

CONVERSION OF A TAILING IMPOUNDMENT TO A FRESHWATER RESERVOIR, THE EAGLE PARK RESERVOIR PROJECT, CLIMAX MINE, COLORADO¹

by

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Abstract. The Climax Molybdenum Mine, located near Leadville, Colorado, is the site of a lengthy mining history spanning more than 80 years. In the 1960's, extraction of molybdenum from oxide ore located adjacent to the massive molybdenite sulfide deposit resulted in the construction of an earthen core dam to impound fine-grained oxide tailing in the Eagle River Valley. Through recognized value of water storage and reclamation opportunities, a tailing removal project was initiated in 1993 to convert the impoundment facilities to a post-mining beneficial land use of developed water resources. An evaluation of the effect residual materials and lake dynamics would have on in-stream water quality was performed. Eagle Park Reservoir stands as a model for future reclamation efforts that involve water delivery to highly sensitive receiving waters. This paper provides a case study on project development, the evolution of water quality assessment, and the regulatory framework that contributed to this project's success.

Additional Key Words: water rights

Introduction

This paper describes a tailing removal project that occurred between 1993 and 1996 at the Climax Mine, Climax, Colorado that was designed to obtain a post-mining beneficial land use of developed water resources in the Eagle River Valley. Conversion of the Oxide Pond into the freshwater Eagle Park Reservoir was accomplished through the cooperative effort between Climax and the Eagle Valley Consortium. The Consortium, a group of water users and ski industry interests in the Eagle Valley, supported development of the project for upstream replenishment of water depletions during low flow periods. Discussed in this paper are the removal of tailings from the tailing pond, employment of pollution prevention from upstream mine process water sources, water quality assessment and review, and reclamation of the 25 ha water body.

Background

The Climax Mine, located at the Continental Divide (elevation 3450 m) on Fremont Pass in central Colorado

(Figure 1), is the largest identified molybdenite orebody in the world. The first processing of molybdenite from Bartlett Mountain occurred in 1918. Climax has since led research and development of molybdenum use in day-to-day products and applications.

The location of the Climax Mine is unique in that the facilities straddle the Divide and encompass the headwaters of three drainages: Tenmile Creek, draining north to Lake Dillon and the headwaters of the Blue River, the Eagle River draining to the Colorado River through the central portion of the Upper Colorado River Basin, and the Arkansas River, flowing south then east to the Mississippi River. The mine receives approximately 63 cm of precipitation annually, 75 percent of which is snow. Average annual snowfall at the site is 6.9 m. Major activities at the site currently include water treatment and water management for a multitude of downstream water uses.

Climax developed a system of water delivery to support consumptive water use in the processing of molybdenite. Today the system serves as an extremely flexible water delivery and trans-basin conveyance network that serves both future molybdenum processing and the management of water allocations in three major Colorado drainages.

The Oxide Process

In 1961, the Climax Molybdenum Company explored potential molybdenum extraction techniques from an ore zone containing oxide molybdenum (ilsemanite; $\text{Mo}_3\text{O}_8 \cdot n\text{H}_2\text{O}$) that surrounded the central molybdenite orebody. Recognizing that molybdenum could be extracted from this mineralized source, Climax embarked on processing of the oxide ore. The process consisted of a complex treatment of

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selected mixed ores fed to a 5,100 metric ton per day processing plant capable of recovering 0.7 kg of molybdenum per ton of plant feed. The process began with preconcentration following basic classification for tailings that had passed through the sulfide flotation circuit. Fines were separated in the preconcentration step and pumped as a pulp to the oxide plant where the pulp was agitated with sulfur dioxide and sulfuric acid. Desorption tanks were then used to drive off sulfur dioxide. Air was injected into the system to reoxidize the dissolved molybdenum allowing it to adsorb onto carbon filters. The carbon filters containing molybdenum were then subjected to stripping columns using a gaseous stream of ammonia (Amax, inc., 1966).

This process produced a solution of ammonium molybdate that was purified and heated to a crystallized form. Finally, this ammonium molybdate was roasted and converted to commercial grade molybdenic oxide. The entire Molyoxide process was complex and sensitive to rather precise control of temperatures, pressures, and volumes.

