Mine Drainage from Lynx 8 & 10 Levels and its Implications to Reclamation & Closure Plans at Myra Falls Operations

G.C Dirom, M.Sc., A.Ag.
Myra Falls Operations, Boliden Westmin (Canada) Ltd.

Abstract

This paper summarizes mine drainage research conducted from 1997 to 1999 at the Lynx underground mine. The poly-metallic mine is part of Boliden-Westmin's Myra Falls Operations (MFO), located in Strathcona Provincial Park. The Lynx mine is situated on the lower slope of Phillips Ridge, receiving greater than two metres of precipitation annually. The mine's ore body is geologically hosted within a volcanogenic massive sulphide (VMS) deposit: and resultant acid rock drainage (ARD) is known to discharge from mine workings. The primary goal of the research program was to improve the understanding of the mine drainage from Lynx's 8 and 10 levels in order to help evaluate the longterm implications for mine closure. The quantity and quality of mine discharge waters and their relationships to precipitation formed the technical basis of the study. The research findings indicate that seasonally acidic conditions occur in certain mine workings during the late summer and early fall months. The Lynx mine's hydrologie response to precipitation events is generally rapid, causing ARD products to be flushed-out during infiltration from freshet rains occurring in the fall. Data analysis and re-interpretations of previous research efforts indicate that the existing conceptual Closure Plan options for decommissioning the Lynx mine would not likely be sufficient to effectively seal the portals and mitigate mine drainage.

1.0 Background

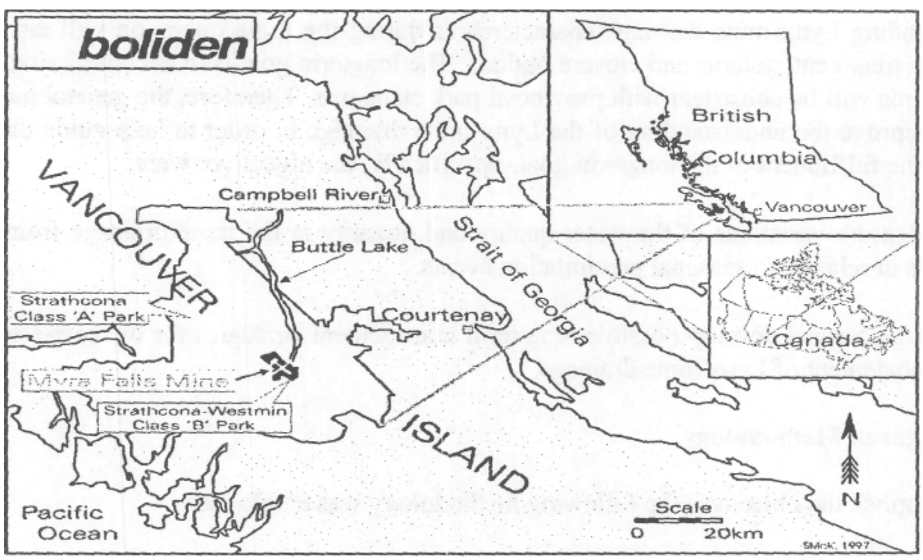


Figure I-.Location map for Myra Falls Operations & Strathcona Park, B.C.

The Lynx mine, both an underground and open pit mining operation, is the oldest mine at MFO. Mining for zinc, copper, lead, gold and silver began in 1967. With this relatively long history comes the recognition that the operations will eventually be closed and decommissioned. Currently, the MFO property is zoned as Strathcona-Westmin (Class B) Provincial Park, which is a special land designation within Strathcona (Class A) Provincial Park that accommodates Boliden-Westmin's mining claim.

The climate of the Myra Creek valley (Figure 2) is classified as Marine West Coast (MWC) as per the Koppen Classification System (Mchaina, 1995). Weather patterns are typical of coastal regions of western Canada, where frequent mild weather fronts from the Pacific Ocean combine with orographie influences to produce temperate rain forest conditions - mild winters, warm summers, and a small annual temperature range.

