MANAGING SURFACE WATER AT CVRD INCO'S INTEGRATED MINING, MILLING AND SMELTING OPERATIONS IN SUDBURY ONTARIO: IMPLEMENTING MODERN SOLUTIONS TO LEGACY CHALLENGES[1]

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This paper describes a number of improvement projects that were implemented to address an old challenge: to manage process effluent, mine water, tailings transport water, storm runoff and mill water reclaim from an integrated mining, milling and smelting operation that was developed long before environmental laws were written. The problem definition, options review, project planning, engineering and implementation stages of select projects are described as well as some local history and legal history for context. Also described are some interesting technical aspects of the various improvement projects which included; flood routing analysis, hydraulic routing analysis, dam break and inundation assessment, tailings management planning as an integral part of water management planning, process (plant) engineering, dam stability evaluations, tailings liquefaction assessment, flow control structure design, new pumping stations and construction of a remote monitoring and control system which links an integrated system of major lakes and reservoirs together with a fibre optic network. Gone are the days of manual water control structures that need to be monitored and manipulated, at all times of the day or night, to avoid hydraulic overload at a large centralized Water Treatment Plant.

Key words: *flow equalization, water management and treatment, dam safety, flood routing analysis, remote monitoring and control systems.*

Introduction

Surface water management is an increasingly important aspect of all mining projects regardless of what stage your project is at in the mining life cycle, or where in the world your project happens to be located. As globalization continues in the mining industry, variables in the regulatory environment are being replaced by international standards in the areas of closure planning and reclamation, tailings management, discharge water quality, drinking water quality and groundwater quality. Depending on climatic and process variables, mine water management falls into two basic categories: 1) managing a net-annual water surplus in a temperate or wet climate; or 2) managing a net-annual loss in an arid or semi-arid climate. Even in the case of perfect balance under average annual conditions, there may be droughts and wet periods when there is either not enough or too much water to handle without an integrated management plan and the appropriate infrastructure.

Background

CVRD Inco and its predecessor companies have been mining, milling and smelting in the Sudbury area for more than 100 years. During the advancement of the Canadian Pacific Railway in 1883, copper and

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nickel sulphide ore was first discovered in a right-of-way rock cut on the rim of what is now referred to as the Sudbury Basin. This particular orebody later became the Murray Mine, which operated until the Murray Pit was allowed to flood in 1992.

By 1930, approximately 28 million tonnes of sulphide ore had been heap roasted near the present day communities of Copper Cliff, Coniston, O'Donnell and Victoria. The environmental effects of heap roasting and logging were profound at that time and are well documented. In 1930, the Copper Cliff Smelter Complex was brought into production, allowing the practice of heap roasting to be discontinued. Since 1930, the Smelter Complex has been renovated and improved to increase throughput, reduce emissions and produce a number intermediate and finished products in an ever changing market.

Milling has historically occurred at several locations including Creighton, Copper Cliff, Frood and Levack. In 1971, the Clarabelle Mill was commissioned to reduce production demand from the Copper Cliff Mill. By 1989, all Inco Ontario Division milling was consolidated at the Clarabelle Mill which has operated recently at a capacity between about 10 – 12 million tonnes per year.

The Copper Cliff Central Tailings (CCCT) area has been in operation as a Tailings Storage Facility (TSF) since 1937. Since commissioning, tailings have been deposited sequentially in the A-, CD-, M-, P-, Q-, and R-Areas. Tailings disposal to R-Area began in 1985 with tailings being deposited in the R1-, R2-, and R3-Areas. The R4-Area development began in 1994 with continuous spigotting of tailings beginning in 1995. The R-Area will provide for disposal of tailings from the Clarabelle Mill to year 2030 and possibly beyond and will impound an additional 300 million tonnes of Potentially Acid Generating (PAG) tailings. The CCCT Area also receives an assorted stream of wastes including non-hazardous solid waste, water and process treatment plant sludges, asbestos, and sewage sludge from the Region of Sudbury and CVRD Inco operations. The CCCT Area receives approximately 27,000 tonnes of tailings per day from Inco's Clarabelle Mill (approximately 9,000 tonnes of tailings per day is used for backfill). To date, the CCCT facility contains more then 450 million tonnes of tailings. The average pyrrhotite content (FeS) of these tailings is about 7%. The residual sulphide present above the water table has the potential to produce low-pH, metal-contaminated seepage and runoff that will require long-term collection and treatment during the operating and post closure phases.

Problem Statement

The challenge is to manage process effluents, tailings transport water, seepage, ARD impacted runoff, process water recycling and wastewater treatment in a net surplus climate located in a historic mining centre in north-eastern Ontario. The challenge in developing an appropriate Water Management System (WMS) for the Copper Cliff Waste Water Treatment Plant (CCWWTP) watershed required understanding of several issues, the most significant of which, are described below.

