PRELIMINARY GROUND WATER MODEL RESULTS
RED DEVIL MINE SITE
RED DEVIL, ALASKA

Prepared For:

U.S. Department of Interior
Bureau of Land Management
National Sciences and Technology Center

Prepared By:

Dynamac Corporation
20440 Century Boulevard
Germantown, Maryland 20874

Work Assignment No.: BLM3-60R
Date Prepared: May 11, 2001
BLM Contract No.: 1422-N660-C98-3003

Dynamac Corporation (Dynamac) was tasked by the Bureau of Land Management (BLM), National Sciences and Technology Center (NSTC) to develop an analytical approach and perform simulations of metal transport in groundwater at the Red Devil Mine Site. The area of concern determined by BLM is between the Retort Building area and Red Devil Creek, and the chemicals of concern are arsenic and mercury.

Introduction

This Memo has been prepared to report the findings of the modeling simulations run to estimate the concentration of arsenic and mercury in groundwater over time after completion of future remedial activities at the Red Devil Mine (i.e., excavation, consolidation, and cap placement). A separate simulation was run to model the effects of limited remedial activities (i.e., no capping). The modeling approach was based on scarce hydrogeological and analytical data contained in the *Red Devil Mine Source Area Removal and Investigation*, prepared jointly by Harding Lawson Associates and Wilder Construction Company (HLA/Wilder), and dated March 2001. The data included the dimensions of the source area, distances between well points, and physical properties of the indigenous soils (i.e., bore logs). The soil properties provided in the HLS/Wilder boring and well logs were used to estimate the values of conductivity and permeability. The following general assumptions and steps were the basis of this modeling exercise:

- Groundwater modeling is being used as an evaluation tool in the development and design of a capping system for the main source area at the site; that is, the area surrounding the Retort Building.

- Two different models that describe advection-dispersion transport in groundwater and the vadose zone were used to simulate metal transport in the subsurface. The use of comprehensive geochemical models, which require more site specific data than is currently available at this time, were not used.

- Analytical data provided in the HLA/Wilder report were used to estimate aquifer parameters, by performing calibration runs of contaminated groundwater flow along the following line of wells: MW07, MW01, and MW04. The aquifer parameters were estimated using a one-dimensional analytical solution model (SOLUTE). The aquifer parameters were necessary to run the more complex 3-D groundwater modeling simulations.

- The 3-D model "SWMS_3D" was used to complete the modeling efforts; that is, to estimate the concentration of arsenic and mercury over distance and time from the source area (Retort Building) to Red Devil Creek.

It should be noted that the modeling simulations generated a non-unique distribution of metals. This can

be attributed to the availability of only one analytical data set and approximations of site specific hydrogeological conditions and soil properties. Therefore, the results of this modeling exercise includes uncertainties attributable to the tendencies of hydrodynamic processes, and should be considered as preliminary. Regardless, the modeling results provide useful information with respect to the mitigation of contamination under a capping scenario. To more accurately model the groundwater flow conditions and contaminant fate and transport, the following data should be collected: a minimum of two additional rounds of groundwater analytical data; hydrogeological parameters of the aquifer; and geotechnical/physical properties of the indigenous soil.

Background and Evaluation of Available Data.

The Red Devil Mine was established in 1921 and in 1946 operations were shut down. Mining operations were resumed in 1952, intermittently producing mercury until 1972. The mine itself has not operated since 1971.

A limited investigation of the groundwater was conducted at the site. The investigation was limited to the collection of stratigraphic information and groundwater quality data. The investigation did not include activities to define the aquifer characteristics.

Aquifer parameters were estimated based on bore logs and data collected from the five groundwater monitoring wells that were installed at the site. Specifically, the general direction of groundwater flow was determined to be to the north/northeast toward Red Devil Creek and the Kuskokwim River. This was based on an interpretation of water level data and an interpolation of well placement. The wells considered in the interpretation/interpolation included MW01, MW03, MW04, MW06, and MW07 (HLA/Wilder, Figure 10). Furthermore, the borehole data (e.g., aquifer consists mostly of low permeability sandy silt and sandy gravelly silt) was used to help interpolate the aquifer parameters.