Production at the Molyoxide plant ran from July of 1966 to September of 1968. Curtailment of production occurred largely due to the plant's interruption of efficiencies in the sulfide milling circuit that processed 40M tons of sulfide ore daily. Obvious additional expenditure was also foreseen as federal environmental legislation of the late 1960's came into play (Voynick, 1996).

Wastes generated from the Molyoxide process required special handling. The silt size fraction of the tailing material prevented their incorporation with the slurried and cycloned sulfide tailings deposited on the Tenmile Tailing Pond (Figure 1). The separate circuits also required separate water handling to prevent poisoning of one circuit in the management of another. At the time, Climax was producing tin, tungsten, and pyrite as well as molybdenum. Implicit in the development of the oxide ore processing circuit was the need to impound the tailing materials from the process in a manner that did not disrupt the handling of other ores and extraction processes at the Climax Mine and Mill. To accomplish this, Climax constructed an earthen core dam at

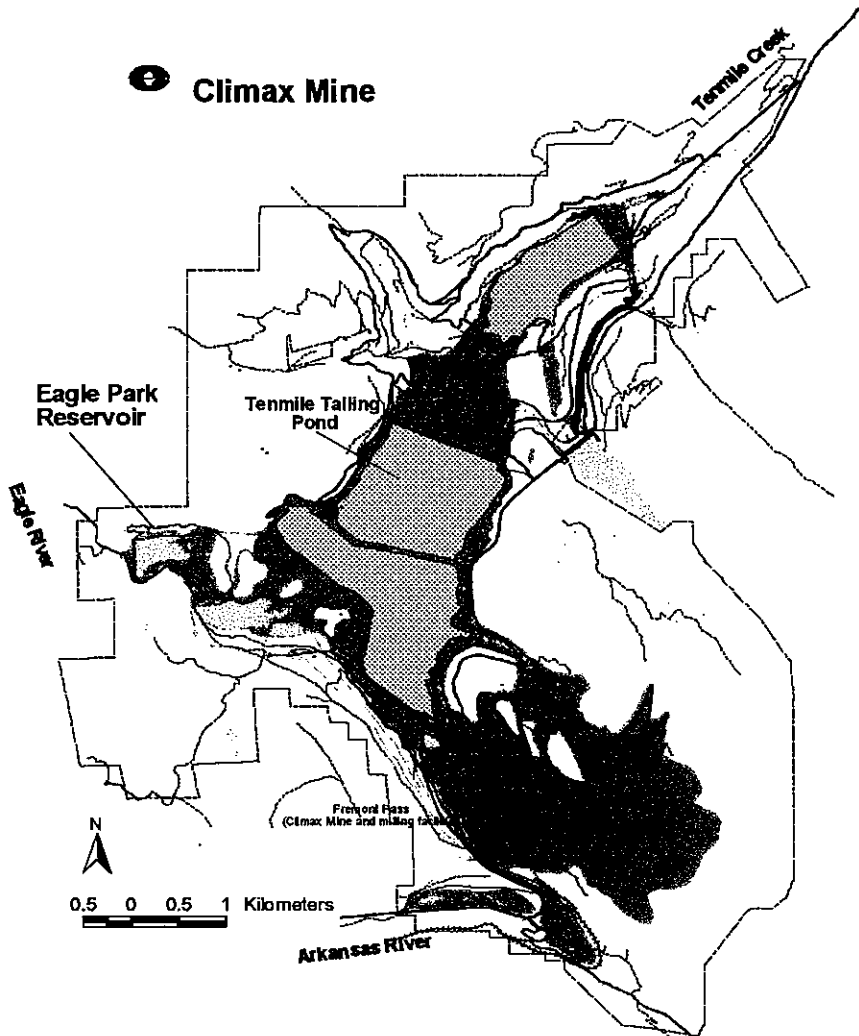


Figure 1. Diagram of the Climax Mine showing locations of the three drainages and the location of Eagle Park Reservoir

the head of the East Fork of the Eagle River west of the primary tailings disposal facilities in the Tenmile drainage. In the two years of operation of the Molyoxide plant, 917M m³ of tailing were deposited in this facility known as the "Oxide Pond".

