Abandoned Mine Site
Pilot Study
Ten-Mile and Basin Creek Watershed
Rimini, Montana

Task 2. Pilot Study Technology Review/Alternative Selection.

Prepared for

U. S. Army Corps of Engineers

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Preliminary Pilot Demonstration Report

Pilot Study Technology Review/Alternative Selection

1.0 Statement of the Problem

The historic mining activities in the Tenmile Creek drainage have released heavy metals into Tenmile Creek. Degradation of Tenmile Creek is caused primarily from the residual waste rock/tailings piles and discharging mine adits at many of the approximately 150 abandoned rock mine sites located in this watershed. Mining-related releases in the Tenmile Creek drainage potentially contaminate the water supply. A review of environmental data from these mining sites demonstrates the release of arsenic, cadmium, copper, lead, zinc, and other metals. Tissue samples from Tenmile Creek fish have shown elevated levels of arsenic. Tenmile Creek is used as a municipal water supply source. Because mining wastes potentially contaminate drinking water supplies for Helena and the community of Rimini, there is potential for human exposure. Previous remedial actions taken by EPA and Montana DEQ in the Tenmile Creek drainage focused on solid mining wastes and tailings piles, but did not address acid mine drainage that discharges into Tenmile Creek.

The site is primarily within Lewis and Clark County near Helena, Montana. The site comprises the upper portion of the Tenmile Creek drainage basin, which extends from U.S. Highway 12 South to the drainage divide adjoining the Basic Creek, Cataract Creek and Telegraph Creek watersheds. To the west, the site is bounded by the Continental Divide. Upper Tenmile Creek flows to the northeast from its headwaters and then to the north through a deep gorge between Red Mountain and Lee Mountain until it enters a relatively wide alluvial valley as it exits the site near Highway 12. The headwaters of upper Tenmile Creek are about five miles upstream of the community of Rimini, which is located in the approximate center of the site.

2.0 Summary of Known Investigations and Actions at the Sites

Redwater Mine

The Redwater Mine adit discharge was sampled in 1995 (Pioneer, 1995). This effort included an analysis of the site history and current conditions for the Montana Department of Environmental Quality (MDEQ). A permit was not required or issued for this analysis (Personal Communication, 2002f). Pioneer's results are presented in Tables 1 and 2 (Pioneer, 1995).

A reclamation project was conducted for the Redwater mine (Weston, 1997). The reclamation removed the waste rock and tailing materials that had high potential to contaminate surface water and soil. The remaining waste rock was recontoured, covered (capped) with topsoil and revegetated. The discharge from the Redwater mine adit was not remediated by the removal action. This adit discharge was piped from the mine adit under the remediated area and discharges directly into Tenmile Creek. The mine adit discharge was characterized and those characterization data are presented in Tables 1 and

2 (Weston, 1997). Weston did not require a permit to characterize the adit discharge (Personal Communication, 2002f).

Camp Dresser and McKee (CDM) analyzed the Redwater adit discharge under a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) investigation of the Upper Tenmile Creek Mining Area (CDM, 2001). The purpose of CERCLA investigation was to characterize the nature and extent of contamination. The contamination and releases resulted from waste materials left in the environment at numerous abandoned historic hardrock mining and ore-processing facilities at the Upper Tenmile Creek Mining Area. The Remedial Investigation (RI) report provided the information and data necessary to assess potential risk to human health and the environment, and to evaluate remedial action alternatives for eliminating, reducing, and controlling those risks. A permit was not required to conduct the RI (Personal Communication, 2002f). CDM data are summarized and presented in Tables 1 and 2.

Table 1 Total Recoverable Metal Concentrations (μg/l) Redwater Mine Adit

Date	Discharge CFS	Arsenic	Cadmium	Copper	Lead	Zinc	Iron
MCLs[1]	---	10	5	1.3	10	---	---
WQB-7[2]	---	18	0.163	5.2	3.2	673	1000
4-Oct-95	0.0223	153	53.2	13.3	3.8	9670	6538
25-Jan-96	0.0334	99.3	68.6	17.7	0.73	12100	5990
9-May-96	0.0223	99.4	68.2	19	0.41	12000	6180
26-Aug-96	0.0345	163	50.7	16.9	2.3	9390	6400
22-Jun-00	---	123	31.5	6.7	0.58	7270	4800

μg/l – micrograms per liter
1. Maximum Contaminant Level (EPA)
2. WQB-7 is, Circular WQB-7 Montana Numeric Water Quality Standards. Value is the lowest of Aquatic Life Chronic or Human Health for Surface Water. (December 2001).
3. Value is hardness dependent.

