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WATER MANAGEMENT OF THE STEEP ROCK IRON MINES AT ATIKOKAN, ONTARIO DURING CONSTRUCTION, OPERATIONS, AND AFTER MINE ABANDONMENT

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ABSTRACT

The Steep Rock Iron Mines at Atikokan, Ontario operated from 1944 to 1979. The iron ore was located at the bottom of Steep Rock Lake and water management was a key factor in developing the mines. Open pit mining required a massive water diversion scheme, including the diversion of the Seine River, draining of Steep Rock Lake, and construction of various dams and other diversion structures. In order to abandon the mine, the Province of Ontario required a suitable abandonment and long-term water management plan, and assessment of the condition of the various water control and diversion structures. Reclamation of the Seine River to its original course was not possible and, consequently, the water control structures, primarily dams and tunnels, will be operating in perpetuity. The water management during the development of the mines and during operations is described, as well as some insight into future water management options after abandonment.

INTRODUCTION

The richest undeveloped deposit of hematite iron ore on the North American continent at the time was discovered in 1938 beneath Steep Rock Lake, near Atikokan, Ontario. Atikokan is located as shown on Figure 1. Stimulus for the development of the mine came during World War n when steel mills were facing a critical shortage of iron ore. Increased steel production to supply the allied war effort coincided with attacks by Nazi U-boats on iron ore ships from South American mines. There was considerable interest in the Steep Rock iron ore deposit because; the deposit was such a high-grade ore that it could be charged directly into the blast furnaces. Development of the Steep Rock Iron Mines commenced during the war in 1943 on an accelerated basis, authorized under Canada's War Measures Act.

Since the iron ore was beneath Steep Rock Lake, and the Seine River flowed through Steep Rock Lake, one of the key factors in development of the open pit mines was to successfully manage the water. The development and the operation of the mines required a massive water diversion scheme, including the diversion of the Seine River, draining of Steep Rock Lake, construction of various dams, tunnels, and

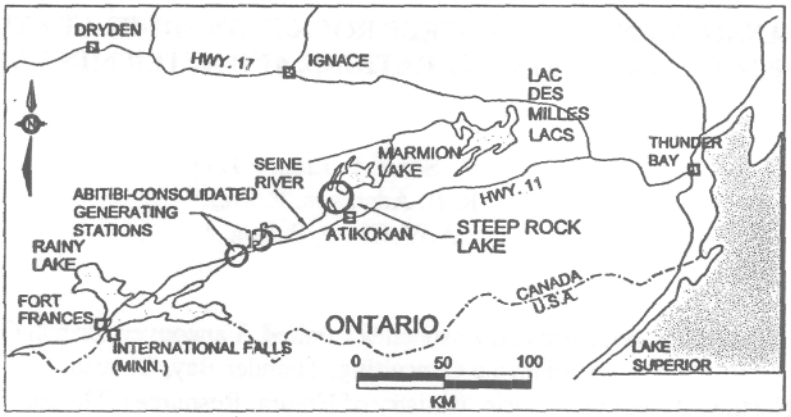

Figure 1 - Location of Steep Rock Lake

other diversion works, and dredging of 210 million cubic metres of very soft lake bottom sediments to expose the iron ore. The mining project at that time was the largest mega project of its type undertaken in Canada.

Mining at the Steep Rock Iron Mines commenced in 1944 and ceased in 1979, and during the life of the mine 88 million tons of iron ore was mined. In 1985 the mining company wished to abandon the mines and return the mining lease to the Province of Ontario (Crown). Prior to accepting the mining property, the Crown required an abandonment and a long-term water management plan, and an assessment of the condition of the various water control and diversion structures.

Ideally it would have been preferable to reclaim the land occupied by the open pit mines to its original condition to allow the Steep Rock Lake to become re-established and the Seine River to flow through the Steep Rock Lake. However, this was riot possible. Firstly, the diverted Seine River could not be returned to its original channel because the river would then be flowing through 90 million cubic metres of disposed dredged lake bottom sediments and the resulting increased sediment load would have serious environmental effects on the fish habitat downstream. Secondly, some of the water diversion and water control works, including some dams and drainage channels, were taken over by Ontario Power Generation as part of the water control facilities required for their coal-fired Atikokan Electrical Generating Station.

