium	3	2	3	3	6	3	4	4	3	1
CaCO3 Alkalinity	162	136	168	110	210	157	204	199	118	147
CO3 Alkalinity				0	0	0	0	0	12	63
HCO3 Alkalinity	198	166	205	134	256	192	249	243	118	1
Acidity as CaCO3	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Sulfate	24	15	35	20	70	12	78	58	46	9
Chloride	2	< 1	< 1	< 1	2	< 1	3	2	4	2
Aluminum	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	6	< 0.1
Cadmium	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0001	< 0.0001	0.0002	0.0003	0.0001	< 0.0001
Copper	< 0.001	< 0.001	0.003	< 0.001	0.001	0.001	0.012	< 0.001	0.03	< 0.001
Iron	0.12	< 0.01	0.09	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	5.91	< 0.01
Lead	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.001	< 0.001	0.006	< 0.001
Manganese	0.072	0.049	0.3	0.036	0.24	0.12	0.19	0.14	0.22	< 0.005
Zinc	0.02	0.03	0.03	< 0.01	0.01	< 0.01	0.01	< 0.01	0.02	< 0.01

Note: All chemical constituents are dissolved as filtered through a 0.45-micron filter.

2.4.3.1 Slug, Packer, and Permeameter Tests

Slug tests were performed in three bedrock wells (SB-23, SB-102, and SB-108) and six glacial till wells (SB-22TS, SB-24T, SB-101TS, SB-101TD, SB-103TS, and SB-103TD). Data gathered during these tests were analyzed by both Hvorslev (1951) and Bouwer-Rice (1976) methods. Early and late data for several tests were analyzed separately. Hydraulic conductivity values resulting from these analyses did not vary significantly from analyses using the entire data set. Appendix H-1 contains data and printouts of the slug test results and analyses. Slug test results (Table 6) indicate hydraulic conductivities of bedrock ranges from $1.9x10^{-3}$ to $8.7x10^{-6}$ centimeters per second (cm/sec). Hydraulic conductivity values for the glacial till ranged from $6.5x10^{-3}$ to $4.3x10^{-6}$ cm/sec.

Packer permeability tests were performed on granite bedrock in boreholes SB-22, SB-23, and SB-24 in 1991. These boreholes were drilled by CBMI to evaluate bedrock hydrologic conditions in the area. Hydraulic conductivity values calculated for bedrock from the packer tests ranged from $1x10^{-4}$ to $3x10^{-6}$ cm/sec (Table 6).

Laboratory hydraulic conductivity tests were conducted in August 1999 on two undisturbed samples of glacial till collected from boreholes SB-24TS and SB-101. These laboratory tests resulted in the lowest hydraulic conductivity values determined for the glacial till, and varied from $2.1x10^{-7}$ to $3.4x10^{-8}$ cm/sec (Table 6 and Appendix D). Two permeameter tests were also performed on bulk glacial till material collected from test pits RRSO-06 and RRSO-09 in July 1999. These samples were remolded to 90% maximum density as determined by moisture density curves, and resulted in hydraulic conductivity values of $2.4x10^{-6}$ to $9.3x10^{-7}$ cm/sec (Table 6).

2.4.3.2 Aquifer Pumping Test

A three-day aquifer pumping test was performed on bedrock well SB-101 during October 4-7, 1999. Three observation wells (SB-101TS, SB-101TD, and SB-101TDD) completed at various depths near SB-101 in the glacial till were monitored during the test (Figure 9). Additional monitoring wells, located from 500 to 1,100 feet from the pumped well, completed in both bedrock and glacial till were also monitored during the test. No water level changes were observed in any of the wells outside of the SB-101 well cluster. Following termination of the pumping test, well SB-101 and the observation wells were monitored for a period of five hours before the pump was removed from the well. During the five-hour recovery period, well SB-101 recovered approximately 75% of the total drawdown that occurred during the test.