Project Development

In 1989 a clear understanding of the water asset value of the property and a desire to reduce care and maintenance costs led to the assessment of alternatives for site footprint reduction and reclamation. Review of the oxide pond, from which over 370M m³ (300 acre-feet) of water had been annually pumped to the Tenmile water treatment facilities for the 30 years following curtailment of the Molyoxide processing, determined that removal of the tailing in the reservoir was feasible (Woodward-Clyde Consultants, 1998).

The Climax Mine Reclamation Permit, held with the Colorado Division of Minerals and Geology, calls for reclamation of the Oxide Pond and several other mine facilities to a post-mining beneficial land use of *Developed Water Resources*. The methods by which Climax would obtain this designated post-mining land use are not specifically outlined in the permit. Climax evaluated long-term management of tailing in the pond and considered tailing removal using dredge and pump systems, truck and shovel removal, or capping and fix-in-place alternatives to retire the facility. Both physical and chemical characteristics of the materials were reviewed in the pre-feasibility evaluation.

The study found that cost effectiveness, long-term maintenance costs, and the most favorable environmental protections were best obtained through tailing removal (Woodward-Clyde Consultants, 1998). The driver for this project ultimately became the regional recognition of the potential beneficial use of stored water at the headwaters of the Eagle River.

The Eagle Valley of Colorado is host to recreation and residential development activities in support of a thriving ski industry. Water use in the Eagle Valley increases during winter low flow months for snowmaking and municipal water treatment during the winter tourist season. Stream depletions in the Eagle Valley are not replenished until the Eagle River and the Colorado River converge well downstream of water use. Upstream replenishment of in-stream depletions was therefore a desire of Eagle Valley water users, the Colorado Water Conservation Board, and other stakeholders for water use in the valley. The location of the Oxide Pond, on private land at the headwaters of the Eagle River, coupled with the presence of an earthen core impoundment capable of storing fresh water rather than tailing, provided the site for basin water storage. Capacity of the new facility would be 3.9MM m³ (3,148 acre-feet) with a live yield of 2.5MM m³ (2,016 acre-feet) (W.W. Wheeler & Assoc., 1994). In 1993, Climax and Vail Associates entered a cooperative agreement to perform tailing removal and tailing pond reclamation using the preferred removal options outlined in the pre-feasibility process.

Project Construction

The preferred option using removal by hydraulic monitoring and pumping began in 1993. This initial method proved untenable due high plasticity of the material and inadequate tailing density in the slurry being pumped under high head. A truck and shovel operation was initiated in early 1995 to remove the tailing from the Eagle River basin to the Tenmile Creek basin, a distance of approximately 4.8 km. Truck and shovel operations continued through the summer of 1996.

Management of the tailing and dewatering activity proved to be the largest challenges of the construction project. The initial assessment of the tailing revealed that the material was predominantly composed of silt-sized particles with liquid limits ranging between 32 and 40 and plasticity indices ranging from 1 to 6. Moisture content of the material ranged from 35 to 49 percent indicating that the moisture content of the oxide tailing was above the liquid limit. Materials were considered to be of very low strength, and large settlements were anticipated under small loads (Woodward-Clyde Consultants, 1998). During excavation, the material did behave as a heavy liquid, requiring short loading of trucks and the installation of special tailgates to hold liquefied tailing during the haul.

An equally important aspect of the removal operation was the management of water during the period of excavation and hauling. Water management was an important task in allowing equipment access and egress. In addition, thirty years of tailing storage in the impoundment had contaminated dam foundation materials as water seeped through the dam to a seepage return system at the dam's toe. This seepage and all water in the reservoir throughout the removal project required pumping to the Climax Water Treatment System in the Tenmile Creek basin. Climax treats all mine water under a National Pollution Discharge Elimination System (NPDES) permit in an active lime neutralization process to a discharge point in Tenmile Creek.