Table 2 Dissolved Metal Concentrations (µg/l) Redwater Mine Adit

Date	Discharge CFS	Arsenic	Cadmium	Copper	Lead	Zinc	Iron
MCLs[1,4]	---	---	---	---	---	---	---
WQB-7[2,4]	---	---	---	---	---	---	---
4-Oct-95	0.0223	52.7	47.4	4.4	0.16	9310	2700
25-Jan-96	0.0334	18.4	63	3.5	0.16	12200	2230
9-May-96	0.0223	19.7	59.7	8.7	1.8	11800	2270
26-Aug-96	0.0345	33.2	55.6	3	1.6	9620	2060
22-Jun-00	---	26.9	28.6	0.84	0.1	7040	2110

µg/l – micrograms per liter

1. Maximum Contaminant Level (EPA)
2. WQB-7 is, Circular WQB-7 Montana Numeric Water Quality Standards. Value is the lowest of Aquatic Life Chronic or Human Health for Surface Water. (December 2001).
3. Value is hardness dependent.
4. Criteria are applicable to "total recoverable" only.

Susie Mine

The Susie site was first characterized in 1993 (AMRB/APT, 1993). The sampling was conducted as part of their report on "Abandoned Hardrock Mining Priority Sites" for the Montana Department of State Lands Abandoned Mines Reclamation Bureau. AMRB/PTS did not require a permit for the investigation (Reid, MDEQ). A summary of that data is presented in Tables 3. They did not sample for dissolved contaminant concentrations (AMRB/PTS, 1993).

Pioneer sampled the Susie mine adit as part of an Adit Baseline Characterization study for the Montana Department of State Lands. AMRM/PTS did not require a permit for the investigation (Personal Communication, 2002f). The investigative results are presented in Tables 3 and 4 (AMRB/PTS, 1998)

In 2000, Parrett and Hettinger sampled the Susie mine adit discharge as part of a water quality characterization in the Upper Tenmile Watershed. This was a report to the US Geological Survey. A permit was not required for the investigation (Personal Communication, 2002f). The results of their samplings are displayed on Tables 3 and 4 (Parrett and Hettinger, 2000).

Table 3
Total Recoverable Metal Concentrations in the Susie Mine Adit Discharge (μg/l)

Date	Discharge CFS	Aluminum	Arsenic	Cadmium	Copper	Iron	Lead	Zinc
MCLs[1]	---	--	10	5	1.3	---	10	---
WQB-7[2]	---	**87**	18	0.16[3]	5.2	1000	3.2	67[3]
7/13/93	0.04	--	27700	91.8	33.8	171000	13.2	27200
5/2/2000	0.01	3000	7600	250	120	110000	14	34000
6/8/2000	---	10000	7600	240	110	--	17	31000
6/20/2000	0.01		9000	240	120	--	11	32000
9/9/1998	---		5400	466	260	147000	7.1	48600
Unknown	---	2260	6140	258	122	112000	6.6	26000

μg/l – micrograms per liter
1. Maximum Contaminant Level (EPA)
2. WQB-7 is, Circular WQB-7 Montana Numeric Water Quality Standards. Value is the lowest of Aquatic Life Chronic or Human Health for Surface Water. (December 2001).
3. Value is hardness dependent.