Water management during the development of the mines and during the mine operations is described in this paper. Also, the general plan for abandonment and long-term water management is described. Since

reclamation of the Seine River to its original course was not possible, the Seine River diversion will need to be maintained in perpetuity. Consequently, most of the water control structures, primarily dams and tunnels, will also need to operate in perpetuity. The abandonment and water management plans required assessment of the condition of the structures, and when required, implementation of remedial measures for long-term operation.

The Ontario Ministry of Natural Resources assessed the Steep Rock Iron Mines abandonment and water management plans. The development of the Steep Rock Mines resulted in the construction of 40 water control structures. In view of the large number of water control structures that the Ministry was taking over on behalf of the Crown, the Ministry arranged for an engineering study by an engineering consultant specialist on the condition of 17 water control structures, which included 14 dams and 3 tunnels. Some of *UK* results of this engineering study have been presented elsewhere (Sowa et al. 2001).

The Steep Rock Iron Mines operated from 1944 to 1979 but the construction of most of the water control structures and the development of many of the water management procedures occurred during the period from commencement of mine construction in 1943 to about 1961. During this time there are essentially four main phases in the development of the mines and water management procedures, and the construction of the water control structures, and these are described in the following sections. Some of this information is presented in a book written on the project (Taylor, 1978).

WATER MANAGEMENT DURING MINE DEVELOPMENT AND THE CONSTRUCTION OF WATER CONTROL STRUCTURES

Phase 1 - Pre-Developmeat - 1929 to 1942 (Figure 2a)

The Seine River flows from Lac Des Mille Lacs to Marmion Lake, as shown on Figure 1, and from the outlet at Marmion Lake, the river drops 30 m en route to Steep Rock Lake. The Seine River then continues southwest to Rainy Lake. In 1929 the Ontario-Minnesota Pulp and Paper Company Limited (now Abitibi-Consolidated) constructed three power dams on the Seine River and a fourth dam to regulate flows. One power generating site was at Moose Lake (Figure 2a), and the other two sites are downstream of Steep Rock Lake as shown on Figure 1.

In 1938 the existence of high-grade iron ore beneath Steep Rock Lake was proven by drilling. Steep