Additional pollution protections and infrastructure construction occurred through 1998. A concrete cutoff wall was constructed to a bedrock foundation in the drainage between upgradient process water facilities and the reservoir. Climax managed seepwater at the toe of the dam through pump upgrades and pipeline improvements. Because the Oxide Pond was designed to prevent the release of water down the Eagle Valley, outlet works in the Class 1 dam, reconstruction of the emergency spillway, and installation of conveyance and flow measurement devices were required. These dam improvements were subject to review by the Colorado Office of the State Engineer.

Since reservoir capacity was to be maximized, additional excavation occurred after identification of growth media (topsoil) residing beneath the tailing. During the fall of 1996, 41M m³ (33 acre-feet) of growth media were hauled 6 km to temporary stockpiles for reclamation of overburden wastes near the Climax milling complex. This activity provided badly needed materials for successful high-altitude

reclamation at other site locations while increasing the total yield of the reservoir.

Reservoir sediment and Water Quality Assessment

Reservoir Sediments

Early review of the project had determined that residual materials and impacted soils beneath the oxide tailing could pose a concern to water quality of the reservoir following tailing removal. Eagle Park Reservoir, once source tailing material was removed, would not be subject to NPDES permit requirements. Criteria upon which water delivery would be predicated, however, had not been determined. The concern for ultimate deliverability of impounded freshwater from the reservoir culminated in a Sampling and Analysis Plan (SAP) to define and measure the chemistry of soils and waters during and following tailing removal.

Sampling of the reservoir tailing in the prefeasibility stage of the project showed the tailing chemistry to be characteristic of geochemical profiles from the Climax orebody. The tailing were non-toxic but acidic due to the nature of the extraction process that used sulfuric acid. The tailing also had a slight neutralization capacity and only minimal sulfide sulfur, therefore the acidity was borne of the extraction process, as opposed to the oxidation of sulfide materials. Parameters measured in the pond water and tailing reflected parameters assigned to Eagle River standards under Aquatic Life Class 1 Cold, Recreation Class 1, and Water Supply (Table 1). Initial testing revealed that, as with the Climax Water Treatment System, manganese, iron, zinc, and to a lesser degree aluminum and copper, were the primary constituents found in the tailings and Oxide Pond waters.

The Sampling and Analysis Plan (SAP) was designed to demonstrate source removal and prove limited interaction of residual material with the large volume of water storage (Titan Environmental Corp., 1996). The SAP consisted of a reservoir bottom material sampling event utilizing composite samples taken at a depth of 0 to 15 cm on thirty 0.8 ha sample plots. QA/QC followed EPA's CLP standards to ensure data quality for soil and water samples. Soil samples were subjected total metals analysis and to a modified Meteoric Water Mobility Procedure of the Nevada Division of

Environmental Protection (Nevada Division of Environmental Protection, 1990). This test used lixiviant adjusted to a pH of 7.5 to 8.0 to reflect background water pH ranges measured in the diversion canals used to fill the reservoir. Further analyses were made for total organic carbon and soil texture. Results of these soil and sediment analyses are provided in Table 2.

Several factors led to the identification that residual materials would not pose a threat to ultimate water quality in the reservoir. First, there was a clear distinction between the tailing material and the underlying soils and rock overlain by tailing deposition. Second, any waters introduced to the reservoir that would be in contact with residual materials would be small compared to the overall volume of the reservoir. Third, following thirty years of tailing storage, more soluble components of the tailing had already dissolved. Mineral components of the remaining tailing were considered to be much less soluble than those in the material originally deposited (Titan Environmental Corp., 1996). Other factors that aided in the understanding of low potential soil and sediment impacts to water quality included the presence of bedrock over much of the reservoir floor, and the removal of growth media as described above. Reservoir configuration and depth (35 m) were considered favorable in that lake turning and stratification (10 m) would limit the suspension of lake sediments.

Reservoir Water

Using results of the reservoir sediment analyses, a straight dilution model assuming 100 percent mobility of metals revealed that primary standards for the East Fork of the Eagle River could be obtained following reservoir fill. However, this conservative modeling for secondary drinking water standards for Mn (50 µg/l) showed reservoir levels slightly above the standard. Freshwater delivery of water into Eagle Park Reservoir began in the spring of 1997 through two diversion canals that bracket the Climax water treatment and process water circuit upgradient of mine facilities. These freshwater sources had previously been used to divert freshwater around the reservoir to the Eagle River. The 50 ha basin below the diversion canals provided additional water to fill the reservoir. Figures 2 and 3 show water quality in the reservoir for selected parameters through the filling period and SAP sampling conducted in 1997.