Table 4
Dissolved Metal Concentrations in the Susie Mine Adit Discharge (μg/l)

Date	Discharge CFS	Aluminum	Arsenic	Cadmium	Copper	Iron	Lead	Zinc
MCLs[1,4]	---	--	10	5	1.3	---	10	---
WQB-7[2,4]	---	**87**	18	0.16[3]	5.2	1000	3.2	67[3]
5/2/2000	0.01	2990	7600	299	156	119000	7.2	32600
6/8/2000	---	--	7300	215	116	--	5.2	23400
6/20/2000	0.01	--	6400	261	101	--	6.6	21800
9/9/1998	---	4870	3550	508	272	143000	3	49900

μg/l – micrograms per liter
1. Maximum Contaminant Level (EPA)
2. WQB-7 is, Circular WQB-7 Montana Numeric Water Quality Standards. Value is the lowest of Aquatic Life Chronic or Human Health for Surface Water. (December 2001).
3. Value is hardness dependent.
4. Criteria are applicable to “total recoverable” only.

URS removed soil and surface mining wastes at the Susie Mine under a CERCLA removal action. The area of removal has been recontoured, capped and revegetated as part of the removal action. Drainage was designed to divert precipitation and runoff from the capped area (CDM, 2001). This action removed 11,173 CY of waste rock from the Susie Mine site. Following the removal, approximately 40 tons/acre of crushed limestone (econo-lime) was added to the remaining soils on site near the bank of Tenmile Creek, to raise and stabilize the soil pH. In addition, 500 kg/acre of triple-super-phosphate was added to reduce the mobility of the remaining contaminants and reduce the residual arsenic available for plant uptake. The lime and phosphate were incorporated into the post removal site soil. The site was backfilled/ covered with a minimum thickness of one foot of clean, six-inch-minus fill, and recontoured. The surface was then covered with six inches of clean topsoil to facilitate revegetation. The coarse six-inch-minus fill reduced upward capillary movement and direct exposure threat to remaining contaminants, and further stabilize the site. The site was then revegetated. The adit drainage ditch was modified by installing several settling pools and relining the adit drainage path with geotextile covered with limestone rock and gravel. The modifications were made to minimize releases to Tenmile Creek from the adit drainage until the problem is addressed more permanently by EPA's Remedial Program. The mine opening was covered with clean, six-inch-minus fill and the discharge was piped from the adit. The discharge from the pipe flows through a channel into Tenmile Creek (URS, 2001). A permit was not required for this remedial action (Personal Communication, 2002f). URS sampled Tenmile Creek upstream and downstream of the Susie Mine adit. Table 5 presents those data and the average and 95 percent Upper Confidence Limit (95UCL) for dissolved and total metals data (URS, 2001).

Table 5
Total and Dissolved Metal Concentrations
Upstream and Downstream of the Susie Mine Adit (µg/l)

Sample	Statistic	Aluminum	Arsenic	Cadmium	Copper	Iron	Lead	Zinc
				Dissolved				
MCL	---	---	---	---	---	---	---	---
WQB-7[4]	---	---	---	---	---	---	---	---
Up Stream	Average	100	8.5	15.5	13.3	60	26.7	2034
Down Stream	Average	580	120	49.2	62	5277	65	7262
Up Stream	95UCL	---	11.3	25	23.1	186.3	52.4	3009
Down Stream	95UCL	853	217	82.3	83.7	7879	111	10515
				Total				
MCL	---	--	10	5	1.3	---	10	---
WQB-7[2]	---	87	18	0.163	5.2	1000	3.2	673
Up Stream	Average	267	9.8	14	15	175	30	1832
Down Stream	Average	533	240	63.7	50	5735	72	6355
Up Stream	95UCL	524	11.2	20.5	21.8	269.7	43.6	2719
Down Stream	95UCL	719	360	92.2	71.3	8755	101	9360

µg/l – micrograms per liter
1. Maximum Contaminant Level (EPA)
2. WQB-7 is, Circular WQB-7 Montana Numeric Water Quality Standards. Value is the lowest of Aquatic Life Chronic or Human Health for Surface Water. (December 2001).
3. Value is hardness dependent.
4. Criteria are applicable to "total recoverable" only.

3.0 Decisions to be Made – Based on Selected Technology

The decisions to be made by completing the Pilot Study are related to the identified problem – potential releases of heavy metals to Tenmile Creek. Identified decisions, listed below as questions to be answered by the Pilot Study include:

> Can an innovative technology treat metals released from mine adits?
>
> Can the treatment process meet remedial action objectives (RAOs)?
>
> What are the capital and operating costs of a treatment process?
>
> What are the properties of process byproducts or residuals?

