MANAGING THE HYDROLOGIC IMPACTS OF MINING ON MINNESOTA'S MESABI IRON RANGE[1]

by

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Abstract. Research conducted by the Bureau of Mines, Twin Cities Research Center, and the Minnesota Department of Natural Resources is helping to define the environmental impacts of mining and mineral extraction on the hydrology of Minnesota's Mesabi Iron Range. Cooperative research studies are concentrating on the unique reclamation problems associated with mining on the Range. One study focuses on the impact of open pit mining on surface and groundwater. The ultimate goal of this project is to develop a model which will predict the impacts of these mine pits on the hydrologic balance. This model can be used by mining companies for future mine planning as well as closure operations. The first phase of this project has been to determine the evaporation from open pits as they fill with water at the cessation of mining. The second phase will be to evaluate the groundwater component by assembling and analyzing historical pumping records and pit water levels. Another joint research study is evaluating the use of sulfate reducing bacteria for removing heavy metals from mine waste rock drainage. Four locally available organic materials are being evaluated to determine their effectiveness in removing heavy metals and raising pH. A second phase of this study will determine the most effective organic material for a constructed wetland substrate in field scale experimentation.

Additional Keywords: hydrology, Mesabi Iron Range, groundwater, mine pit, hydrologic balance, sulfate reducing bacteria, heavy metals, wetland

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Introduction

Iron mining has long been a major part of Minnesota's history. Natural iron ore was first discovered on the Vermilion Range in 1850 and on the Mesabi Range in 1866 (Minnesota Mining Directory 1989, Figure 1). Ore shipments first left the Mesabi Range by rail in 1892, from the Mountain Iron Mine. Since much of the natural ore was near the surface, open pit mining was extensively used. Thousands of acres of open pit mines stretch across the Mesabi Range. From 1892 to 1988, the total iron ore shipped from the

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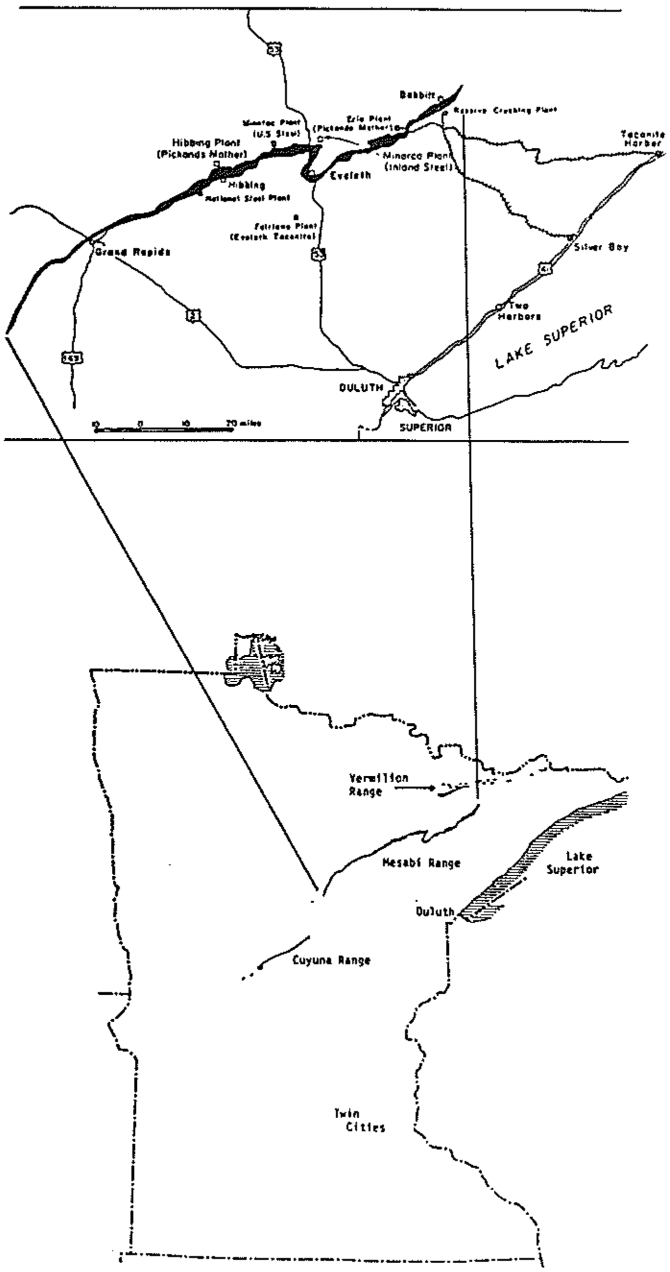

Figure 1. - Minnesota's Iron Range District

Mesabi Range was over 3.5 billion tons (Minnesota Mining Directory 1989). The last natural iron ore mine ceased operation in Minnesota in 1991.