Figure 6 shows the configuration and completion intervals of the wells in the SB-101 cluster. Figures 7 and 9 show water levels in the pumped and observation wells before and during the test. Two weeks prior to the aquifer test, all wells in the SB-101 cluster were bailed and sampled. Water levels were measured in the wells before sampling and from that time until the aquifer test. Water level measurements collected from wells SB-101TS and SB-101TD during the early part of the pumping period indicate that these two wells were likely still recovering. Water level decline in these two wells during the later part of the test is attributed to drawdown surrounding pumping well SB-101 during the aquifer test.

Additional factors that influence the analysis of data collected during the pumping test include the heterogeneous and anisotropic characteristics of the natural system. Other aquifer test assumptions that may have been modified by site conditions include an aquifer of infinite aerial extent, nonleakance from other hydrostratigraphic units, constant pumping rate, and complete penetration of the aquifer by the

TABLE 6
SUMMARY OF HYDRAULIC CONDUCTIVITY VALUES FOR BEDROCK AND GLACIAL TILL
SB-4 AREA
Phase II Repository Site Investigation
New World Mining District - Response and Restoration Project

Well	Type Test	Depth Interval (feet)	Test Date	Hydraulic Conductivity (1) (cm/sec)		
				Hvorslev (1951)	Bouwer-Rice (1976)	Value or Average (if multiple)
Bedrock Wells						
SB-22	Borehole Packer	55.0 - 70.0	9/28/91			3E-06(2)
SB-23	Borehole Packer	33.0 - 50.5	9/29/91			6E-06(2)
SB-23	Borehole Packer	52.5 - 70.5	9/29/91			2E-05(2)
SB-24	Borehole Packer	31.5 - 44.5	9/30/91			2E-07(3)
SB-24	Borehole Packer	45.5 - 57.5	9/30/91			7E-06(3)
SB-24	Borehole Packer	57.5 - 70.5	9/30/91			1E-04(2)
SB-23	Slug Out	46.5 - 70.5	8/19/99	1.0E-04	7.5E-05	8.8E-05
SB-102	Slug In	17 – 30	7/8/99	9.1E-06	8.3E-06	8.7E-06
SB-108	Slug In	25.0 - 32.0	10/7/99	2.0E-03	1.8E-03	1.9E-03
SB-108	Slug Out	25.0 - 32.0	10/7/99	3.9E-04	2.8E-04	3.3E-04
					Median Bedrock Wells	**8.8E-05**
Glacial Till Wells - Slug Tests						
SB-22TS	Slug In	19 – 24	8/19/99	3.1E-04	3.0E-04	3.1E-04
SB-24T	Slug In	4 – 10	8/6/99	2.7E-03	1.0E-02	6.5E-03
SB-101TS	Slug In	17 – 23	8/18/99	2.5E-04	1.9E-04	2.2E-04
SB-101TD	Slug In	29 – 36	8/18/99	5.5E-06	4.2E-06	4.8E-06
SB-101TD	Slug In	29 – 36	8/25/99	3.4E-05	2.7E-05	3.1E-05
SB-103TS	Slug In	8 – 14	8/13/99	6.4E-05	4.3E-05	5.4E-05
SB-103TS	Slug Out	8 – 14	8/13/99	3.7E-05	2.5E-05	3.1E-05
SB-103TD	Slug In	14 – 22	8/11/99	5.1E-06	3.5E-06	4.3E-06
					Median Glacial Till Wells	**3.1E-05**
Glacial Till Test Pit Samples- Laboratory Tests						
SB-24TS	Permeameter	11.0 - 11.5	8/1/99			3.4E-08
SB-101	Permeameter	30.0 - 30.5	8/1/99			2.1E-07
RRSO-06	Remolded to 90% max density	3.0 - 11.0	8/1/99			9.3E-07
RRSO-09	Remolded to 90% max density	3.2 - 10.0	8/1/99			2.4E-06
RRSO-11	Remolded to 90% max density	10.4 - 10.9	11/19/99			3.1E-07