Hydraulic Overload

CVRD Inco employ a "collect and treat" strategy to manage process effluent, mine water, tailings transport water, waste dump seepage, perimeter dam seepage and runoff from approximately 48 km^2 of lands (11,900 acres) that drain to the Copper Cliff Waste Water Treatment Plant (CCWWTP). Pumped and diverted inflows, mine water and effluents from other mining operations increase the collect and treat service area of the plant to more than 53 km^2 (13,100 acres). Since about half of the drainage area to the CCWWTP is Canadian Shield watershed (25 km^2), runoff during spring melt or due to heavy rainstorms previously caused frequent hydraulic overload at the plant. Unless the release is due to "extraordinary hydrologic event" a bypass at the plant could constitute a spill under current law in Ontario (i.e. Ontario Regulation 560/94). Note that a spill is a release of non-compliant effluent, whether it is 100 litres over 10 minutes or the flow over Niagara Falls for 10 days.

Figure 1 shows the major drainage areas serviced by the CCWWTP. The areas include the CCCT Area, the Creighton Mine Complex, the North Mine Complex, parts of the Frood Stobie Complex, parts of the Smelter Complex, the Town of Copper Cliff, South Mine and portions of the Copper and Nickel Refineries.

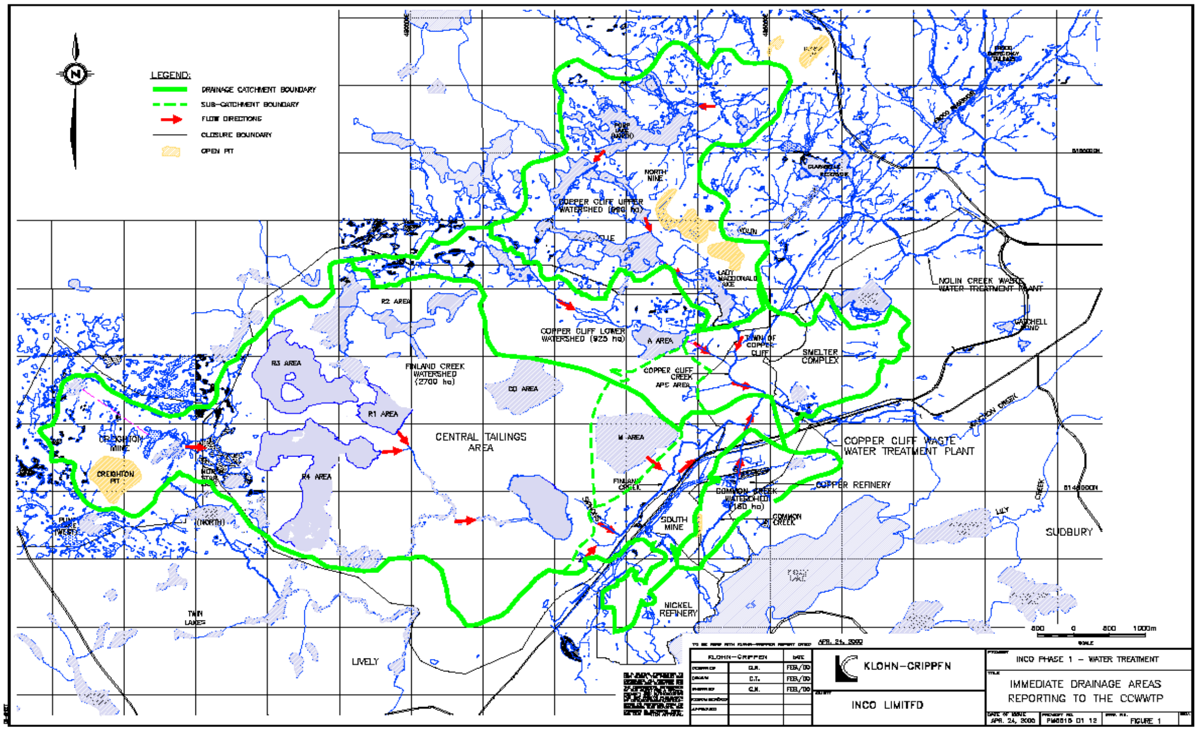

Figure 1: Immediate drainage areas that are collected and treated at the CCWWTP.

A photograph of Copper Cliff Creek, which is diverted and pumped through the CCWWTP to achieve compliant effluent, is shown in Figure 2.