Table 1. Water Quality Standards for Segment 3 of the Eagle River

Physical/Biological	Inorganic (mg/l)		Metals (ug/l)		
D.O.=6.0 mg/l	NH ₃ (ac/ch)=TVS	S=0.002	As(ac)=50(Trec)	Fe(ch)=300(dis)	Ni (ac/ch)=949.2/988.4 TVS
D.O.(sp)=7.0 mg/l	Cl ₂ (ac)=0.019	B=0.75	Cd (ac)=10.3 TVS(tr)	Fe(ch)=1000(Trec)	Se(ac)=135 TVS
pH=6.5-9.0	Cl ₂ (ch)=0.011	NO ₂ =0.05	Cd (ch)=1.17TVS	Pb (ac/ch)=101.9/4.1 TVS	Ag (ac)=2.2 TVS
F.Coli=200/100ml		CN=0.005	CrIII (ac)=50(Trec)	Mn (ch)=1000(Trec)	Ag (ch)= 0.3 TVS
		Cl=250	CrVI (ac/ch)=18.4 TVS	Mn (ch)=50(dis)	Zn (ac/ch)=120.8/109.5 TVS
		SO ₄ =250	Cu(ac/ch)=18.4/12.2 TVS	Hg(ch)=0.1	

TVS = Table Value Standards based on hardness of 103.8 mg/l as CaCO₃
Trec = Total recoverable

ch = Chronic
dis = Dissolved
ac = Acute

Table 2. Reservoir Sediment Total and Leachable Metal Concentrations

	As		Cr		Cu		Fe		Pb		Mn		Ni		Zn		Ag	
	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)	Total (mg/kg)	Leachable (mg/l)
Min	0.55 U	0.0025 U	5.6 U	0.004 B	5.6 U	0.005 U	27 B	0.01 U	9	0.001 U	2.8	0.11	5.6 U	0.01 U	17	0.01 U	1.4 U	0.05 U
Mean	2	0.0025	13	0.01	24	0.05	16,741	0.01	48	0.001	180	4.93	12	0.02	45	0.02	2.3	0.05
Max	4 B	0.0025 U	20	0.018 B	51	0.07 B	22,400	0.03 B	84	0.001 U	444	16.7	20	0.05 B	89	0.07 B	2.8	0.05 U

U = Analyte was not detected at the Method Detection Limit (MDL).

B = Analyte concentration detected between the MDL and the Practical Quantitation Limit (PQL)

Note: boron, cadmium, selenium, mercury, chloride, and nitrate were removed from the parameters analyzed in preliminary screening analysis.