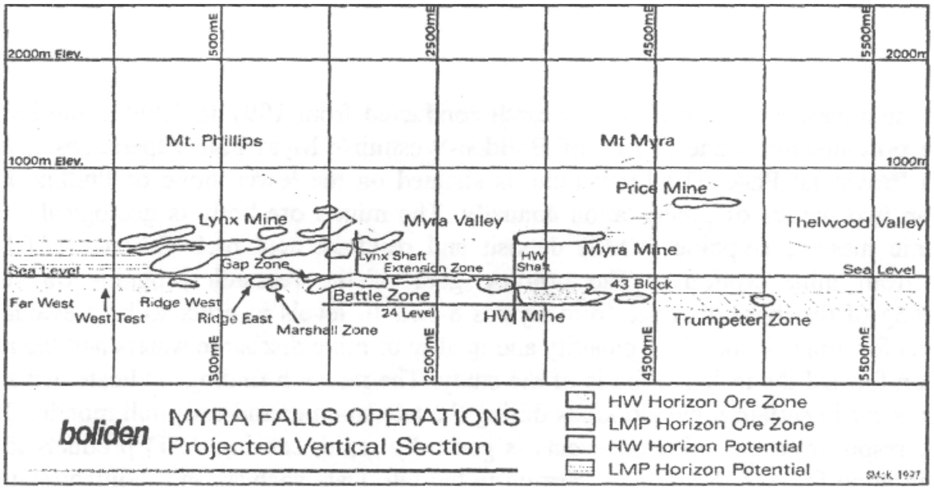


Figure 2: Vertical Profile of Myra Falls Operations & the Lynx Mine

2.0 Research Objectives

Understanding Lynx mine drainage characteristics during the mine operation will aid in evaluating and designing treatment systems and closure options. The longterm goal is to decommission the Lynx mine so that the area will be consistent with provincial park standards. Therefore, the general purpose of the study was to improve the understanding of the Lynx mine drainage in order to help guide the closure planning towards the fulfillment of the longterm goal. Specifically, the objectives were:

- To measure variations of the water quality and quantity in the mine drainage from Lynx 8 and 10E levels in relation to seasonal precipitation events.

- To evaluate and develop possible long-term management strategies for the cost-effective remediation and abatement of Lynx mine drainage.

2.1 Research Methodology

To accomplish the objectives the following methodology was employed:

- Reviewed historical literature and prepared project purpose
- Designed a field sampling and flow monitoring network to provide a continuous stream of data for two years via automatic multisensor datalogging equipment
- Collected field chemistry samples weekly at three locations within Lynx 8 level, one location at Lynx 10E level portal and one location at Myra 10L portal
- Interpreted new data to assess the Impacte of the Lynx 8 and 10E level effluents
- Maintained quality control throughout the project by employing accepted standard practices

2.2 Site Profile

The Lynx mine is located on the north side of Myra Valley, facing south (49°34' north, 125 °36' west). The mine comprises an open pit and twelve levels of underground mine workings numbered as: 5, 6, and 8 to 17. The mine levels were developed at intervals of 45 to 90 metres (Becherer, 1992). Upper levels were driven from surface into the mountainside, except level 9, which was accessed internally. The lower levels (11 to 17) are accessed via Level 10 by an internal shaft, 333m deep that transports workers, equipment and ore. It is important to note that the mine must be continually pumped out to avoid flooding. Substantial flow from this pumping system eventually exits Lynx 1OE portal, via a discharge pipeline just inside the portal.

Levels 5 & 6, which are situated above Level 8, reportedly have neutral drainage with low flows and were !therefore were not included in this study (Knight Piesold, 1989; Northwest Geochem, 1992). However, it is important to note that there is a vertical raise connecting the back of Level 6 down to Level 8. Knight Piesold (1989) determined that this raise does not appear to be transmitting water.

Lynx 8 level is located halfway from the top of the Lynx open pit. Based on historical data records this is the uppermost area in which acidic conditions have been identified (MFO historical files and Northwest Geochem, 1992). Therefore, this level represents the focus of the data collection undertaken during this study. The portal to Lynx 8 level is located near mine coordinates 17+65m E. and 31+4Om N. at an elevation of 453m above sea level (asl). There is no portal discharge - all drainage from 8 level is directed down ore passes to 9 and/or 10 levels. Lynx 8 level can be divided into two main drifts, north (8-567 X.C.N) and west (8-577 D. W.), that join together about 40m inside from the portal entrance. This is an important aspect to the understanding of the hydrology of the level. Lynx 8 level extends more than 1 kilometre westward, however field reconnaissance identified that the drift becomes blocked by fallen rock at approximately 580m. Observations of water flow appeared minimal at a distance greater than 400m from the portal.

Lynx 10 level is located at mine coordinates 19+63m E. and 30+99m N., at an elevation of 381m asl. The two main portals, 1OW and 1OE, provide access to most of the other mine workings. There is also the 10N portal located approximately 61m inside from the Lynx 10E portal. The fact that Lynx 10E portal discharges a composite of the Lynx mine drainage made this a suitable site to monitor. However, the drainage is affected, and complicated, by the sump's pumping rates. The Lynx 10W portal has no discharge - so it was not monitored during this study.