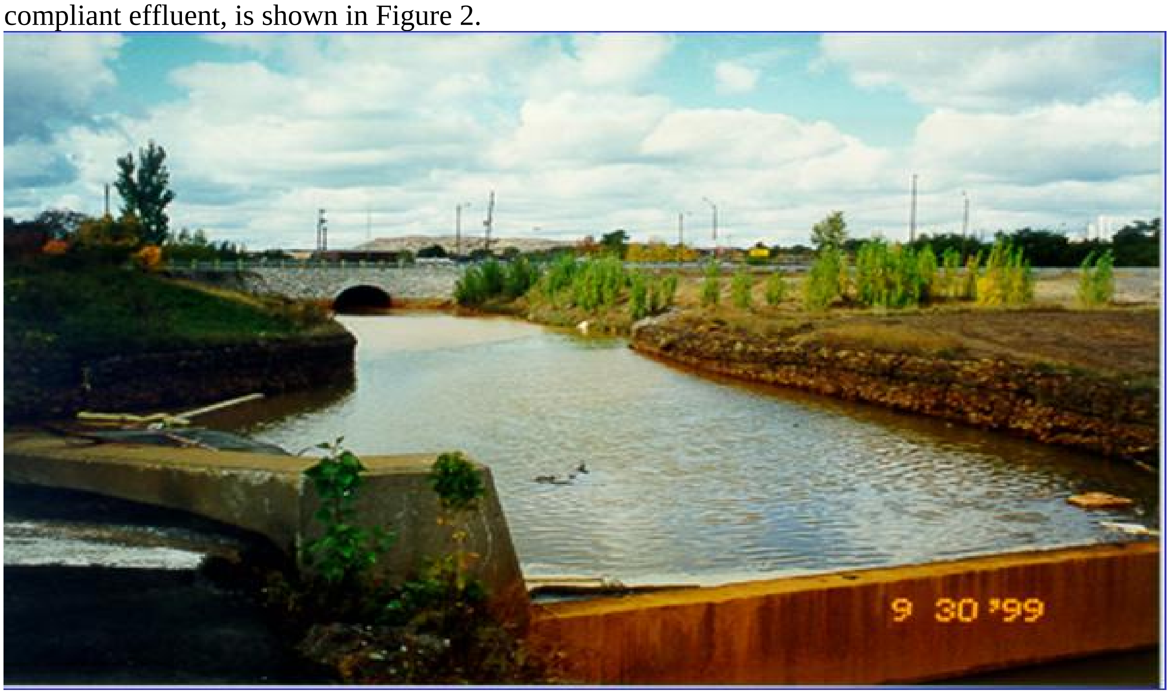

Figure 2: Copper Cliff Creek looking upstream through the CCWWTP Bypass Weir.

The Copper Cliff Central Tailings (CCCT) Area occupies approximately 28 km^2 (6,850 acres) making it about half of the total service area of the CCWWTP. The fact that the CCWWTP is not immediately downstream of the tailings area makes this especially challenging from a flow equalization point of view. While tailings impoundments are primarily designed to store solid wastes, in wet climates and many dry climates around the world they often need to temporarily store supernatant and runoff to attenuate flow for treatment purposes. Waste water treatment plants, particularly Low Density Sludge plants used commonly in the mining industry, can be upset by rapid changes in inflow rate or influent water chemistry. To a wastewater process engineer, the need for flow attenuation is referred to as Flow Equalization.

Dependence on Water Recycling

Another complexity in this system is the need to recycle process water for operations at the Clarabelle Mill, thereby eliminating the use of potable water. Operating continuously, the Clarabelle Mill reclaims between 950 – 1,250 l/s (i.e., 15,000 - 20,000 US gal/min) from Copper Cliff Creek. Water used in the milling process is collected and pumped out to the CCCT Area in the form of slurry. The reliability and security of water recycle is therefore important from an economic and logistic point of view. Figure 3 shows a schematic representation of the loop that mill water makes between Clarabelle, the CCCT Area and the CCWWTP. When runoff conditions allow, treated effluent is recycled to the Mill to improve metallurgical recovery. During heavy runoff conditions, the flexibility to reclaim raw water from Copper Cliff Creek allows 950 – 1,250 l/s to be effectively removed from the influent hydrograph to the CCWWTP (Klohn-Crippen, 1998).

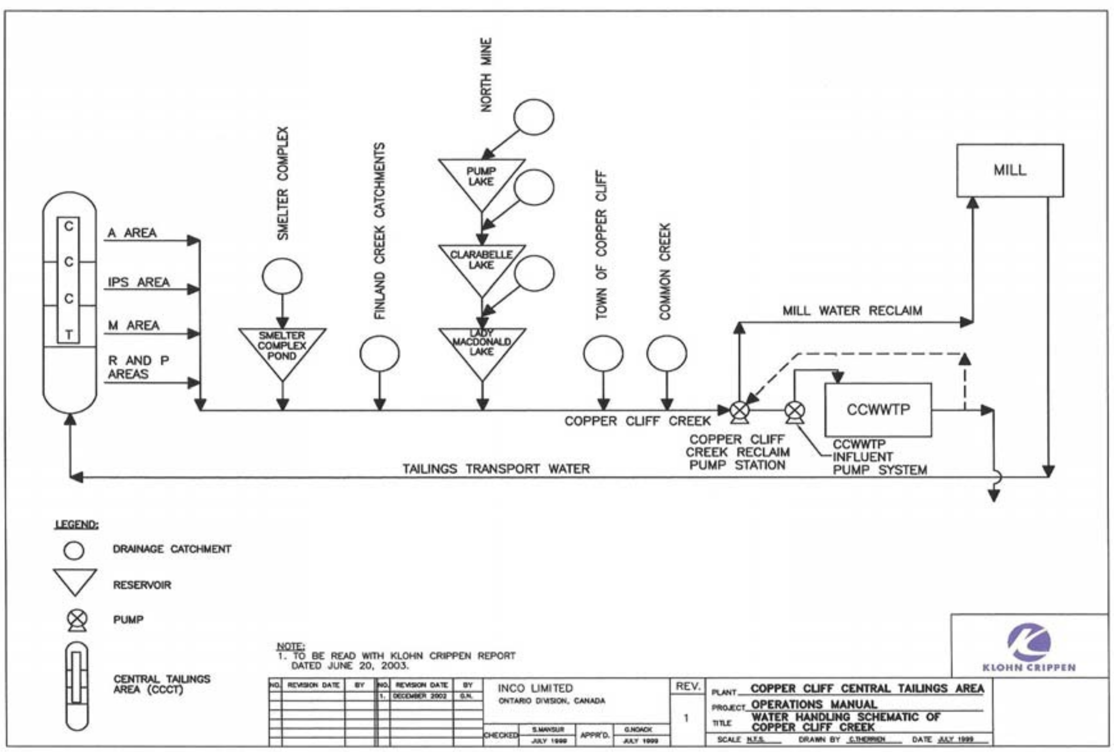

Figure 3: CCWWTP Basin schematic showing the Clarabelle Mill water recycling loop.