From the information contained in the HLA/Wilder report it was assumed that the main source area for arsenic and mercury contamination is located at the Retort Building. Based on the analytical data, the higher concentrations of arsenic and mercury were detected in the groundwater monitoring wells adjacent to the Retort Building. The greatest concentrations of arsenic detected in the groundwater was measured at monitoring well MW03 (129 ug/L) and MW07 (114 ug/L). Both wells are located at the edge of the main source area. Conversely, the lowest arsenic concentrations (25.4-52.3ug/L) were detected at monitoring wells MW04 and MW06 located along the bank of Red Devil Creek, between 300 and 500 feet down gradient from the source area. The same tendency was observed in the mercury concentrations.

Dynamac assumed that declining concentrations of arsenic and mercury along groundwater flow is a result of natural hydrogeological and geochemical processes including advection, dispersion/diffusion, adsorption/desorption, oxidation/reduction, and precipitation/dissolution.

Modeling Objectives

The purpose of the modeling is to assist with the design of the capping system which should mitigate the release of metals to the groundwater. To accomplish this, a model had to be developed that estimated the effects of reducing infiltration by a capping system. The modeling objectives were achieved using two activities: (1) development of a model or a simulation approach that had sufficient capability to be used as an analytical tool to evaluate the hydrogeologic properties of the aquifer; and (2) development and application of a model to test the effectiveness of a capping system.

With respect to the first activity, the objectives were to develop a model that:

- Incorporated lithological, hydrogeologic, and groundwater quality information collected during the field investigation.

- Estimate with reasonable certainty the local hydrogeologic parameters.

To assess the effectiveness of the capping system, the modeling objectives were to perform transport simulations to evaluate the source impact on the contamination of groundwater.

Modeling Approach Development

Two different modeling approaches, advection-dispersion modeling and a more sophisticated geochemical model, are used to assess the fate and transport of chemicals in groundwater. Geochemical modeling considers detailed chemical reactions, such as precipitation/co-precipitation, complexation, and dissolution/adsorption (as well as others), but requires more site specific data and modeling time. Dynamac elected to use the advection-dispersion approach which combines these chemical reactions into a general sorption/desorption term (a lumped parameter): distribution coefficient (Kd) which is commonly included in a more general term -- retardation factor (R). Two different models, SOLUTE and SWMS_3D, were used to assess the movement of arsenic and mercury at the site.

Estimations of Aquifer Parameters

The SOLUTE ONED module was used to estimate the hydrogeological parameters of the aquifer. The module contains analytical solutions involving advection-dispersion equations.

Assumptions

Several assumptions regarding the source of contamination, hydrogeology, boundary conditions, initial distribution of mercury and arsenic in groundwater were made before the construction of the groundwater flow and transport model. The following assumptions were necessary to bridge the gap

between the available data and the requirements of the numerical model.

- Groundwater flow is assumed to be in a steady state in an unconfined aquifer.
- There was no groundwater contamination prior to the initiation of the mining activities.
- There is one source of contamination and that is at the Retort Building Area.
- The concentration of arsenic and mercury in the source area are 114 ug/l and 30 ug/l respectively (approximation from wells MW07 and MW01).
- The distances from the source area to the "observation" wells are as follow: the distance from the center of the source area to MW01 is 200 feet; the distance from the center of the source area to MW04 is 350 feet; the distance from the center of the source area to MW03 is 400 feet; and the distance from the center of the source area to MW06 is 600 feet. [Note: The high concentration of arsenic (129 ug/L) detected in well MW03 is believed to be unrelated to contamination at the Retort Building (possibly attributed to a perched water table) and was ignored in the simulation runs.
- No additional source of contamination has appeared over the past 30 years (i.e., between the end of site operations and the HLA/Wilder investigation).