In the late 1950's, with much of the natural ores nearing exhaustion, ore production was replaced by processing of magnetic taconite materials. Taconite is a metasedimentary rock in the Biwabik Iron Formation of Early Proterozoic age containing hematite and magnetite. It varies in iron content, with about 25 pct magnetic iron present in crude taconite. The Biwabik formation of the Mesabi Range is approximately 100 miles long, 3 miles wide and about 600 feet in thickness (Veith 1988).

Taconite mined in Minnesota in 1989 supplied 70 pct of the Country's usable iron ore (Esparza 1991). The industry provided jobs for over 7500 employees and generated over $940 billion that year in economic activity in the form of payrolls, good and services provided, and State and local taxes (Esparza 1991).

Five companies are presently mining taconite at six locations across the Mesabi Range (Figure 1). These operations include National Steel, Hibbing Taconite, USX Minntac Plant, Eveleth Mines, Inland Steel Minorca Plant, LTV, and Cyprus Mines. All of these are open pit operations, but the mines are much larger than the open pit natural ore mines of the past. Typical taconite mines are several miles long and cover hundreds of acres. Consequently, large quantities of waste material including surface overburden, waste rock, and tailings are generated from these facilities. The abandoned pits also remain to fill with water. Post-mining uses exist, such as recreational facilities, aquaculture, and providing a local water supply if proper management is achieved.

Research conducted by the Bureau of Mines, Twin Cities Research

Center (TCRC), is helping to define the environmental impacts of mining and mineral extraction in Minnesota. Cooperative research studies with the Minnesota Department of Natural Resources (MDNR), Division of Minerals and Division of Waters, are developing models and treatment processes to protect and insure the State's pristine water supplies and resources. This paper is an overview of two ongoing studies focusing on the hydrologic consequences of mining on the Mesabi Iron Range in northern Minnesota.

Open Pit Hydrology Study

In Minnesota, there are two agencies that regulate mining. The MDNR regulates mineland planning and reclamation, including water use and hydrologic impact evaluation. The Minnesota Pollution Control Agency (MPCA) regulates water quality and issues permits based on effluent and receiving stream water standards. These two agencies work jointly to insure that the State has a continued supply of quality water.

To comply with State Reclamation Regulations (Dept. of Nat. Res. Rules Relating to Mineland Reclamation, Chapter 6130) and related statutes (M.S.103G.297), the MDNR must acquire a basic understanding of the hydrologic impacts of mining to ultimately develop management strategies for pre- and post-mine planning.

Iron ore mining in Minnesota has left hundreds of vast open pits on the earth's surface. Like other open pit mines, these pits intercept and store huge quantities of water, significantly altering the hydrology and water balance in the area.

Open pits are managed during deactivation of mining operations to achieve long term suitability for a variety of subsequent uses and may require pit water monitoring, treatment, and/or continued maintenance after deactivation, to insure abandoned pits are non-polluting, stable, and free of hazards.

Groundwater movement, storage, and supply are altered during the mining operation. Pumping activities continue through the life of the mine operation, generally supplying good quality water to downstream natural systems, area residences, and industries. When mining activities cease, pumping generally stops, and the pits fill naturally through surface runoff and groundwater inflow, and the hydrology is again altered.

The quantity and quality of water is often critical to downstream users and is an important environmental consideration for the MDNR and MPCA. TCRC and MDNR are obtaining data relating to water storage, the potential for overflow of the pits, and the ultimate impact on surface and groundwater hydrology in the area to provide data for regulators and mining companies in planning mining operations and assessing environmental impacts.

There is a general lack of information available on the hydrologic consequences of mining on the Iron Range. Research underway will define and predict the hydrological changes that occur when the pits are abandoned. The overall objective of this study is to adapt a hydrologic model which will include evaporation rates and surface- and groundwater components so that impacts and potential utilization of the pits upon mine closure can be determined.

Phase I: Evaporation Component.

The morphology of abandoned pits differs from natural lakes in the region. Abandoned pits often have water depths of over 100 feet and generally exhibit low biological activity. They tend to maximize heat storage due to the clarity of the pit water and the nearly vertical pit walls. Large pit areas intercepting significant amounts of water are a primary component of the groundwater flow, and surface water evaporation is a major component of pit water balance. The large number and size of pits are believed to significantly affect the hydrologic balance of the region.