Potential for Treatment Plant Upset or Power Supply Interruption

The CCWWTP has a rated capacity of 2,600 l/s (60 MGPD). The plant was commissioned in mid 1970's and has undergone a number of renovations to improve performance and reliability since that time. Like any water treatment plant, the system is a train of unit processes that work together to achieve effluent criteria. The process train includes, mechanical screening, raw water pumping, reagent (i.e. lime, flocculent and coagulant) addition, settling and pH adjustment of the settled effluent using sulphuric acid. Many CCWWTP systems require power for raw water pumping, mixing, reagent addition and process control.

Risks associated with achieving compliant effluent include hydraulic overload during periods of heavy runoff, rapid changes in influent chemistry, power supply interruption, mechanical failure, instrumentation failure and the possibility of human error.

Legal Change, Legacy and Compatibility with Closure

It is important to recognize that environmental law did not exist in Canada prior to about 1970, when the Canadian Environmental Law Association (CELA) and the Canadian Environmental Law and Research Foundation (CELRF) were initially founded. To meet the requirements associated with legal change, CVRD Inco and its predecessor have implemented a series of air emission abatement projects, closure planning projects and water treatment and water management improvement projects. The net present value of these projects combined is in the rough order of 2 billion Canadian dollars. The likelihood of future laws becoming more stringent with respect to air and water releases is considered to be very high as well. This reality favours a modular approach to meet current and future challenges.

Due to the long history of operations in the CVRD Inco Sudbury Area, essentially all environmental and water management improvements have had to be retrofitted long after mining activity occurred in the Copper Cliff Creek watershed.

Conceptual Review of Water Management Options

In 1999, Inco Limited retained Klohn Crippen Consultants Ltd. to carry out the Phase 1 – Water Treatment Project. The primary objectives of the Phase 1 study were to evaluate possible alternatives for improving water management and water treatment plant operations at 9 sites, together with order-of-magnitude cost estimates, to allow selection of the preferred alternative for each site (Klohn Crippen, 2000). The nine Ontario Division sites reviewed included:

- Whissel Dam, Mikkola Dam, Rock Dam and Pistol Dam Seepage Stations
- Garson Mine Water Treatment System
- Crean Hill Mine Water Treatment System
- Copper Cliff Sewage Treatment Plant (CCSTP)
- Copper Cliff Waste Water Treatment System (CCWWTP)
- Nolin Creek Waste Water Treatment Plant (NCWWTP)

Six of the nine sites are located in the watershed draining to the CCWWTP and are the main focus of this paper. To improve water management and reduce bypass frequency at the CCWWTP, several alternatives were reviewed including:

1. Pumping and temporary storage in inactive underground workings.
2. Pumping and temporary storage in new surface reservoirs.
3. Reservoir attenuation upstream of the Plant.
4. Reservoir attenuation upstream and downstream of the Plant.
5. Water Treatment Plant capacity and process improvements and new surface reservoirs.
6. Water Treatment Plant capacity and process improvements without new reservoirs.

Option 4 was selected in consultation with key CVRD Inco stakeholders for both technical and economic reasons. The additional objective to recycle treated effluent for metallurgical reasons supported the basic concept of flow attenuation using reservoirs. The high capital and life costs to increase CCWWTP capacity and provide back up power for the plant, also contributed to the selection of Option 4. The development of the WMS was guided by:

- CVRD Inco's Environmental Policy.
- Provisions and requirements under Provincial and Federal Law.
- Compatibility with Closure for Sudbury Area operations dependant on the CCWWTP.
- Relevant dam safety guidelines (i.e. CDA, 1999 and MNR, 1999).
- Compatibility with Filling Plans and tailings management best practice (MAC 1998 and 2003).

Water Management Plan: Components & Implementation Highlights

Shown in Figure 4 are the principal reservoirs associated with Option 4:

- CCCT Seepage Pond Improvements.
- Tailings Area Ponds (i.e. R1/3 Pond, R4 Pond, P-Area Pond, A-Area Pond and M-Area Pond).
- North Mine Lakes (i.e. Pump Lake, Clarabelle Lake and Lady MacDonald Lake).
- CCWWTP Bypass Collection Pond.
- Common Creek Reservoir.
- Smelter Complex Lower Pond Improvements.