1) - Analysis Methods
Bouwer and Rice, 1976. A slug test method for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. Water Resources Research, vol. 12, no. 3, pp. 423-428.
Hvorslev, 1951. Time lag and soil permeability in groundwater observations. U.S. Army Corps of Engineers Waterways Exp. Station Bulletin 36, Vicksburg, Miss.
2) Reported as less than values shown
3) Reported as less than or equal to values shown

TABLE 6 (continued)
SUMMARY OF HYDRAULIC CONDUCTIVITY VALUES FOR BEDROCK AND GLACIAL TILL
SB-4 AREA
Phase II Repository Site Investigation
New World Mining District - Response and Restoration Project

Aquifer Test Results - SB101 Well Cluster							
Well	**Type Test**	**Depth Interval** (feet)	**Test Date**	**Hydraulic Conductivity (1) (cm/sec)**			
				Theis (1935)	**Cooper/ Jacob** (1946)	**Theis/ Jacob** (1935, 1946)	**Hantush/ Jacob** (1955)
Bedrock Well (pumped well)							
SB-101	Pump – drawdown	91.0 - 103.0	10/4/99	3.3E-05	3.0E-05		3.7E-05
SB-101	Pump – recovery	91.0 - 103.0	10/4/99			4.0E-05	
Till Well (observation well)							
SB-101DD	Pump –drawdown	91.0 - 103.0	10/4/99	3.7E-03	8.6E-05		
Vertical Hydraulic Conductivity of Glacial Till							
				Newman and Witherspoon (1972)			
SB-101TDD	Pump – drawdown	72.5 - 77.0	8/1/99	6.6E-06			
SB-101TD	Pump – drawdown	29 – 36	8/1/99	6.0E-07			
SB-101TS	Pump – drawdown	17 – 23	8/1/99	2.5E-06			

1) - Analysis Methods
Cooper and Jacob, 1946. A generalized graphical method for evaluating formation constants and summarizing well field history, Am. Geophys. Union Trans., vol. 27, pp526-534.
Hantush and Jacob, 1955. Non-steady radial flow in an infinite leaky aquifer, Am. Geophys. Union trans., vol. 36, pp. 95-100
Neuman and Witherspoon, 1972. Field determination of the hydraulic properties of leaky multiple aquifer systems, Water Resources Research, vol. 8, no. 5, pp. 1284-1298.
Theis, 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage, Am. Geophys. Union Trans., vol. 16, pp. 519-524.

pumping well. The pumping rate varied between 0.63 and 0.36 gallons per minute (0.04-0.023 liters per second) during the three-day test for well SB-101.

Total water level drawdown in the pumping well (SB-101) during the three-day test was approximately 78 feet. The deepest of the glacial till observation wells (SB-101TDD) had a total drawdown of about 15 feet during the test, with an initial water level decline occurring after about 10 seconds of pumping. For the other two glacial till observation wells (SB-101TD and SB-101TS), total drawdown during the test was approximately 0.3 and 1.2 feet, respectively, with initial water level declines occurring about 50 hours (well SB-101TD) and 33 hours (well SB-101TS) after initiation of pumping in well SB-101.

Drawdown data from the pumping well (SB-101) and observation well SB-101DD were analyzed using the Theis, Cooper-Jacob, and Hantush-Jacob (leaky confined) methods (Table 6 and Appendix H-2). Recovery data from well SB-101 were analyzed using the Theis-Jacob method. Resultant hydraulic conductivity values for bedrock were similar and ranged from 3.0×10^{-5} to 4.0×10^{-5} cm/sec (Table 6). Data from the deep till well (SB-101DD) resulted in "horizontal" hydraulic conductivity values for

Figure 9 - Well Drawdown Data – SB-101 Wells

Figure 9 - back page

glacial till which ranged from 3.7×10^{-3} to 8.6×10^{-5} cm/sec. Aquifer thickness for these analyses was assumed to be the screened intervals of the wells.