The first phase of the study addresses this evaporation component of the water balance. In 1989, a contract was established between the Bureau and MDNR to measure surface water evaporation rates of Mesabi Iron Range pits. Evaporation over bodies of water has traditionally been a difficult parameter to measure due to the small changes over short time periods and effects of dynamic weather conditions. Although direct evaporation measurements can be used, and data intensive methods such as energy budget and mass transfer calculations are accepted, methods of effectively estimating evaporation from available meterological data is limited (Anderson and Jobson 1982).

A pit near the extreme eastern limit of the Mesabi Iron Range near the town of Babbitt, MN, was chosen for investigation, due to its size, ease of access to the water surface, and minimal chance for vandalism (Figure 1). The contract included provisions for direct measurement of pit evaporation and recording and analysis of climatic data for interpretation and extrapolation purposes.

The experiment included the installation of standard evaporation pans, precipitation gauges, anemometers, and thermometers. One pan and weather station were installed on an upland site adjacent to a flooded pit and another was located in the flooded, 4-acre pit. The pit evaporation pan was housed in an aluminum flotation ring, designed by the Bureau, and partially submerged in the pit itself.

Readings were manually recorded at both sites. Results during the first field season indicated significant differences in the temperature and wind patterns between the pit and upland site (Table 1). Pit water surface evaporation during the warmer months of July and August was greater than anticipated - approximately 70% of that recorded in the upland pan. Increased wind velocity recorded in the pit compared to the upland site suggested localized air currents were affecting in-pit evaporation. Water temperature profiles were also recorded to describe diurnal and seasonal patterns and, therefore, predict these influences on evaporation.

Table 1. - Average Daily Data for the 1989 Partial Season (July 18 through October 31).[1]

Month	In-Pit Pan			Upland Pan		
	Net Evaporation(mm)	Min/Max Temp.(°C)	Total Wind(km)	Net Evaporation	Min/Max Temp.(°C)	Total Wind(km)
July	3.69	NA[2]	NA	5.23	NA	NA
August	3.24	18.2/22.8	108	5.0	12.0/24.5	75
September	3.39	13.5/18.0	133	3.44	5.7/17.3	100
October	1.89	8.0/11.7	110	2.20	0.8/10.5	99

[1]1989 Project Status Report, MDNR
[2]NA Not Available

However, manual readings taken several times per week did not provide the resolution necessary to explain evaporation occurrences in the pit, and automatic data recording instruments were installed. Two electronic monitoring stations now record and store average hourly evaporation and climatological information such as solar radiation, wind speed and direction, pit water and pan water temperatures, ambient temperature, and precipitation. The data collected is being used as input in developing a predictive model for estimating pit water evaporation at other locations across the Range.

Results from the 1990 and 1991 field seasons are reported by Adams et al (1992). They indicate that seasonal pan coefficients used to estimate average annual lake evaporation in Minnesota may be unique to the flooded pits, and, hence, of use in mineland impact analyses.

Phase II: Groundwater Component.

Presently, we are expanding our research to address the groundwater component of the water balance equation through a comprehensive evaluation of another taconite pit complex, closed since 1985 and located further west on the Range, between Grand Rapids and Hibbing, MN, (Figure 1). This will give us an opportunity to evaluate evaporative and climatological data in a different geologic setting.

Historical pumping records and pit water levels will be assembled. Data will be compiled on surface watersheds and flows, pit water level changes over time, local weather conditions, and pit morphology, for input into the existing water balance model (the Modified-Penman-Monteith method) to evaluate the groundwater component of the pit complex (Adams et al., 1992).

Sulfate Reduction for Trace Metal Removal from Acid Mine Drainage

Open pit iron mining also creates large waste rock stockpiles. These stockpiles range from 80 to 100 feet high and cover thousands of acres across the Mesabi Range. In general, the iron formation contains low levels of trace metals and the drainage from these stockpiles have not created water quality problems. However, at the east end of the Range, the sulfide-bearing Duluth gabbro formation overlies the iron formation. To reach the underlying taconite ore, the Duluth Complex material was stripped off and stockpiled. Over 55 million tons of Duluth Complex covering over 320 acres have been deposited during the last 25 years (Eger et al., 1981).