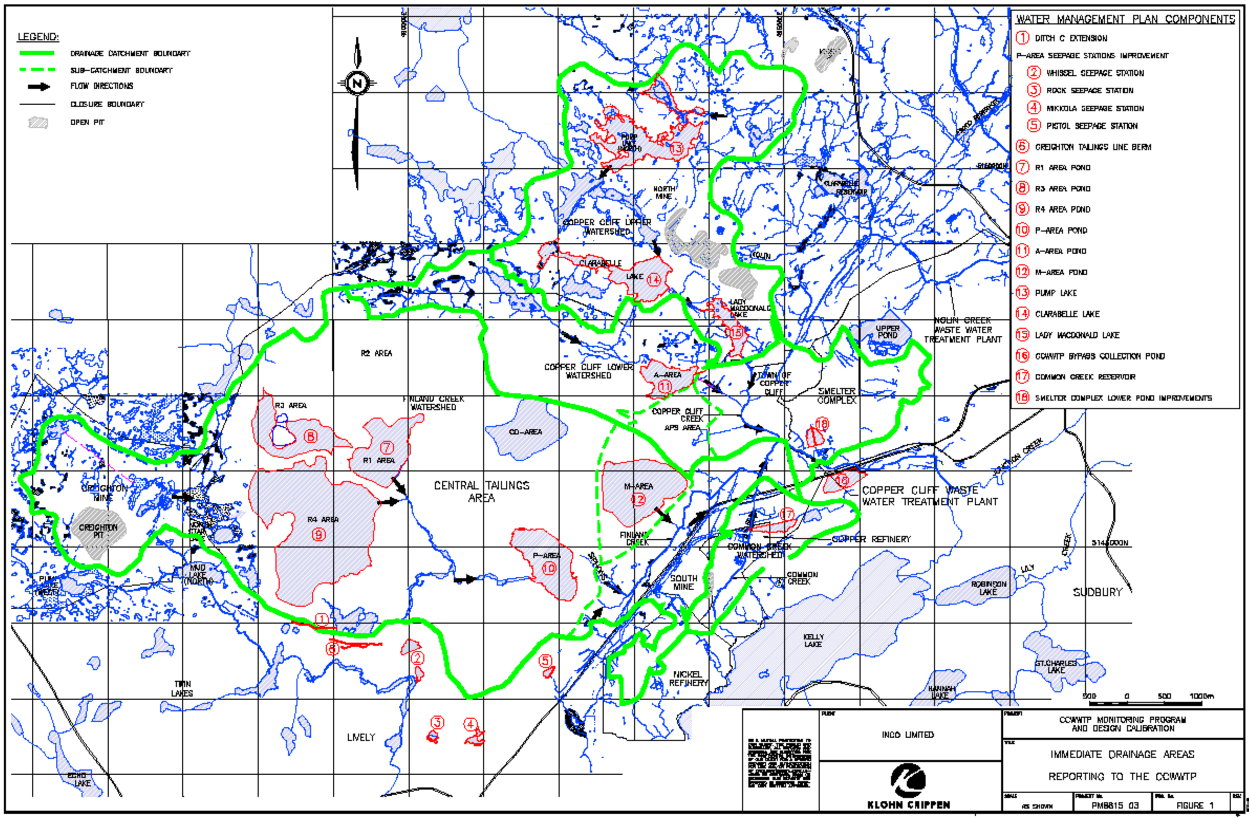

Figure 4: CCWWTP watershed showing recent improvement project locations (in red).

CCCT Seepage Ponds

Three projects were recently completed to improve seepage containment within the CCCT Area. These included: the Ditch C Extension to No. 2 Station Pond, the P-Area Seepage Stations Improvement Project and the Creighton Tailings Line Berm (CTLB) Diversion Structures (see Figure 4).

The Ditch C Extension project was completed to allow the No. 2 Station Pond to be passively managed by directing net runoff and tailings dam seepage to the No. 3 Seepage Station. The project involved approximately 300 m of rock cut channel, in segments as deep as 18 m. The base-width for the trench was 2.4 m for constructability reasons rather than for flow capacity during extreme flooding. In fact, a hydraulic restrictor weir was constructed in Ditch C after the rock was blasted to limit inflow rates to the No. 3 Seepage Station. No. 3 Seepage Station is subsequently pumped to the R4-Pond for eventual treatment at the CCWWTP.

The P-Area Improvement project involved storage and pumping improvements to the Whissel, Rock, Mikkola and Pistol Seepage Stations located downstream of the P-Area perimeter dams (see Figure 4). The work included the construction of 3 new low permeability dykes, raising of 3 existing low permeability dykes and the enlargement of the Whissel (South) Seepage Pond by a combination of dyke raising and reservoir excavation. Engineering for the project was completed in 1999 and construction was completed in fall of 1999 and summer of 2000. Cut and fill quantities during construction were approximately 75,000 m^3 and 45,000 m^3, respectively. Soft soils and focused seepage near the toe of Whissel Dam lead to excavation side-slopes of 3H:1V during pond enlargement. The construction of inverted filters was also necessary in areas where focused seepage intersected the new cut slope. New pumping stations were constructed at Mikkola Seepage Pond and Rock Dam Seepage Pond. The Mikkola

Dam seepage return pipeline was also replaced with a 10 inch diameter buried HDPE pipeline to reduce fiction losses in the pipeline. Horizontal turbine pumps (i.e. 1 duty and 1 standby) in the 4 pumping stations were all replaced to allow standardization of motor ends and to simplify the inventory of critical spare parts. To date the project has eliminated bypasses, which used to occur several times per year during heavy runoff.