Model Setup

The model established a finite difference grid for modeling the aquifer. The entire one-D grid consisted of 12 nodes with 11 uniform 17 meter long elements. The total domain was set at 187 meters, which corresponds to the distance from the center of the source area to the furthest down gradient extent of the contaminant plume (i.e., Red Devil Creek or MW06 well). The node spacing was established to coincide with the "observation wells" monitoring groundwater contamination. The modeled time frame to estimate the aquifer parameters was 11,000 days, or almost 30 years.

Results

A back-calculations (inverse) method was employed over 11,000 days (30 years) to estimate the parameters and a series of simulation runs were performed to calibrate the results. The range of parameters considered in the simulation runs were:

Groundwater (seepage) velocity: 0.05 - 1.0 m/day
Longitudinal Dispersivity: 0.5 - 2.5 m
Retardation Factor (unit less) for Arsenic: 3.5 - 9.0
Retardation Factor (unit less) for Mercury: 3.5 - 14
Decay Constant (lambda) for Arsenic = 0.1E-03 1/day
Decay Constant (lambda) for Mercury = 0.2E-02 1/day

Table 1 presents the final results of simulation runs. The best fitting results were achieved with the following parameters:

Groundwater (seepage) velocity: 0.1 m/day
Longitudinal Dispersivity = 1 meter
Retardation Factor for Arsenic = 5.5
Retardation Factor for Mercury = 7
Decay Constant (lambda) for Arsenic = 0.693E-03 1/day
Decay Constant (lambda) for Mercury = 0.139E-02 1/day

It should be noted that there is an insufficient number of analytical data sets to statistically assess the error of the model simulations. Consequently, the conservative approach employed in the simulations could create an error for some well data. The maximum difference between the actual arsenic concentration reported in the analytical data and that predicted by the model was 61 percent, and occurred in monitoring well MW03.

Table 1- The Calibration Results for Arsenic and Mercury Simulations

Distance from Source Area (m)	Monitoring Well Distance (m)	Concentration (ug/l)			
		Arsenic		Mercury	
		Simulation	Observed	Simulation	Observed
0		114.00		30.00	
17		101.41		23.78	
34		90.21		22.74	
51	MW07(50)	80.25	114.00	18.12	5.48
68	MW01(61)	71.38	58.2	16..32	28.6
85		63.5		9.38	
102	MW04(106)	56.49	52.3	6.43	0.829
119	MW03(122)	50.25	129.00	5.85	5.31
136		44.68		4.36	
153		39.55		2.60	
170		33.77		0.98	
187	MW06(182)	25.15	25.4	0.19	<0.2

Based on the results, there appears that there is a possibility of additional small sources (other than the

Retort Building Area) that may be contaminating groundwater. This is especially evident around monitoring well MW03.

Evaluations of Capping System Effectiveness

The effectiveness of the capping system was assessed using two modeling approaches: one dimensional simulations using SOLUTE; and three dimensional simulations using SWMS_3D.

SOLUTE Model

The model was run for a six-year period under cap and no cap conditions. The transport model results are summarized in Table 2 and Table 3. Modeling results indicate that under the two scenarios the area of the plume will migrate beyond its initial configuration in six years. However, when the "cap condition" simulation was run, it was evident that the capping scenario would lead to a relatively quick reduction of the metal concentrations in the source area and adjacent zones. This condition would eventually reduce/eliminate the further spreading of contaminants.

The one dimensional SOLUTE model does not consider the vadose zone during the simulation run. Interestingly, the results of the model simulations that included a capping system would appear to be a likely result of the **removal** of contaminated material and not, per se, from capping the waste source area. Table 2 and Table 3 show that in six years the quick reduction in metal concentrations occurs in the source area.

SWMS_3D Model

SWMS_3D is a three dimensional model developed by the U.S. Department of Agriculture (USDA). The model was selected since it has the capability to simulate the fate and transport of metals simultaneously in the unsaturated and saturated zone.