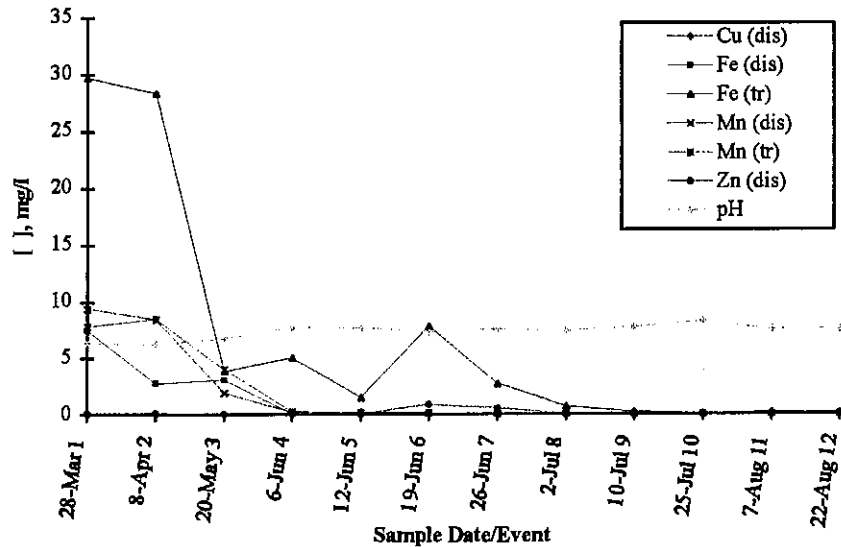


Figure 2. Eagle Park Reservoir Water Quality Trend 1997

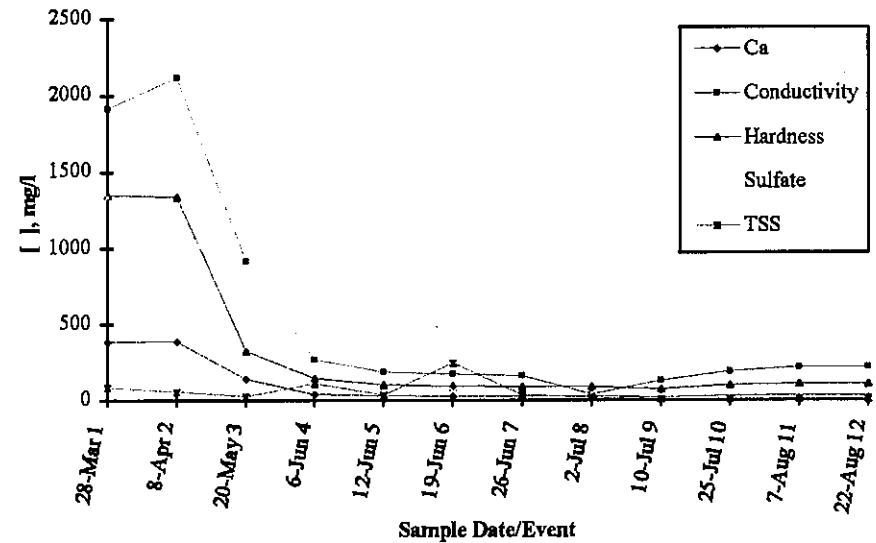


Figure 3. Eagle Park Reservoir Water Quality Trend 1997

SAP sampling of reservoir waters commenced in the spring of 1997. Each sampling event included surface water samples from the north, south and east ends of the reservoir. Initial sampling screened for all constituents for which there were standards. Parameters that were not detected in three screening samples were dropped from the parameter list. Thirteen sampling events occurred between March and September of 1997. During sampling, freshwater delivery to the reservoir amounted to 1.9MM m³ (1500 acre-feet). By July 26, water quality in the reservoir met all standards associated with the Segment 3 of the East Fork of the Eagle River.

Current quarterly sampling in the reservoir demonstrates that water quality has stabilized, with most parameters measured at or below detection limits. Current sampling includes quarterly monitoring in the center of the reservoir at a depth of 10 m. This depth is consistent with measured thermal stratification in the reservoir.

Conclusions

Reclamation of the Eagle Park reservoir demonstrates the public benefits that can accrue through cooperative initiatives between industry and regulatory agencies. Water delivery to the East Fork of the Eagle marks the first time in thirty years that water within the Eagle Park Reservoir basin will be routed to the original drainage.

Literature Cited

AMAX, Inc., 1966, "New Climax Plant," Amax Journal, Vol. 4, No. 4, Amax, Inc., New York, pp 1-6.

Nevada Division of Environmental Protection, Bureau of Mining Regulation and Reclamation. 1990. Meteoric Water Mobility Procedure.

Titan Environmental Corp. 1996. Eagle Park Reservoir Post Reclamation Sampling and Analysis Plan. Titan Environmental Corp., Denver, Colorado.

Voynick, S.M. 1996. Climax: The History of Colorado's Climax Molybdenum Mine. Mountain Press Publishing, Missoula, Montana.

Woodward-Clyde Consultants. 1989. Prefeasibility Level Assessment for Oxide in Dam 4 Considering Enlargement to Water Storage Dam or Retirement, Near Climax, Colorado. Woodward-Clyde Consultants, Denver, Colorado.

W.W. Wheeler and Associates. 1994. Yield Analysis for Eagle Park Reservoir and Robinson Reservoir. W.W. Wheeler and Associates, Englewood, Colorado.

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