The CTLB diversion structures divert seepage and runoff from a segment of the Creighton Tailings Berm that would otherwise drain to Meatbird Creek (see Figure 4). The project included 3 low permeability seepage diversion dykes and 2 channel segments cut in overburden and bedrock. The total length of the diversion works was approximately 900 m. The seepage diversion dykes featured a synthetic low permeability membrane and a concrete plinth cast in-place on prepared bedrock. The synthetic membrane liner was selected in favour of low permeability fill to allow construction to occur later in the season than would normally be the case for clay core, zoned embankment. Construction of the diversion system was completed in approximately 3 months allowing it to be operational prior to the spring of 2003. The works have performed satisfactorily since completion and have eliminated contaminated discharge from this area.

Tailings Area Reservoir Management

The Operation, Maintenance and Surveillance (OM&S) Manual for the CCCT area (INCO, 2003) and latest Filling and Water Management Plan (Klohn Crippen, 2003) outline an operating strategy for the 5 major reservoirs used to control discharge from the tailings area. The operating strategy for the major reservoirs involves drawdown of the ponds to specified target levels whenever capacity is available at the CCWWTP. During heavy runoff periods, runoff, process effluents, sludge, mill water and seepage return water is retained in the R-Areas. Retention for 1 month or more is possible by incorporating sufficient freeboard into the tailings dam design and the dam crest raising schedule. A strategy to retain mill water in the R-Areas during periods of heavy runoff was also incorporated into the WMS to reduce inflow to the CCWWTP. Operating the existing water recycle infrastructure in this manner can produce the same result as an additional 24 MGD reactor clarifier, or the equivalent of 40% more peak capacity at the CCWWTP. The cost to implement the operating strategy was negligible, a classic example of “low hanging fruit”.

The retention of water in the R-Areas also alleviates some pressure from the P-Area Pond, which is controlled by vacuum siphons which are continuously monitored by CCCT and CCWWTP staff. To meet the requirements of the tailings area Filling Plan, the R-Area Pond raising schedule and the WMS for Copper Cliff Creek, the R1-PQ Outlet structure was rehabilitated in 2006. The rehabilitation involved slip-lining the two 60 inch diameter discharge culverts, raising the cast in place concrete inlet structure and extending the discharge culverts beyond the toe of the new east side perimeter dam called Guindon Dam. Continued raising of the R1-PQ Inlet Structure beyond about 25 ft above its bedrock foundation was not recommended due to structural concerns in the event of an extreme earthquake. To service future needs, a new water control structure is being constructed through a bedrock outcrop on the east side of the R-Area. The new water control structure, called the Frood Stobie Tower Outlet will feature two cast in place concrete drop structures, a 140 m long unlined tunnel cut through bedrock and an 800 m long outlet trench cut through soft tailings in the Q-Area beach. The outlet trench was constructed during the winter of 2006 using GPS guided excavators that were programmed to not excavate below pay lines. Due to the soft nature of the tailings, the side-slopes in the outlet channel were cut at approximately 4.5H:1V.

The A-Area Tailings Dam Improvement Project was required to allow storage of runoff in the A-Area and to ensure the dam remains stable in the event of an earthquake that liquefied the original dam which impounded the 5 km^2 area. The project also involved a minor crest raise to provide sufficient freeboard in the event of a Probable Maximum Flood (PMF) and the construction of new hydraulic control structures. The hydraulic control structures feature a remote control low flow outlet controlled by fibre optic communication links, an emergency spillway weir and an unlined bedrock tunnel which outlets to an open channel and stilling basin near the left dam abutment. A key finding during hydrologic simulation of the PMF over the A-Area was the likelihood of spilling from adjacent Clarabelle Lake watershed due to the limited discharge capacity of the tunnel which outlets to Lady MacDonald Lake (see Figure 4). By undertaking the flood routing analysis on the two neighbouring watersheds at the same time, it was possible to foresee the interaction between the two areas. Thus, rather than designing for the 5 km^2 catchment immediately upstream, the emergency spillway for the A-Area was designed for the 13 km^2 catchment it would have to service in the event of a PMF.

North Mine Reservoir Improvements

WMS improvements in the North Mine area involved construction of 3 remote controlled low flow outlets at Pump Lake, Clarabelle Lake and Lady MacDonald Lake. These improvements allow runoff and mine water to be controlled from the entire North Mine complex, comprising an area of about 10 km^2. The new low flow outlets were interfaced with the CCWWTP control room via fibre optic communication links to allow real time monitoring and manipulation, as required to avoid bypasses at the CCWWTP. Emergency spillways for the three lakes were also constructed to safely pass extreme floods up to the PMF. The emergency spillways do not depend on operator intervention to safely pass extreme floods.

While there was significant storage available within the North Mine Complex prior to the improvements, there was no formal drawdown procedure and control structures required a water plant operator to drive out to each structure to monitor levels and make adjustments. Now that the remote control system is in place, manipulations can occur as required year-round, rather than infrequently and based on operator experience. Concerns related to the stability of Lady MacDonald Dam during passage of the PMF led to the construction of a new earth fill dam immediately downstream of the concrete gravity dam. The Lady MacDonald Dam was originally constructed in the early 1900's to serve as a water supply reservoir for the Town of Copper Cliff.