4.0 Summary of Site Data and Information Supporting the Selection of Alternatives

Tables 1-4 identify metal concentrations in acid mine drainage from the Redwater and Susie Mine adits. The concentrations are high and present technical challenges for typical water treatment processes.

The flow discharge rates from the adits are low (4.5 to 15.5 gpm). Water treatment processes are generally designed to treat municipal water supplies and associated high volumes.

Many mine adits have limited accessibility requiring small treatment units if a point of discharge treatment scenario is selected.

5.0 Development and Screening of Alternatives

Tables 1 through 4 depict the maximum contaminant levels (MCLs) allowed by the EPA and concentrations protective of the environment by MDEQ. The effectiveness of removing the high concentration of contaminants in the adit discharges will be the baseline for technology selection. Technologies that cannot meet MCLs and environmental protection criteria will not be considered further.

The next criteria that the technologies will face will be cost effectiveness. Cost effectiveness considers capital and O&M (operation and maintenance) costs. MDEQ said that one of their primary concerns is that the system requires minimal maintenance time, because they do not foresee receiving the funds to create a position to operate the technology (Personal Communication, 2002e).

The technology must be scaleable to the low flows that are expected after the EPA in consultation with MDEQ (and the United States Forest Service, for sites on national forest lands) caps and recontours collapsed shafts/adits and constructs drainage features to reduce storm water and snowmelt from entering mine workings and contributing to contaminated adit drainage. The current combined flow of the mine adits in the area is 75 gallons per minute (gpm) (EPA and MDEQ, 2002). Smith River will screen technologies for capital and O&M costs for systems of 75 gpm and 10 gpm to consider the costs if capping and contouring is not effective.

The technology must also have minimal impact on the citizens of Rimini, the recreational users of the area, and the environment. MDEQ said that impact on the citizens of Rimini and recreational users of the area will be a major factor in determining which system to install (Personal Communication, 2002e).

The first step in development and screening of alternatives is to establish remedial action objectives. The alternatives will be screened against the nine criteria; overall protection of human health and the environment, compliance with ARARs, long-term effectiveness and permanence, reduction of toxicity, mobility and volume through treatment, short-term effectiveness, implementability and cost. This evaluation will not evaluate state and community acceptance because of the limited scope and schedule of the project.

5.1 Detailed Analysis of Alternatives

A detailed analysis of the alternatives would be performed after completion of the pilot study on the selected alternative. A detailed alternatives analysis is not within the limited scope of the project. A detailed analysis will be performed later in the treatment process selection.

5.12 Alternative Development

Alternative development includes development of Remedial Action Objectives (RAOs), general response actions, identifying volumes of media, and identifying and screening alternatives. These topics are discussed in the following subsections.

5.2.1 Development of Remedial Action Objectives (RAOs)

RAOs have been developed for the project. Tentative RAOs are listed below.

- Prevent ingestion of water having metals [carcinogen(s)] in excess of MCLs and a total excess cancer risk of greater than 10^{-6} to 10^{-7}.
- Prevent ingestion of water having metal concentrations in excess of MCLs and a total systemic health risk of a Hazard Index (HI) greater than 1.0.
- Prevent dermal contact with water having metals concentrations that result in a total excess cancer risk of greater than 10^{-6} to 10^{-7} and/or a systemic health risk of an HI greater than 1.0.5.2.1.
- Prevent releases of adit discharges to Tenmile Creek greater than Montana's Circular WQB-7 Aquatic Life Standards.

5.2.2 Development of General Response Actions

General response actions for acid mine drainage include no action, institutional action, treatment and discharge.

5.2.3 Identify Areas or Volumes of Media

The current discharge rates for the Redwater and Susie mine adits were presented in Tables 1 through 4. The Susie Mine adit discharges at approximately 0.001 cubic feet per second (0.5 gpm) and the Redwater Mine adit discharge varies between 0.035 cfs and 0.023 cfs (15.7 and 10.3 gpm). The current combined total flow for all mine adits in the Tenmile Creek drainage area is approximately 75 gallons per minute (EPA and MDEQ, 2002). The total drainage is expected to decrease as the EPA fills and contours collapsed adits and shafts.