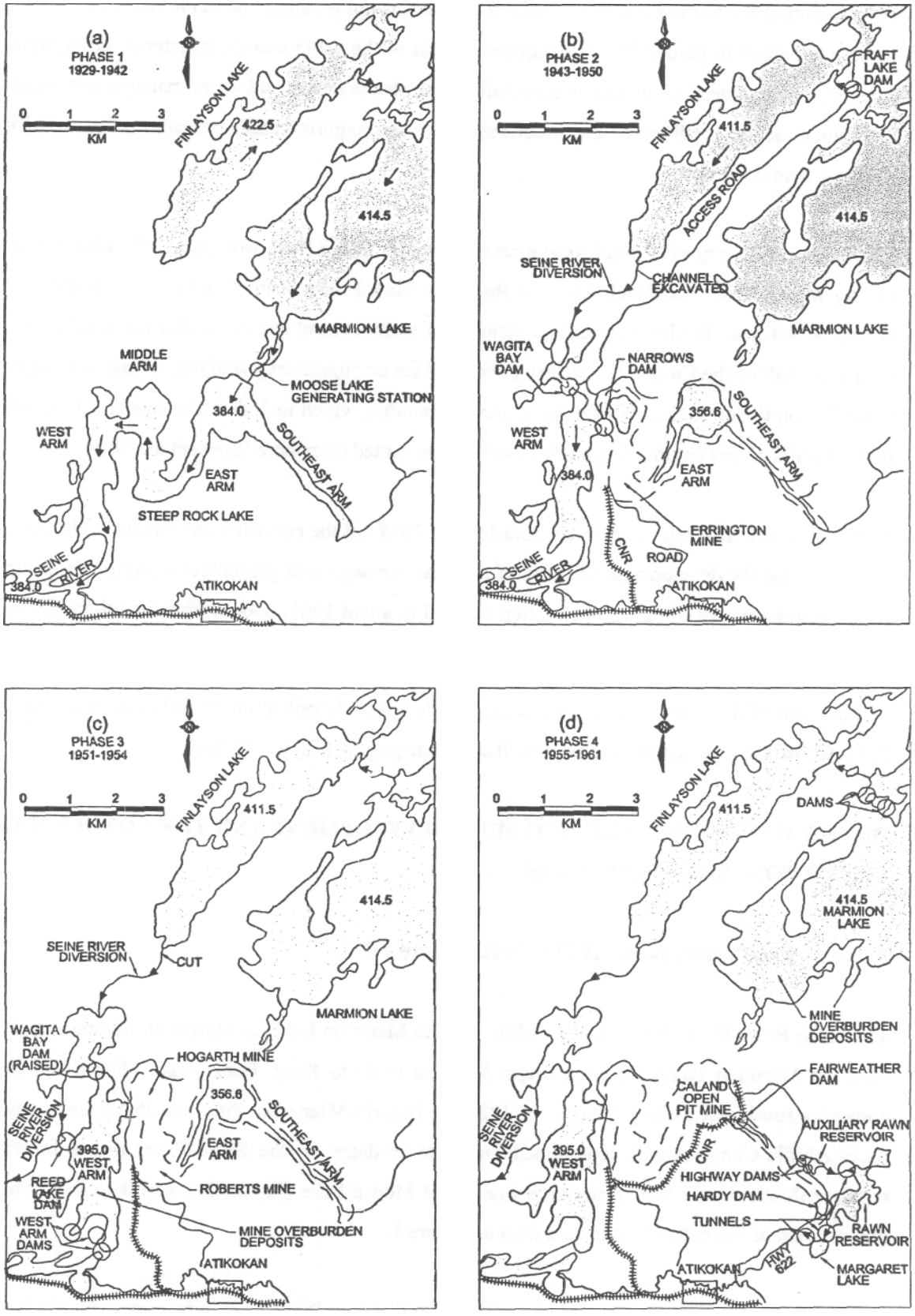

Figure 2 - Historical Development of Steep Rock Lake Mines

Rock Lake forms an "M" shape, with names assigned to each leg, and from west to east they are; West Arm, Middle Arm, East Arm, and Southeast Arm. The initial ore body to be mined was located beneath the Middle Arm.

Phase 2 -1943 to 1950 (Figure 2b)

To begin open pit excavation in 1943 in the Middle Arm of Steep Rock Lake, it was necessary to isolate the Middle Arm and divert the Seine River around it. The route chosen was west of Marmion Lake, through Raft Lake and Finlayson Lake, then south through the West Arm of Steep Rock Lake, as shown on Figure 2b. Execution of this plan involved lowering of the Raft Lake and Finlayson Lake levels by 11 m (McQueen and Simpson, 1945), excavation of a channel from Marmion Lake to Finlayson Lake, and a channel from Finlayson Lake to the West Arm of Steep Rock Lake. Two control dams were constructed, the Raft Lake Dam to regulate Marmion Lake, and the Wagita Bay Dam to control flow into the West Arm. A third dam, the Narrows Dam was constructed across the Steep Rock Lake, at a narrow width of the lake, to separate the Middle Arm from the West Arm. The Moose Lake Generating Plant was closed.

Isolation of the Middle, East and Southeast Arms from the Seine River allowed draining of the Steep Rock Lake by pumping and commencement of dredging. The ore body, about 21 m below the old lake level in the Middle Arm, was covered with a lake bed material that was primarily a silty clay. Approximately 15 million cubic metres of the silty clay lake bed overburden was dredged from the Middle Arm and dumped into the West Arm. The Errington Mine in the Middle Arm was opened, and the first ore was shipped in October of 1944.