Several additional assumptions were made to describe boundary and vadose zone conditions, as well as the rate of recharge and the aquifer properties. These assumptions, which are listed below, were made before constructing the parameters of groundwater flow and transport model:

- The saturated and unsaturated zone are a homogeneous media.
- No previous estimates of the average recharge rate were available for this site. It was assumed that the recharge varies between 5 and 10 percent of annual precipitation (literature-derived value).
- The main groundwater flow is in only one direction (x) from the source area. There is no flow in the y-direction.
- The installation of a capping system reduces infiltration by 90 - 100 percent.

Model Setup

This model was set up to look at contaminant transport from a source area into soil and an unconfined aquifer. Because of the relatively long source area (70-100 meters), the groundwater flow should be uniform from the source area. Therefore, the dimensions of the flow path were defined as one meter wide and 16 meters high (the vadose zone comprising 6.0 meters and the aquifer comprising 10.0 meters). This was done in an effort to reduce computing time. The solution domain was defined as 0 to 270 meters and was divided into three areas as follows: the up gradient area from 0 meters < x < 30 meters; the source area from 30 meters < x < 90 meters; and the down gradient flow area from 90.0 meters < x < 270 meters. The domain was discretized into a rectangular grid comprised of 297 elements and 680 nodes. Nodal spacing was made relatively small (5.0 meters) in the 60 meter wide source area.

Results

Before the cap system evaluations were performed, a series of simulation runs were conducted to calibrate the model parameters, which were derived mostly from available literature. The best calibration results are presented in Tables 4 and 5 in the "2000" column. Notwithstanding, the distribution of arsenic and mercury are similar to the results from the model SOLUTE.

The evaluation of the effectiveness of the cap was performed by reducing the infiltration by 90 percent. Over a six year period and a cap system in place, the concentration of arsenic in groundwater at 80 meters down gradient from the source area decreased between 3 and 20 percent, and mercury concentrations decreased between 0 and 18 percent. The area of "influence" during the six year modeling period is between 40 and 60 meters down gradient from the source area. The concentration predicted for the observation points located greater than 100 meters from the source area show a slight increase over the modeled six year period. However, due to the removal (or reduction) of contaminants in the source area, these values are expected to decrease over time.

Summary and Conclusion

The modeling simulations using SOLUTE and SWMS_3D models suggests that the metal concentrations decrease with distance from the source and increase slightly over time as the contaminant plume moves through. The modeling results also suggest that there may be the possibility of several additional small source areas. Notwithstanding, the results of the simulation appear to indicate that the construction of a cap would result in a sharp reduction in arsenic and mercury contamination.

Table 2- The simulations results of arsenic concentration in groundwater with capping system alternative (SOLUTE model)

Distance from Source Area (m)	Monitoring Well Distance (m)	Concentration, ug/l							
		No cap					With cap		
		Observation	2000	2002	2004	2006	2002	2004	2006
0			114.00	114.00	114.00	114.00	0.00	0.00	0.00
17			101.41	101.41	101.41	101.41	71.23	6.21	0.25
34			90.21	90.21	90.21	90.21	90.21	72.65	18.15
51	MW07(50)	114.0	80.25	80.25	80.25	80.25	80.25	80.19	69.36
68	MW01(61)	58.2	71.38	71.38	71.38	71.38	71.38	71.38	71.30
85			63.5	63.5	63.5	63.5	63.5	63.5	63.5
102	MW04(106)	52.3	56.49	56.49	56.49	56.49	56.49	56.49	56.49
119	MW03(122)	129.0	50.25	50.30	50.31	50.34	50.25	50.25	50.25
136			44.68	44.70	44.78	44.90	44.69	44.69	44.70
153			39.55	39.73	39.86	40.01	39.72	39.75	39.76
170			33.77	35.02	35.50	35.63	34.98	35.30	35.35
187	MW06(182)	25.4	25.15	29.23	31.38	32.79	29.22	30.84	31.33