Water enters the Lynx mine through the extensive workings and through natural infiltration via fractured and faulted rock systems. The primary sources of water infiltration are from hydraulically-connected mine raises and stopes that are positioned sub-vertical to Lynx 8 level, primarily 8G-53 longhole stope (Knight Piesold, 1989 and Northwest Geochem, 1992). Stope 8G-53 was mined hi the 1970's. It is a relatively large open stope over 10Om long, located directly under and to the west of the upper Lynx open pit. Apparently, part of the original stope reserve was mined from the pit. The stope extends to the west approximately 75 meters under the pit back wall.

One of the main infiltration point sources to the LJTIX underground workings was tested and confirmed by Rudy van Dyk (Environmental Coordinator at MFO) in 1992. On June 8th of that year he performed a groundwater tracer test by pouring 2000 gallons of red dye onto an upper permeable bench of the Lynx open pit, above stope 8G-53. He discovered that the red dye appeared at Lynx 8 level portal approximately one hour after introducing the dye.

2.3 Monitoring Program

The study was conducted between August 1997 and October 1999. Temporal variations of the drainage characteristics were automatically recorded via multi-parameter sensors and battery-powered dataloggers. Weekly field sampling of effluent chemistry enabled an assessment of the trends of ARD indicator contaminants. The effluent characteristics were then correlated to precipitation data to help understand the site-specific relationship between hydrology and mine portal discharge.

Five monitoring stations were established for the study. Three were located within Lynx 8 level, one at the portal of Lynx 1OE level and one was at Myra 10 level portal. In Lynx 8 level, physical groundwater parameters were recorded every 6-hours to a datalogger. The physical parameters included electrical conductivity, water temperature, water pressure in a 'packed-off diamond drill hole (DDH-8-53) and water stage measured at two V-notch weirs with ultrasonic water level sensors. Lynx 1OE portal flows were also measured using a V-notch weir and an ultrasonic water level sensor. Greater than 300 weekly water quality samples, representing more than 70 separate sampling days, were collected through the research period. The samples were prepared in MFO's Environmental Laboratory and shipped to the Geological Survey of Canada's (GSC) Mineral Resources Laboratory, located in Ottawa, Ontario. Key ions were analyzed by ICP-MS, ICP-ES and AA methods. Sample quality assurance and control methods such as filter blanks, duplicates and splits were employed throughout the project.

Correlations of the weather to mine drainage flow patterns were made using precipitation data collected at Environment Canada's climatological recording station, located outside MFO's powerhouse building at approximately 36Om asl. This station is maintained and operated by MFO personnel.

3.0 Research Findings

In general, the findings from the thesis research indicate that mine drainage from the Lynx underground workings typically carries high metal and sulphate concentrations at near neutral pH. Only Lynx 8 level shows seasonal acidic conditions, with resultant higher metal concentrations (Table 1). From Lynx 8 level, trace metal concentrations were found to steadily increase through the summer months; reaching peak concentrations in the early fall months. The lowest pH values (<3 pH in the early fall) preceded the highest flow periods occurring in late fall months. The seasonally acidic drainage from Lynx 8 level is diluted when combined with all other Lynx underground flows before exiting Lynx 1OE portal.

Table 1: Chemistry summary for Lynx 8-1 sample location, Myra Falls Operations

Lynx 8-1	T-Al	T-Ca	T-Cd	T-Cu	T-Fe	T-Mg	T-Mn	T-Pb	T-SO4	T-Zn
	ppm	ppm	ppm	Ppm	ppm	ppm	ppm	ppm	ppm	ppm
Minimum	0.240	42.00	0.052	1.50	2.60	3.40	0.20	0.012	75.30	14.00
Maximum	8.700	95.00	0.480	14.00	110.00	28.00	4.60	0.220	725.00	110.00
Mean	1.095	60.64	0.181	5.06	13.93	6.94	0.63	0.039	193.97	40.04
Median	0.710	58.00	0.160	4.20	9.30	5.75	0.47	0.029	153.00	33.00
Std. Dev.	1.25	11.31	0.10	3.13	15.84	3.69	0.61	0.03	112.95	21.78
N=	70	70	70	70	70	70	70	70	75	70
CSR-AW	0.5	n/a	0.018	0.09	3.0	n/a	1.0	0.11	n/a	0.3

Because most of these metals have high solubilities at near neutral pH, hydrolysis to metal hydroxides may not occur until the pH is raised. This is an important consideration when assessing various treatment options. Mine hydrology and the weather regime are also important variables to study and consider.