Phase 3 -1951 to 1954 (Figure 2c)

During this period Steep Rock Iron Mines developed the Hogarth and Roberts mines in the Middle Arm, Figure 2c. Dredging of the soft silty clay overburden from the Middle Arm began in December 1950 and the dredged material was dumped on the ice of the West Arm during the winter of 1950-51. The lake bed material was a very soft silty clay soil which tended to liquefy easily. Areas of the dredged lake bottom, which had been exposed for more than a year, were still so soft that even with a good vegetation cover established, could not be crossed on foot unless snowshoes were used, (Leggett, 1958).

A significant amount of the dredged silty clay that was dumped on the ice in the West Arm was eroded

during the spring melt of 1951 into the Seine River, and transported downstream as far as Rainy Lake, Figure 1 The suspended colloidal silty clay particles did not settle out readily and the Seine River turned a brown colour. Residents along the Seine River and Rainy Lake became quite upset about the discolouration and the effect that the suspended clay might have on the domestic water supplies and on fishing. The residents of Minnesota on the south side of Rainy Lake were more vocal than Canadians, and various actions were threatened. Requests were made to the International Joint Commission for an inquiry, and both the Ontario and Canadian governments became involved in solving the problem. Impetus for solving the dredging pollution problem arose, because as in Phase 2, the dredging being undertaken in Phase 3 was considered an essential war effort, this time due to the Korean War. In the summer of 1951 when the pollution was most serious, there was a chance of the war escalating and supplies of iron ore had to be secured. Accelerated development of the new open pit iron ore mines was encouraged by the defence departments in both Ottawa and Washington.

The solution to the dredge pollution problem was to isolate the West Arm of Steep Rock Lake to create a retention basin to allow settlement of the dredged colloidal clay. Isolation of the West Arm was achieved in 1952 by constructing a series of dams to divert the Seine River to the west of the West Arm as shown on Figure 2c. The Reed Lake concrete dam was constructed, and the Wagita Bay concrete dam was raised between January and March, 1952 to prevent the Seine River from entering the West Arm. Three earthfill dams, West Arm Dams No. 1, 2, and 3 were constructed at the south end of the West Arm to retain the dredged silty clay overburden deposits, and to regulate the water level. A tunnel was bored through the bedrock at the abutment of West Arm Dam No. 2 to provide an outlet from the West Arm. For greater detail on the location of the water control structures, refer to Figure 3. The West Arm, which once had water depths of up to 60 m, was almost completely filled with the deposition of 90 million cubic metres of dredged overburden. The present water elevation of 391.4 m is 7.3 m above the original lake level. The depth of water covering the dredged silty clay overburden is typically about 0.6 to 1.8 m.

A specific water control problem arose during the creation of the West Arm retention basin, particularly during the construction of the West Arm Dam No.l, which was a homogenous earthfill dam, (Sowa et al. 2001). Construction records for the West Arm Dam No. 1 could not be located. However, recollections by a Steep Rock staff member indicated the construction of the dam commenced by end-dumping fill across the arm of the Apungsisagen Lake (Seine River) just before winter. The end-dumped fill was maintained a couple of metres above the lake level. After the fill was placed across the lake arm, additional fill was placed and compacted *to* complete the construction of the dam.