5.2.4 Identify and Screen Remedial Technologies and Process Options

Identification of general response actions and remedial technologies is presented in Figure 5.X. The shaded areas of Figure 5.X identify the process options that have been eliminated from further evaluation. A new community well process option is currently being pursued for the residents of Rimini and will not be evaluated further. The rationale and evaluation of response actions and technologies are discussed below.

5.2.4.1 No Action

The NCP (National Contingency Plan) requires consideration of a no action response. The no action response leaves conditions as they currently exist, with out change. The "no action" response does not meet the RAOs identified in Section 5.2.1. Therefore, the no action alternative is removed from further evaluation.

5.2.4.2 Institutional Action

Institutional response action was identified. The technologies under institutional actions include access restrictions and alternate water supply. Access restrictions are not practical for acid mine drainage that is released to Tenmile Creek. Tenmile Creek is diverted, in its entirety, to become a municipal water supply. Access restrictions would not meet the RAOs identified in Section 5.2.1. Therefore, an access restriction under institutional action is eliminated from additional evaluation.

A second remedial technology within the institutional action response action is an alternate water supply. This response action is being pursued by EPA for the residents of Rimini Montana. However, this response action does not meet the RAOs identified in Section 5.2.1 for residents of Helena Montana nor for the protection of the environment. Therefore, this alternative is eliminated from additional evaluation.

5.2.4.3 Treatment Technologies

A treatment response action was identified. The remedial technologies under the treatment response action include biological and physical and/or chemical treatment. Biological technologies include an artificial wet lands and a biological processing unit, which are discussed below.

Biological Technology.

Artificial wet lands technology is a promising technology for the treatment of metals in acid mine drainage. Wet lands technology is promising and is likely to meet the RAOs identified in Section 5.2.1. This technology is being tested at the SSMS mine site near headwaters of Tenmile Creek. There are physical constraints at the Red Water Mine adit and residential constraints at the Susie mine adit that make wet land technology impractical. Creation of a wet lands treatment facility at the Susie Mine site would not eliminate potential dermal contact of acid mine drainage with younger Rimini residents.

A biological treatment facility for the Red Water and Susie Mines is not practical because of the small volume of water to be treated and the high capital and operating costs associated with a biological treatment unit. Biological treatment units are not practical to treat small volumes of water. Because of these constraints, biological technology was eliminated form further consideration.

Physical and/or Chemical Treatment.

Physical and chemical treatment includes the following identified process options; membrane filtration, absorption, precipitation and ion exchange. Each of these process options is discussed below.

Membrane filtration. Membrane filtration separates contaminants from water by passing it through a semi permeable barrier or membrane. The membrane allows some constituents to pass through, while blocking others. Three types of membrane processes have been utilized to remove arsenic from water: reverse osmosis (RO), nanofiltration (NF), and microfiltration (MF). This process option can potentially meet the RAOs identified in Section 5.2.1. This process option is promising and will be retained for a more detailed evaluation.

Absorption. In adsorption, solutes concentrate at the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase. The adsorption media is usually packed into a column. As contaminated water is passed through the column, contaminants are adsorbed. This process option can potentially meet the RAOs identified in Section 5.2.1. This process option is promising and will be retained for a more detailed evaluation.

Precipitation. Precipitation uses chemicals or electro-physical means to transform dissolved contaminants into insoluble solids. In the treatment of metals in water, precipitation is accompanied by coprecipitation. In coprecipitation, the target contaminant may be dissolved or in a colloidal or suspended form. Precipitation/coprecipitation is the most frequently used technology for treating arsenic in water. This process option can potentially meet the RAOs identified in Section 5.2.1. This process option is promising and will be retained for a more detailed evaluation.

Ion exchange. Ion exchange is a physical/chemical process in which ions held electrostatically on the surface of a solid are exchanged for ions of a similar charge in a solution. It removes ions from the aqueous phase by the exchange of cations or anions between the contaminants and the exchange media. The most commonly used ion exchange media are synthetic, strongly basic anion exchange resins. This process option can potentially meet the RAOs identified in Section 5.2.1. This process option is promising and will be retained for a more detailed evaluation.