Previously Uncontrolled Sub-Catchment Areas

With reservoir controls and operating plans in place for the CCCT, North Mine, Creighton Mine and Frood Stobie Mine, the remaining "uncontrolled areas" that were targeted for improvement included:

- Common Creek, a roughly 2 km^2 area including contributions from the Copper Refinery, Nickel Refinery and South Mine.
- The Town of Copper Cliff, a 2 km^2 area that is largely developed.
- The southern portion of the Smelter Complex, a roughly 2 km^2 area with heavy industrial land-use.
- Portions of the Finland Creek valley, a roughly 2 km^2 area that borders the CCCT, with Regional Road 55 running through it.

To control runoff from these areas (Figure 5), the following major reservoirs were recommended:

- Regional Road 55 Bypass Collection Pond
- Common Creek Reservoir
- Improvements to the Smelter Lower Ponds

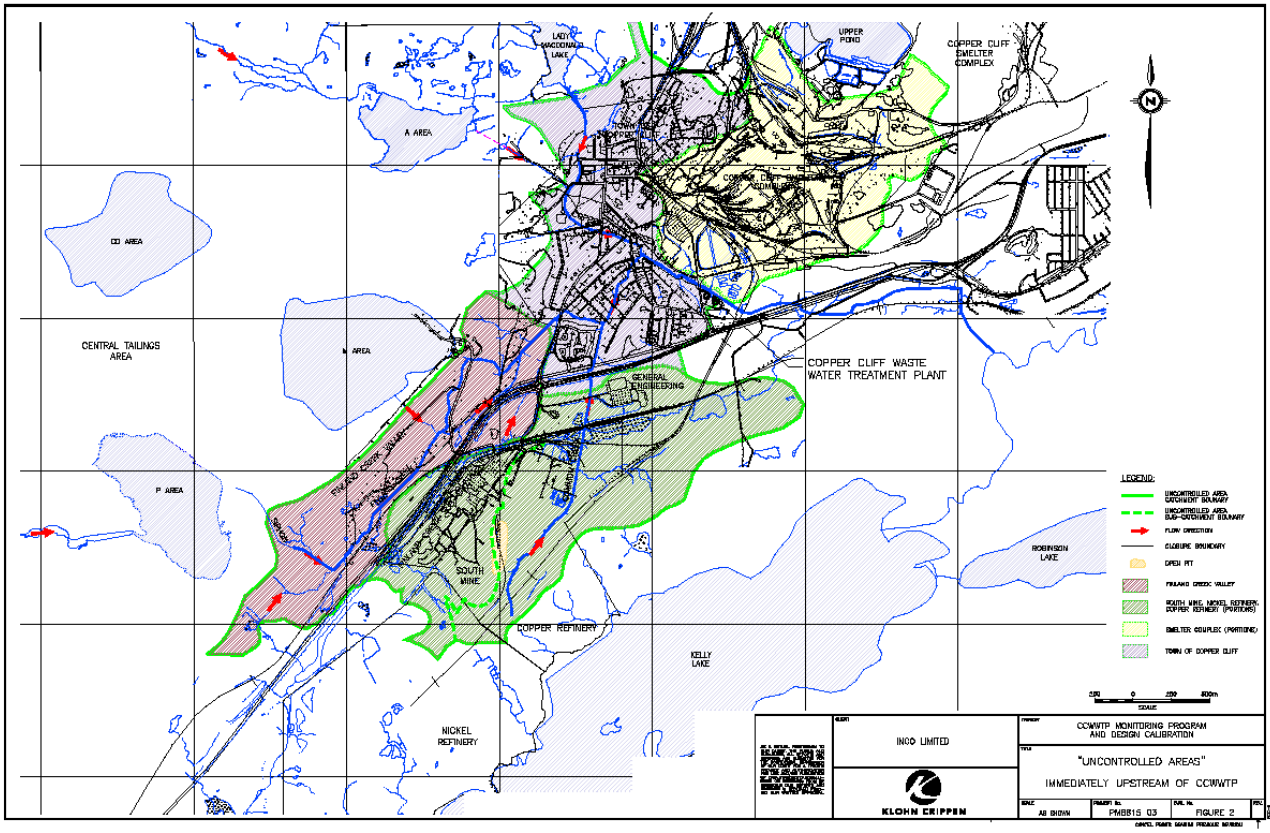

Figure 5: Previously "Uncontrolled Areas" draining to the CCWWTP (circa 1999).

The Regional Road 55 Bypass Collection Pond was constructed in 2001 to provide 140,000 m^3 of storage capacity immediately downstream of the CCWWTP (Figure 4). The reservoir concept, operating plan and design storage details were established in association with INCO as part of the Phase 1 Water Treatment Project. A pumping station returns water to the plant according to available capacity and rule curves. Water level monitoring and pump control for the pond occurs at the CCWWTP Control Room via fibre optic communication links. Since commissioning in the fall of 2001 the facility has contained numerous of runoff events and prevented bypasses during a number of unforeseeable events (i.e. power supply interruption, treatment process upset or other equipment problems).