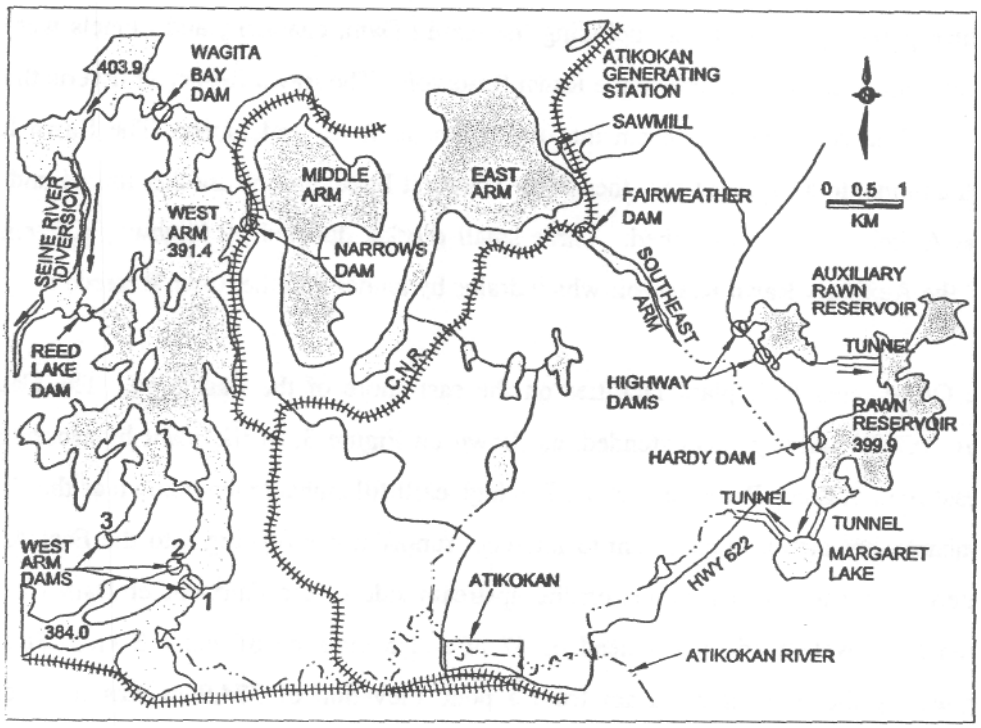

Figure 3 - General Arrangement of the Steep Rock Mines Area

To the best recollection of the Steep Rock staff member, a spillway was constructed in the dam fill at the west abutment to provide an outlet for the West Arm Retention Basin. The bottom of the spillway channel was about elevation 393.2 m and was protected with rock riprap. The spillway channel was extended down the 2.5H to 1.0V downstream slope of the dam and was also protected with rock riprap. The West Arm Dam No. 1 was constructed late in 1952 and the spillway washed out in early 1953. The washed out fill extended about 60 m downstream of the dam. The Steep Rock staff member believed that the cause of the spillway failure might have been due to an inadequate amount of riprap, or riprap that was too small, or a combination of these factors. Following the washout of West Arm Dam No. 1, a tunnel was driven through the north rock abutment of West Arm Dam No. 2 to provide an outlet for the West Arm Retention Basin. West Arm Dam No. 1 was then rebuilt without a spillway.

Phase 4 -1955 to 1961 (Figure 2d)

In 1953 Steep Rock Iron Mines Limited entered into an agreement with Caland Ore Limited to develop an open pit mine in the East Arm of Steep Rock Lake. The drainage basin contributing runoff into the East Arm is 65 km^2, and pumping the runoff from the open pit would be a significant operating expense.

To reduce pumping costs, dams, including the Hardy Dam, channels, and tunnels were constructed as shown on Figure 2d and 3 to create the Rawn Reservoir. The Rawn Reservoir diverts the runoff from 40 km^2 of the East Arm drainage basin into the Atikokan River watershed. The Rawn Reservoir drains through a tunnel to Margaret Lake, then from Margaret Lake through another tunnel under Highway 622 into the Atikokan River watershed. Three small creeks, damned by Highway 622 embankment fills, created the Auxiliary Rawn Reservoir which drains by tunnel into the Rawn Reservoir.

Caland Ore erected their plant facilities on the east shore of the East Arm. The Canadian National Railways (CNR:) railway was extended, as shown on Figure 3, to the plant by crossing the dewatered Southeast Arm of Steep Rock Lake on a 21 m high earthfill embankment known as the Fairweather Dam. The embankment also acts as a dam to intercept runoff water flowing into the East Arm mining area. The intercepted water which ponds on the upstream side of the Fairweather Dam was pumped to the Marmion Lake watershed over a head of 47 m and a distance of about 2 km. Pumping the water intercepted by the Fairweather Dam from a pond elevation of 374.9 m was more economical than allowing the water to enter the East Arm since pumping from the bottom of the open pit mine floor would have been more expensive.