Trace metal concentrations of copper, nickel, cobalt and zinc have been measured in the natural leachate of gabbro waste rock stockpiles at levels 10 to 10,000 times natural background levels of local undisturbed streams (Eger et al., 1981). Trace metals may cause adverse biological impact on aqueous populations at concentrations less than 0.010 mg/L (Thingvold et al. 1979, Lind et al., 1978). Data collected between 1976 and 1980 showed concentrations of copper and nickel exceeded the 48 hr LC50 for *Daphnia pulicaria*, and nickel exceeded the 96 hr LC50 for the fathead minnow (LC50 is a concentration that is lethal to 50% of the test organisms in the indicated amount of time)(MDNR 1990). Potential contamination is significantly enhanced for surface- and ground waters, wildlife habitats, and fisheries in nearby Bob Bay of Birch Lake, where elevated levels of metal concentrations have been measured in sediments and plant tissues (MDNR 1990, Lapakko and Eger 1981).

In 1989, the cooperative research agreement with the MDNR included a task to evaluate biological remediation methods for removing metals from acid metal mine drainage and to measure the success of various, locally available organic materials in sustaining sulfate reduction. The study is also supported by the Bureau of Mines Pittsburgh Research Center (PRC), and adds additional treatment technologies in their in-house investigations of acid mine drainage in coal mines.

Sulfate reduction has been defined as "a bacterial reaction in which bacteria use the oxygen present in the sulfate to oxidize organic matter to carbon dioxide, producing sulfide species as a by-product" (Drever 1988). When sulfate is reduced to sulfide, metals present in the drainage react to form insoluble metal sulfides. This method has been used successfully in field-scale tests by PRC scientists on acid coal mine drainage (Dvorak et al., 1991).

The sulfate reduction field study in northern Minnesota began in 1990. Bureau scientists determined that sulfate reducing bacteria could grow in the drainage from the Duluth Complex material (McIntire personal communication). Acid drainage collected from a waste rock stockpile was subsequently fed through reaction barrels containing four locally available organic materials (Eger 1992).

Materials included 45-day-old composted municipal solid waste, composted yard waste, horse manure mixed with sawdust, and composted municipal solid waste followed by sawdust. Input and output water chemistry is being determined to evaluate the effectiveness and efficiency of the different organics in removing heavy metals and raising the pH.

Results to date are very promising, with all organic substrates producing an improvement in water quality (Table 2). The influent, which has a pH of 5.1, has been neutralized by all substrates. Concentrations of copper and nickel and levels of sulfate are significantly reduced in all treatments (Table 2). First year analytical results and conclusions are reported in these proceedings by Eger.

Additional rows of barrels are now proposed to evaluate a 180-day-old municipal compost which is more readily available and may release fewer nutrients than the 45-day-old compost. Drainage from another stockpile which has a pH of around 4 and higher levels of trace metals will also be treated.

Summary

The evaporation component of the hydrologic balance may be unique to the abandoned minepits on the Iron Range compared to natural lakes. Seasonal surface evaporation in open pits averages around 95 pct of that in on-land evaporation stations, compared to a standard evaporation coefficient for natural lakes in MN of around 78 pct.

Analysis of the evaporation, meterological, and groundwater components will enhance our ability to estimate and predict the effects of the flooded mine pits on the Range-wide hydrologic balance. The primary benefit of this open pit evaporation project will be to provide technological data to regulators and mining companies to aid in pre- and post-mine planning operations to insure that sound environmental decisions are made.

Leachate flowing from Duluth gabbro waste rock stockpiles is significantly improved by sulfate reducing bacteria present in the organic material in the barrel reactor study. pH of the influent is neutralized, and concentrations of copper and nickel are reduced up to 90 pct in all treatments. Sulfate levels are reduced from 860 mg/L in the influent to around 230 mg/L in the effluent treated with 45-day-old composted municipal waste.

Plans are to continue the sulfate reduction trials to evaluate performance of the organic substrates for removing trace metals and increasing pH, to determine the effect of residence time on metal removal and to determine the effect of pH on removal efficiency. Bureau and MDNR researchers plan to include additional field-scale investigations which will utilize the "best" organic material in a constructed wetland substrate.

Table 2. - Water quality, influent, and effluents, 1990 averages[1].

Parameter	Influent	Effluents[2] Row 1	Row 2	Row 3	Row 4
pH	5.1	7.2	7.6	6.9	7.1
Cu (mg/L)	6.4	0.18	0.07	0.07	0.11
Ni (mg/L)	24.4	0.22	0.08	0.10	0.12
Co (mg/L)	1.2	0.06	0.05	0.05	0.05
Zn (mg/L)	1.4	0.26	0.08	0.09	0.17
SO_4 (mg/L)	860	230	620	660	290

[1]1990 Project Status Report, MDNR
[2]Row 1 - 45-day old composted municipal waste
Row 2 - Composted yard waste
Row 3 - Horse manure mixed with wood chips
Row 4 - 45-day old composted municipal waste compost followed by wood chips

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