5.2.4.4 Discharge Treatment

The remedial technologies identified for the discharge response action are limited to off site treatment. On site treatment is not considered because the acid mine drainage from the Red Water and Susie Mines is currently being discharged to Tenmile Creek on site and that condition does not meet the RAOs identified in Section 5.2.1. Off site treatment includes transport to an off site POTW, RCRA facility or to a more distant river. The remoteness of the Red Water and Susie Mines makes it not practical to perform off site treatment. This response action does not meet the RAOs identified in Section 5.2.1 for human health nor for the protection of the environment. Therefore, this alternative is eliminated from additional evaluation.

5.3 Alternatives Screening Process

The following process options were retained for evaluation, membrane filtration, absorption, precipitation and ion exchange. The evaluation uses the criteria of effectiveness, implementability and cost for each process option. This screening process does not evaluate interaction between media, because the other media at the Red Water and Susie mines have been remediated.

5.3.2 Screening Evaluation

The retained alternatives are organized and compared with their ability to meet the RAOs. The alternatives are defined to provide information to allow differentiation among alternatives with respect to effectiveness, implementability, and cost. The objective is to identify differences among the alternatives. Differences in size and configuration, time frame to meet RAOs, treatment rate, and spatial requirements will be examined.

5.3.2.1 Effectiveness

This evaluation is effectiveness relative to other identified technologies. The order of the effectiveness discussion is membrane filtration, absorption, precipitation, and ion exchange.

Membrane Filtration

Membrane filtration separates contaminants from water by passing it through a semi permeable barrier or membrane. The membrane allows some constituents to pass through, while blocking others. Three types of membrane processes have been utilized to remove arsenic from water: reverse osmosis (RO), nanofiltration (NF), and microfiltration (MF). NF and RO require a relatively high pressure (50 to 150 pounds per square inch [psi]), while MF requires a relatively low pressure (5 to 100 psi). Low-pressure processes primarily remove contaminants through physical sieving and the high-pressure processes primarily remove contaminants through chemical diffusion across the permeable membrane. Because arsenic species dissolved in water tend to have a relatively low molecular weights, only NF and RO membrane processes are likely to effectively treat dissolved arsenic. MF has been used in conjunction with precipitation/coprecipitation to remove solids containing arsenic. Membrane filtration processes generate two treatment residuals from the influent waste stream: a treated effluent (permeate) and a rejected waste stream of concentrated contaminants (reject) (EPA, 2002). The rejected waste stream can have Arsenic and TDS levels of approximately four to five times the level of the influent stream. The rejection waste stream is 15 to 20% of influent waste stream (Brandhuber, 2002a).

RO primarily removes smaller ions typically associated with total dissolved solids. The molecular weight cutoff for RO membranes ranges from 1 to 20,000, which is a significantly lower limit than for NF membranes (EPA, 2002).

NF primarily removes larger divalent ions associated with hardness (for example, calcium [Ca], and magnesium [Mg]) but not monovalent salts (for example, sodium [Na] and chlorine [Cl]). The molecular weight cutoff for NF membranes ranges from approximately 150 to 20,000. NF is slightly less efficient than RO in removing dissolved arsenic from water (EPA, 2002).

MF is a low-pressure process that primarily removes particles with a molecular weight above 50,000 or a particle size greater than 0.050 micrometers. The pore size of MF membranes is too large to effectively remove dissolved arsenic species, but MF can remove particulates containing arsenic and solids produced by precipitation/coprecipitation processes (EPA, 2002).

Adsorption

There are very high concentrations of adsorbable contaminants coming from the Susie and Redwater adits. The capacity of the adsorption media increases with increasing contaminant concentrations. The high concentrations of heavy metals in the Susie and Red Water adit discharges would require frequent replacement or regeneration of adsorbent. The high concentrations might also lead to an increased number of spent media that cannot be regenerated. This would require additional treatment or disposal cost. The optimal pH to maximize adsorption of arsenic by AA is acidic (pH 6). The pH of the aqueous stream treated by AA can affect the total volume of wastewater that can be treated before regeneration of the AA is required (EPA, 2002)

Precipitation/coprecipitation

Chemical and electro-physical reactions are the basic mechanism of precipitation/coprecipitation technologies. Higher contaminant levels should be able to be dealt with by putting in a larger amount of precipitating chemicals or altering the electro-physical process (current, amps, voltage, pressure, contact time, etc). The amount of precipitates needed to meet the MCL and the characteristics of the sludge may make the technology cost prohibitive in some sites. This is a very important concern for the abandoned mine adits in the Upper Tenmile watershed due to their high contaminant levels. The filters at the end of the system are typically mechanical in nature and should not be vulnerable to fouling if backwashed properly. Maximum contaminant limits on the technology have not been identified, indicating that the effectiveness of precipitation/coprecipitation is high.