Analysis of the aquifer test data indicates that the glacial till confining unit was likely supplying leakance water to the bedrock aquifer during the later portion of the test. This is indicated by the divergence of the drawdown plots for the Cooper-Jacob and Theis methods of analysis (Appendix H-2). For the Theis plot, the drawdown curve begins to flatten during the latter part of the test and follows the Hantush-Jacob type curves for a leaky aquifer (Appendix H-2). This leakance is from the glacial till as pumping in the underlying bedrock creates a downward hydraulic gradient between the two units. Some additional recharge to the pumping well could come from bedrock zones of greater permeability that are encountered by the expanding cone-of-depression.

Water level data from the three glacial till wells were also analyzed by a method devised by Newman and Witherspoon (1972) to evaluate the hydrogeologic properties of aquifer confining layers (Table 6). This method resulted in "vertical" hydraulic conductivity values ranging from 6.6×10^{-6} to 6.0×10^{-7} cm/sec for glacial till at the site. These values are one or two orders of magnitude lower than the horizontal hydraulic conductivity values.

2.4.4 Dye Tracer Investigation

Fluorescent dyes were injected at the SB-4B and SB-4I sites to support our conceptual model of groundwater movement at and near the sites and document the preferential movement of groundwater in the area, if occurring. On October 7, 1999, 2.5 kilograms of eosin OJ (CI Acid Red 87) dye was injected in bedrock monitoring well SB-101 (Figure 10) at 1640 hrs. The dye was injected approximately 5.6 hours after well SB-101 was pumped at a constant discharge rate for 72 hours. Well SB-101 is screened in granitic bedrock with the well screen extending from 92 to 102 feet below ground surface. The dye was driven into the bedrock formation by chasing the dye with approximately 300 gallons of water. The chase water consisted of formation water pumped from well SB-101 during the aquifer test.

On the same day at approximately 1700 hrs, 2.5 kilograms of uranine (CI Acid Yellow 73) was injected in a shallow backhoe pit at repository site SB-4I (Figure 10). The backhoe pit was excavated about three feet deep into glacial till approximately 200 feet upgradient from monitoring well SB-103. A third fluorescent dye, phloxine B (CI Acid Red 92), was injected in a backhoe pit excavated at proposed repository site SB-4B (Figure 10) at about 1800 hrs on October 7, 1999. Both dyes injected into the backhoe pits were chased with water obtained from well SB-101.

Water samples were collected from 10 surface water stations and 22 wells to monitor the movement of dye. Dye monitoring stations are shown on Figure 10. Samples were collected every six hours during the first day of testing from the sample sites closest to the dye injection points. Samples were then collected from all stations every 12 hours until October 13 and then daily until October 25. From October 25 to the end of November, monitoring was decreased to once per week, and then decreased further to once every two weeks in December. The last sampling event in 1999 will be December 27. During the months of January through May 2000, one sample per month will be collected. In June and July, sampling frequency will be increased to once per week.

As of November 23, 1999, dye has been detected at one till well and one bedrock well. Eosin OJ was first detected in till well SB-101TDD on October 19, 1999, with concentrations continuing to increase in each sample collected from the well since that date. On November 23, eosin OJ was first detected in bedrock well SB-24. This well is located about 1,100 feet downgradient of the injection well. These results indicates that groundwater is moving upward from bedrock (SB-101 injection point) into till and flowing laterally downgradient to the south-southeast. These dye tracer results support the conceptual model of groundwater movement. Neither of the two dyes injected into the till test pits have been detected as of November 23.

Figure 10 - Dye Tracer Sampling Location Map

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3.0 SUMMARY AND CONCLUSIONS

Results of the Phase II repository investigation provide a detailed characterization of geologic and hydrogeologic conditions present at the SB-4B and SB-4I sites. These data indicate the following:

- **SB-4I -** The area considered suitable for a mine waste repository at this site was determined by delineating an area within relatively thick glacial till deposits (as determined by geophysical survey and drilling), and avoiding surface water drainages and designated wetlands. Using these criteria, a site of about 13 acres was identified. Runoff from the site and surrounding area drains into Soda Butte Creek from several small ephemeral and perennial drainages. The site slopes to the southeast at a gradient of about 23%.