An interesting component of this project included the constraints imposed by the soft sensitive clay foundation soils and how they influenced design of the pumping station, containment dyke and reservoir cut slopes. Hydraulic assessment based on existing regional flood-line models for the study area allowed the High Operating Water Level (HOWL) to be established while providing the required freeboard (see Figure 6) against Regional Road 55 sub-grade in the event of a 1:25-year flood (Klohn Crippen, 2001).

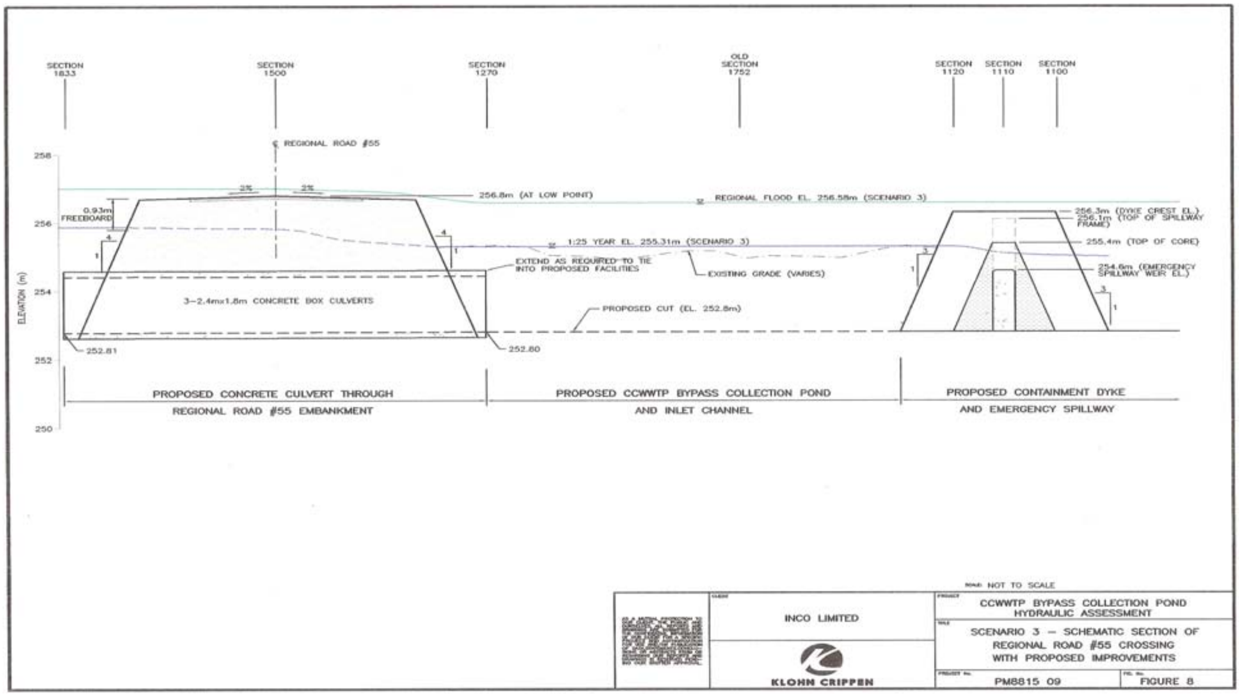

Figure 6: Hydraulic profile and Regional Road 55 freeboard criteria govern the HOWL for the pond.

Common Creek Reservoir

Construction of the Common Creek Reservoir began in the summer of 2007 to provide 130,000 m^3 of storage capacity south of Regional Road 55. The facility will attenuate runoff from about 2 km^2 of partially developed lands including parts of the Nickel Refinery, South Mine and former Copper Refinery sites. The design storage for the pond was the first in the WMS system that was intended to be modular, or expandable, when required to accommodate future mining development. The low-flow decant will also be fibre optic controlled and the motorized gate valve will be a standard size and model to simplify the inventory of critical spare parts. Interesting design aspects of this project include the soft sensitive clay foundation soils and their influence on facility layout, cut slope design and containment dyke design. Utility interferences including a buried natural gas main-line, a 44 KV overhead line, several smaller overhead lines, a buried fibre optic trunk line and a Canadian Pacific Railway main line right-of-way add excitement and constrain the design and construction phases.

Smelter Complex Reservoir

Pre-Feasibility engineering for the Smelter Complex Pond Improvement Project was completed in 2006 and is currently under review, awaiting findings from interrelated studies including process engineering, waste product recovery / recycling studies and groundwater characterization and assessment. It is expected that the next phase of engineering will commence in the last quarter of 2007 to attenuate runoff from about 2 km^2 of highly developed land in the Smelter Complex.

Closing Remarks

CVRD Inco is in the process of implementing a leading edge WMS for their 60 km^2 integrated mining, milling and smelting operations in Sudbury Ontario. While a remotely controlled system of lakes, ponds and reservoirs may seem elaborate at first glance, it is an operationally superior system compared with manual control structures. Over the life cycle of CCWWTP operations, the remotely controlled WMS also makes clear economic sense.

It is important to note that this WMS is more than just infrastructure. Also critical to WMS success are the appropriate management systems with clear accountability, the implementation of OM&S systems, fail-safe and risk analyses, preventative maintenance programs and commitment from all involved, including the operators who make it all work, every day and night.

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