Caland Ore encountered the same type of silty clay overburden covering the ore body that had caused Steep Rock Mines so much difficulty. The southern part of Marmion Lake was converted into a retention basin and 120 million cubic metres of silty clay overburden was deposited into the Marmion Lake retention basin.

At the time, the hydraulic dredges used at Steep Rock Lake were the largest in existence, and the dredging was the largest earth-moving project in history. The corresponding water management and disposal of dredged material was a major challenge, bearing in mind that dredging continued during the winter in temperatures as cold as - 40 to – 45°C. The dredges were electric-powered, and at that time the dredging operation was Ontario Hydro's largest industrial user of electrical power.

WATER MANAGEMENT DURING MINE OPERATIONS AND THE FIRST 20 YEARS AFTER MINE ABANDONMENT

After the development of the various mines and the construction of the water control structures was essentially completed by 1961, water management consisted primarily of:

- monitoring and maintaining the water control and diversion structures, and
- continuously pumping runoff water and water seepage that accumulates in the bottom of the open pit mines in the Middle and East Arms, and upstream of Fairweather Dam.

The depth of the open pit mines increased substantially as the mining progressed and when the mining operations were terminated in 1979, the bottom of the open pit mines was about 300 m below the original level of the Steep Rock Lake. Water collected in the Caland Ore open pit mine had to be pumped over a height of land to discharge into the Marmion Lake watershed, and this required pumping the water a total height of about 330 m from the bottom of the open pit mine. When the mining was terminated in 1979, the pumps were turned off and the water commenced rising in the open pit mines.

A schematic drawing of an idealized section through the Steep Rock Mines and some of the water control structures is shown on Figure 4. The original level of Steep Rock Lake was elevation 384.0 m and this is shown as a dashed line on Figure 4. The water level in the Seine River to the west of the West Arm, and outside the influence of the Steep Rock water diversion system, is at the same elevation of 384.0 m as shown on Figure 4. The water level in the West Arm is about elevation 391.4 m, and is above the Seine River and the original level of Steep Rock Lake. Since the West Arm was filled with dredged material, the water level in the West Arm is maintained at a higher elevation of 391.4 m to provide a water cover over the dredged material. The Hardy Dam was; constructed to create the Rawn Reservoir to reduce the amount of runoff water flowing into the East Aim. The elevation of the Rawn Reservoir is about 399.9 m as shown on Figure 4. The Fairweather Dam intercepts runoff water flowing into the Southeast Arm, which is then pumped into the Marmion Lake watershed. The water level in the Fairweather Dam collection pond is about elevation 379.4 m. The water level in the open pit mines in the Middle and East Arms is considerably below the water levels of other water control structures, as shown on Figure 4, but is gradually rising.

Some changes that have an impact on water management occurred after the mining was terminated in 1979. In 1985 the coal-fired Atikokan Electrical Generating Station, constructed by Ontario Power Generation east of the Southeast Arm, Figure 3, took over many of the dams and water control structures constructed for the mine as part of the water control system for the Atikokan Generating Station. Ontario Power Generation also assumed responsibility for pumping the water that collects upstream of the Fairweather Dam. The Auxiliary Rawn Reservoir, as shown on Figure 3, was essentially eliminated in 1987 when a culvert was installed under one of the highway dams to drain the Auxiliary Rawn Reservoir