  Within the area studied, geology is characterized by glacial till overlying granite gneiss bedrock. Till thickness ranges from 14 to 85 feet with the till composed of a heterogeneous mixture of coarse fragments, sand, silt, and clay. The percentage of fine-grained silt and clay in till ranges from 25 to 29%. The heterogeneous nature and amount of fine-grained material in the till result in relatively low horizontal and vertical hydraulic conductivity. Horizontal hydraulic conductivity of glacial till ranges from 10^{-3} to 10^{-6} cm/sec, with an average of about $1x10^{-4}$ cm/sec. Vertical hydraulic conductivity of glacial till ranges from 10^{-6} to 10^{-8} cm/sec.

  Horizontal hydraulic conductivity of bedrock ranges from 10^{-3} to 10^{-7} cm/sec as determined by slug and pump testing. The average hydraulic conductivity is low, about $3x10^{-5}$ cm/sec. The low hydraulic conductivity of bedrock tested at this site would likely result in sub-optimal performance as an aquifer for domestic well use.

  Groundwater flow in bedrock is upward into till. This upward potential decreases in the till as the distance from the till/bedrock increases. A horizontal component of flow in both bedrock and till is toward the south-southeast. Groundwater probably discharges from the till into drainages surrounding the site.

  The total capacity of the site for placement of mine waste, using certain engineering design constraints, is about 240,000 cubic yards. The area is well vegetated and the soil is suitable for use as coversoil in a soil cap.

- **SB-4B -** The area considered suitable for a mine waste repository was determined at this site by delineating an area within relatively thick glacial till deposits (as determined by geophysical survey and drilling), and avoiding surface water drainages and designated wetlands. Using these criteria, a site of about 7.5 acres was identified. Runoff from the site and surrounding area drains into Soda Butte Creek via several small ephemeral and perennial drainages. The site slopes to the southeast at a moderate gradient of about 16%, somewhat less than the average slope at SB-4I.

  Within the area studied, geology is characterized by glacial till overlying granite gneiss bedrock. Till thickness ranges from 15 to 33 feet with the till consisting of a heterogeneous mixture of coarse fragments, sand, silt, and clay. Physical and chemical analyses of till from this site are similar to, and within the range of, variability encountered at the SB-4I site. Although only two slug tests were completed at this site, horizontal and vertical hydraulic conductivity in till and bedrock likely fall within the range measured at the SB-4I site.

  Groundwater flow is expected to be similar at the SB-4B site as at SB-4I. Upward potentials have not been measured in bedrock because water levels in paired bedrock/till wells had not sufficiently recovered as of this report writing. Water level measurements will continue to be made through the winter to document groundwater flow potential. The horizontal component of flow in both bedrock and till at this site is similar as at the SB-4I site - toward the south-southeast. Groundwater probably discharges from till into drainages surrounding the site.

The total capacity of the site for placement of mine waste, using numerous engineering design criteria, is about 110,000 cubic yards. The area is well vegetated and the soil is suitable for use as coversoil in a soil cap.

Results of the Phase II investigation indicate that both SB-4B and SB-4I are suitable for mine waste disposal in an engineered repository. Both sites have similar geologic and hydrogeologic conditions that are conducive to siting a repository. One main difference between the two sites is the estimated total storage capacity. The useable area of the SB-4B site is more constrained by surface drainages, wetlands, and topography, resulting in less than half the capacity of SB-4I. Moderately steep slopes present on portions of the SB-4I site may limit the disposal of fine-grained saturated waste material, such as tailings, due to seismic stability issues. Such materials may require treatment with stabilizing amendments before placement at this site.

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