Table 3 - The simulations results of mercury concentration in groundwater with capping system alternative (SOLUTE model)

Distance from Source Area (m)	Monitoring Well Distance (m)	Concentration, ug/l							
		No cap					With a cap		
		Observation	2000	2002	2004	2006	2002	2004	2006
0			30.00	30.00	30.00	30.00	0.00	0.00	0.00
17			23.78	23.78	23.78	23.78	21.18	4.64	0.42
34			22.74	22.74	22.74	22.74	18.44	18.22	10.30
51	MW07 (50)	5.48	18.12	18.12	18.12	18.12	18.12	18.12	18.12
68	MW01(61)	28.6	16..32	16.32	16.32	16.32	16.32	16.32	16.32
85			9.38	9.38	9.38	9.38	9.38	9.38	9.38
102	MW04(106)	0.829	6.43	6.43	6.43	6.43	6.43	6.43	6.43
119	MW03(122)	5.31	5.85	5.88	5.89	5.89	5.88	5.89	5.89
136			4.36	4.57	4.64	4.66	4.57	4.64	4.66
153			2.60	3.20	3.51	3.64	3.20	3.51	3.64
170			0.98	1.67	2.26	2.63	1.66	2.25	2.63
187	MW06(182)	<0.2	0.19	0.51	1.01	1.52	0.51	1.01	1.52

Table 4- The simulations results of arsenic concentration in groundwater with capping system alternative (SWMS_3D model)

Distance from Source Area (m)	Monitoring Well Distance (m)	Concentration, ug/l							
		No cap					With cap		
		Observation	2000	2002	2004	2006	2002	2004	2006
- 20			98.78	98.78	98.78	98.78	93.56	80.62	74.06
0			113.57	113.56	112.5	112.7	105.01	98.00	84.00
20			98.45	98.44	98.39	98.17	97.21	89.65	78.14
40	MW07(50)	114.0	89.67	89.44	89.35	89.15	88.25	85.19	83.36
60	MW01(61)	58.2	78.32	78.80	78.35	78.38	76.35	74.38	73.78
80			67.50	67.57	67.34	67.23	67.15	66.53	65.66
100	MW04(106)	52.3	57.24	57.34	57.28	57.59	57.49	57.49	57.49
120	MW03(122)	129.0	51.33	51.32	51.11	51.34	53.25	54.25	54.25
140			45.49	45.73	45.66	46.13	45.72	45.75	45.67
160			37.42	38.21	39.50	39.60	38.98	38.30	39.35
180	MW06(182)	25.4	27.15	29.12	30.89	32.67	28.22	29.84	28.33

Table 5- The simulations results of mercury concentration in groundwater with capping system alternative (SWMS_3D model)

Distance from Source Area (m)	Monitoring Well Distance (m)	Concentration, ug/l							
		No cap					With cap		
		Observation	2000	2002	2004	2006	2002	2004	2006
- 20			26.48	26.56	25.56	24.67	22.89	18.78	16.56
0			30.61	30.00	29.56	29.30	28.56	26.67	24.87
20			27.82	27.82	27.78	27.82	25.18	23.64	20.46
40	MW07(50)	5.48	25.54	25.74	26.02	26.44	24.44	18.22	17.30
60	MW01(61)	28.6	23.23	23.82	23.12	23.12	23.12	23.17	23.56
80			18.12	18.26	18.32	18.66	18.72	18.34	18.23
100	MW04(106)	0.829	12.13	12.78	13.38	13.66	12.38	12.38	12.89
120	MW03(122)	5.31	8.45	8.73	8.43	8.93	8.43	8.43	8.73
140			5.67	6.17	6.44	6.32	5.57	5.66	6.26
160			2.42	2.83	3.46	3.89	1.99	2.48	2.84
180	MW06(182)	<0.2	0.45	0.53	0.61	0.77	0.51	0.67	0.76