Ion Exchange

Ion exchange is a physical/chemical process in which ions held electrostatically on the surface of a solid are exchanged for ions of a similar charge in a solution. It removes ions from the aqueous phase by the exchange of cations or anions between the contaminants and the exchange media. The most commonly used ion exchange media are synthetic, strongly basic anion exchange resins. Strong base resins are utilized because dissolved arsenic is usually in the anionic form and weak bases tend to be effective over a smaller pH range. The resin is usually packed into a column, and as contaminated water is passed through the column, contaminant ions are exchanged for other ions such as chloride or hydroxide in the resin. Ion exchange is often preceded by treatments such as filtration and oil-water separation to remove organics, suspended solids, and other contaminants that can foul the resins and reduce their effectiveness.

Ion exchange resins must be periodically regenerated to remove the adsorbed contaminants and replenish the exchanged ions (EPA, 2002). Typically, 300 to 3,000 bed volumes (BVs) can be treated prior to regenerating the column, depending upon the water quality and the resin used (HDR, Ion). Like adsorption, ion exchange can be operated using multiple beds to reduce the need for bed regeneration and allow for continuous operation while beds are being regenerated. Ion exchange beds are typically operated as a fixed bed, in which the water to be treated is passed over an immobile ion exchange resin. One can also operate the bed in a non-fixed, countercurrent fashion in which water is applied in one direction, usually downward, while spent ion exchange resin is removed from the top of the bed. This method can reduce the frequency of ion regeneration (EPA, 2002). One drawback of the ion exchange process is that its regeneration forms hazardous residuals (Brandhuber, 2002b).

Ion exchange media's performance is affected by several site-specific factors: valence state, presence of competing ions, fouling, presence of trivalent iron, and pH level. Ionic exchange generally does not remove As (III). Competition for the exchange ions can reduce the effectiveness of ion exchange if ions in the resin are replaced by ions other than arsenic, resulting in a need for more frequent bed regeneration (EPA, 2002). Ion exchange is not recommended for arsenic removal where the concentration of total dissolved solids is greater than 500 mg/L or the concentration of sulfate is greater than 150 mg/L (HDR, Ion). Other anions, especially sulfate diminish the ability of the resin to adsorb arsenic. The presence of organics, suspended solids, calcium or iron can cause fouling of ion exchange resins. The presence of Fe (III) could cause arsenic to form complexes with the iron that are not removed by ion exchange. For chloride-form strong-base resins, a pH in the range of 6.5 to 9 is optimal. Outside of this range effectiveness decreases quickly (EPA, 2002).

5.3.2.2 Implementability

This evaluation includes technical and administrative feasibility of a technology process.

Membrane Filtration.

Several site-specific factors affect membrane filtration performance. The presence of suspended solids, high molecular weight, dissolved solids, organic compounds and colloids in the feed stream could cause membrane fouling (EPA, 2002). Membrane fouling is the condition where, at a constant temperature and pressure, the permeate flux declines with increasing cumulative volume of water treated due to reduction of the permeability of membrane. In simple terms, the membrane clogs (Brandhuber, Membrane). As (III) is smaller than As(V) and diffuses more easily through the membrane than As(V). The pH might affect the adsorption of the arsenic on the membrane by creating an electrostatic charge on the membrane surface. Low influent temperatures decrease membrane flux. Increasing system pressure or increasing the size of the membrane surface area can compensate for low influent stream temperature (EPA, 2002).

Absorption

The high concentrations of heavy metals in the Susie and Red Water adit discharges would require frequent replacement or regeneration of adsorbent. The high concentrations might also lead to an increased number of spent media that cannot be regenerated.