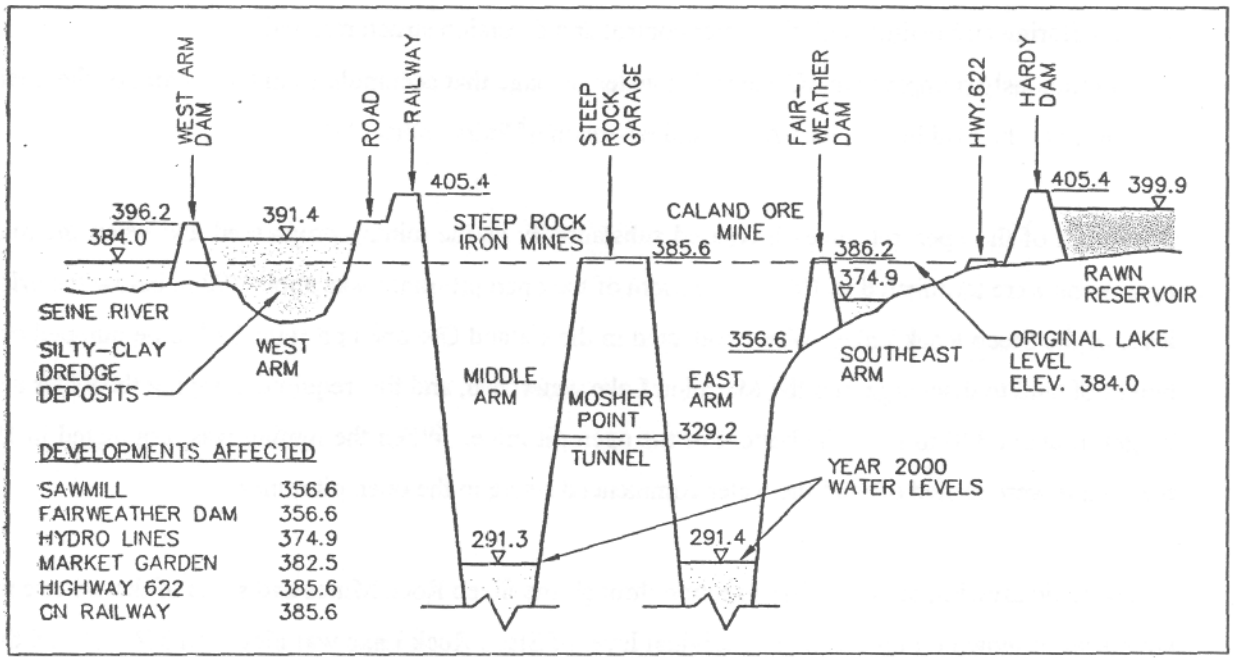

Figure 4 - Schematic Layout of an Idealized Section through the Steep Rock Mines Area

into the Southeast Arm. The outlet from the West Arm retention basin is through a tunnel in the north abutment of the West Arm Dam No. 2. There was some concern with the possibility of caving and blockage of the tunnel, and as a result, a spillway was constructed on West Arm Dam No. 2 to provide an alternate outlet, and the tunnel was sealed. The outlet from the Rawn Reservoir is through two tunnels and to provide for the possibility of a blocked tunnel, an emergency overflow spillway was constructed on the South Auxiliary Hardy Dam.

The Caland Ore plant buildings on the East Arm, Figure 3, are now operated as a sawmill. The sawmill is located 27 m below the original level of Steep Rock Lake. Other developments on the old lake bed of Steep Rock Lake are a ski hill just upstream of the Fairweather Dam, a hydro line and transformer station, and a market garden operation just below the Hardy Dam beside the highway.

FUTURE WATER MANAGEMENT OPTIONS FOR THE ABANDONED STEEP ROCK MINES

A very important aspect of the Steep Rock Iron Mines abandonment plan is the future water management. There are four main water control systems that require long-term operation and maintenance to ensure public safety, protection of existing developments, and environmental protection of the dredge spoil material impounded during the mining operation. The four water control systems are:

- The Seine River Diversion around Steep Rock Lake,
- Maintaining a water cover on the silty clay dredge spoils deposited in the West Arm of Steep Rock Lake and in Marmion Lake, including maintaining the artificially high water level in the West Arm,
- Protection of facilities constructed on the old Southeast Arm lake bed, some of which are shown on Figure 4, from rising water levels, and
- The Rawn Reservoir diversion system constructed to reduce future pumping costs.