Precipitation

The implementability of the precipitation/coprecipitation process option technologies is most easily implemented.

Ion Exchange

Ion exchange is often preceded by treatments such as filtration and oil-water separation to remove organics, suspended solids, and other contaminants that can foul the resins and reduce their effectiveness. Ion exchange resins must be periodically regenerated to remove the adsorbed contaminants and replenish the exchanged ions (EPA, 2002).

5.3.2.3Cost

This is an evaluation of relative capital and O&M costs rather than detailed estimates. Cost evaluation plays a limited role in the screening process. General cost estimates were taken from the Federal Remediation Technology Roundtable Screening Matrix (Federal Remediation, 2001). The capital and O&M costs are given as high or low in comparison to the other technology options. Systems with traditionally high O&M costs (Membrane Filtration, Absorption, and Ion Exchange) are expected to experience a dramatic increase in O&M costs due to media overloading from the adits' high metal concentrations.

Membrane Filtration: High Capital, High O&M

Absorption: Low Capital, High O&M

Precipitation: High Capital, Low O&M

Ion Exchange: High Capital, High O&M

Systems with traditionally high O&M costs (Membrane Filtration, Absorption, and Ion Exchange) are expected to have increased O&M costs when treating mine adit discharge due to media overloading from the adits' high metal concentrations (Personal Communication 2002d). Precipitation technology is versatile enough to remove the high metal loads of the discharging adits. The other technologies were designed for contaminated drinking water systems with much lower metal concentrations (Personal Communication 2002d).

5.4 Alternatives Screening

Alternatives with the most favorable overall evaluation are retained for further consideration. The implementability and cost evaluations eliminated membrane filtration, absorption, and ion exchange for further evaluation. Smith River focused the evaluation on specific precipitation/coprecipitation technologies.

Of the variety of precipitation/coprecipitation technologies on the market, Smith River evaluated Kinetico Inc. *Macrolite® Coagulation and Filtration System, Model*

CPS100CPT, New Earth Systems™ *CentrO$_3$fier* and Watermark Technologies *eVox® Model 5*, which are available technologies using precipitation methods. The Kinetico and Watermark technologies have been verified by EPA's Environmental Technology Verification Program (ETV) for arsenic removal (EPA ETV, Coagulation). New Earth Systems™ *CentrO$_3$fier* combines precipitation with the capability of additional treatment by secondary adsorptive/ion exchange polishing. The *CentrO$_3$fier* technology does not use chlorine compounds in the oxidation process, which eliminates the formation of chlorinated byproducts (Personal Communication 2002b).

The Director of Technology for Kinetico, the high metals concentration in adit discharge are of concern for a single stage precipitation approach and a single stage is unlikely to reduce metal concentrations sufficiently to meet RAOs. A multistage unit would be required (Personal Communication, 2000d). Kinetico indicated that a multi-stage unit is likely to require oxidation, initial clarification, iron injection, *Macrolite®* filtration, and ion exchange (as an final polishing step). A cost estimate using a multistage process is in preparation and it would require six to eight weeks to construct a pilot Unit (Personal Communication 20002d).

The *eVox®* system, Watermark Technologies, is currently untested on mine adit water containing extremely high concentrations of heavy metals, although preliminary testing results appear favorable. Watermark Technologies estimated that up to fifteen working days are needed to complete a pilot test of the mine adit discharge (Personal Communication, 2002a).

The time constraints for this study are not consistent with this treatment system (Personal Communication, 2002a). This constraint is not likely to be present in future pilot treatment programs.

New Earth Systems™, Inc., indicated that the *CentrO$_3$fier* system could treat the mine adit discharge to meet MCLs and RAOs (Personal Communication, 2002b). The advantage of the New Earth Systems pilot plant is that it contains multiple processing units that can be activated during the pilot test. The actual tests will determine the number of stages of the existing system is required to meet RAOs.

5.5 Recommended Alternative

The *CentrO$_3$fier* by New Earth Systems, Inc. was selected for the pilot program because it meets the effectiveness, implementability and cost evaluations discussed in Section5.3.2. In addition, the New Earth Systems process can meet the RAOs the project budget and the project schedule.

Figure X.1. Technology and Process Option Screening

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