The rate at which the mines are filling with water after termination of pumping in 1979 is an important factor in planning future water management The rate has been estimated, based on various assumptions, and the results are shown on Figure 5 for the East Arm for various times after 1979. The estimated rate is very similar for the Middle Arm. Independent predictions by the Ministry of Natural Resources and Steep Rock Mines are shown, and both are very similar, given the various assumptions that need to be made. Periodically the actual water elevation in the mines is recorded, and the results are shown on Figure 5. These results show that the actual water levels are very similar to the Ministry estimated values, which provides confidence in using the results of Figure 5 for future water management planning.

The abandoned mines are slowly filling with water and eventually will affect water control structures and developments in the mine area. Numerous alternatives for managing the future rising water levels were considered by the Ministry of Natural Resources, but the three main water management options are:

(1) Protect all developments in the abandoned mines from flooding. This will mean maintaining the water levels artificially low to protect the lowest development at elevation 356.6 m from the rising water, and this will require the installation and operation of large pumping capacity.
(2) Allow the water in the abandoned mines to rise to the West Arm level at elevation 391.4 m and then flow by gravity. The developments affected by the rising water will need to be moved or protected.
(3) Maintain a water level elevation between the above two limits of elevation 356.6 m and 391.4 m, with the amount of pumping based on a cost-benefit analysis at the time that a decision is required.

A final decision on the above three future water level management options is not required until the water level in the East Arm reaches elevation 356.6 m, which will be in about 30 years in Year 2031, as can be seen from Figure 5. In the meantime the current water management procedures can be followed, and the water control systems and the various water control structures must be maintained in a safe and reliable condition.

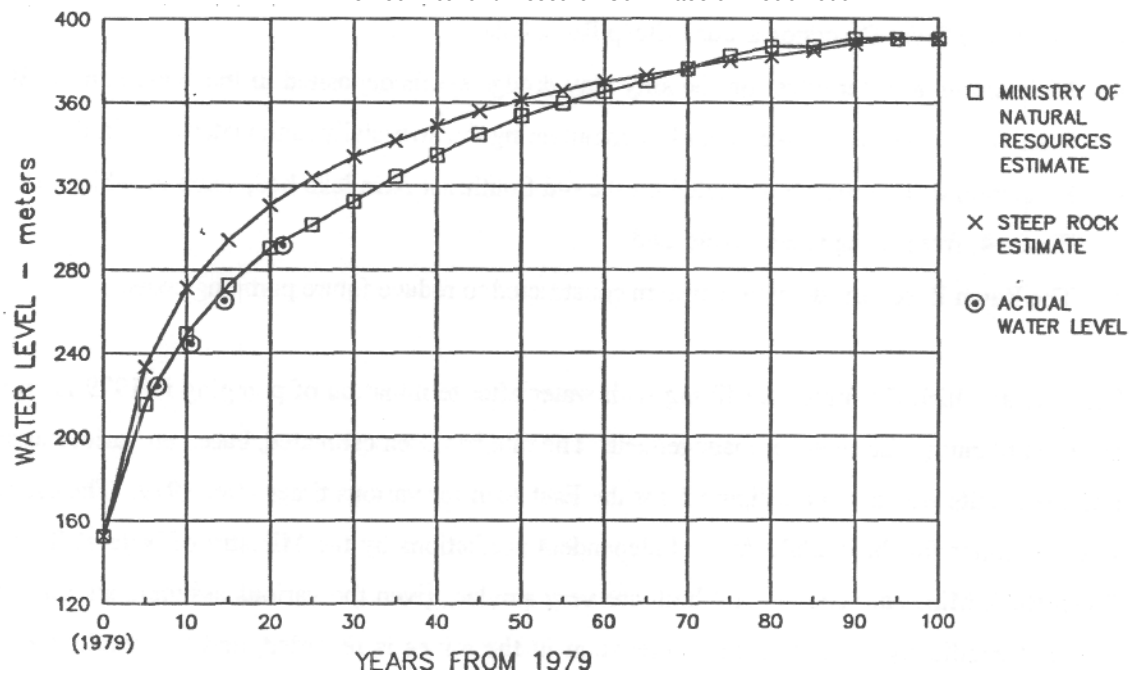

Figure 5 - Estimated rate of Water Level Rise in the abandoned mine in the East Arm of Steep Rock Lake

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