The precipitation trend for 1997-1999 generally follows the 16-year trend, 1979-1994. During the study period, annual precipitation at the site averaged 2126 mm. However, 1998 had above average snow cover since most of the precipitation that occurred in February fell as snow. Summer 1998 was comparatively dry, while August 1999 had a similar precipitation total as 1997. Significant rains were recorded in November 1999.

Field observations indicate that precipitation quickly infiltrates the mine workings through hydrologie conduits such as faults, fractures, drillholes and stopes. Lynx mine discharge patterns were found to closely correlate to precipitation events. On a macro scale, Figure 3 below depicts the patterns of hydrologie response to seasonal precipitation events.

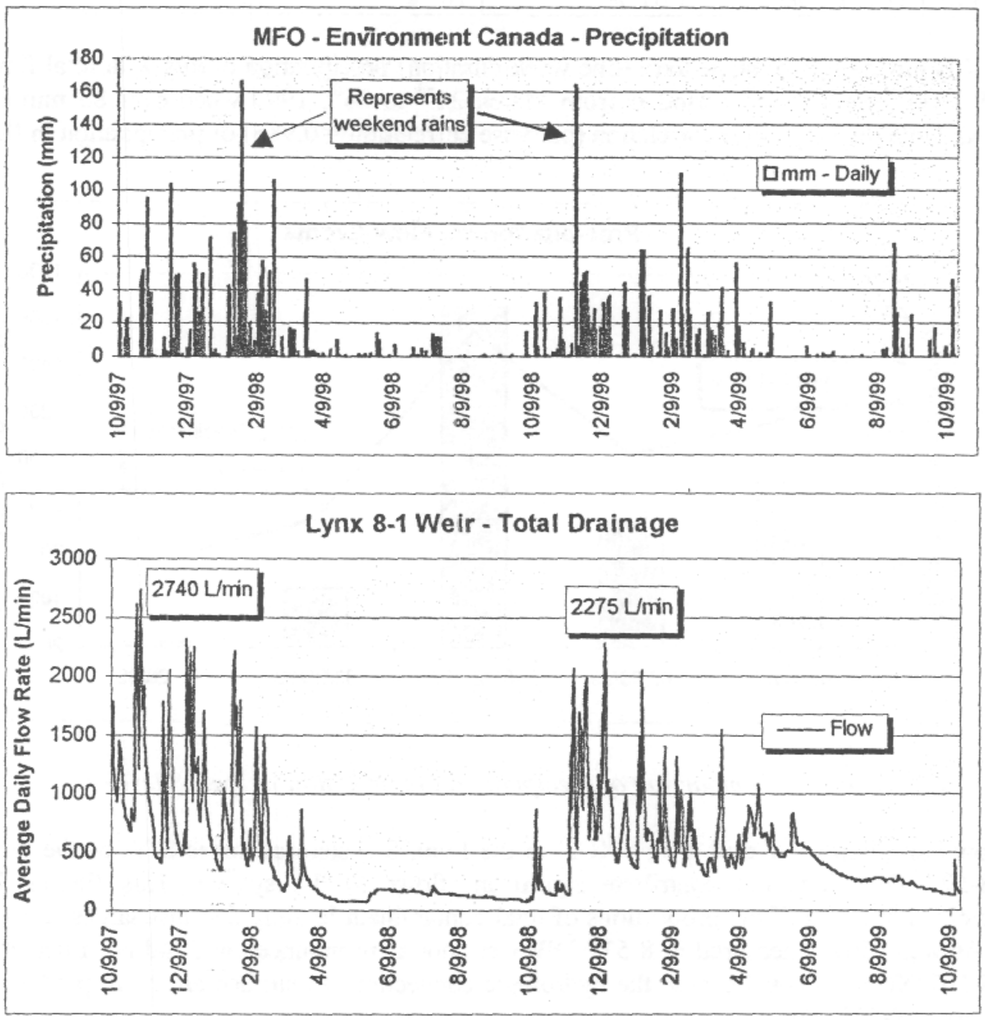


Figure 3: Comparison of precipitation regime to flow patterns in Lynx 8 level

The flow and precipitation regimes were organized into three periods: November to February, March to June and July to October (Table 2, next page). Most of the precipitation and corresponding flows occur in the November to February period. However, the flow percentage is not as high as the precipitation percentage, likely due to recharging groundwater aquifers and mine workings. When these zones are fully saturated they begin to discharge through the March to June period, which results in the apparent higher percentage of flow as compared to precipitation. In contrast, the summer months are rather dry, receiving just 13% of the annual total precipitation - representative of low precipitation, base flow periods.

Table 2: Flow and precipitation regimes as percentage of the year (199 7-1999)

	November to February	March to June	July to October
Precipitation as % of annual total	71 %	16 %	13 %
Flow as % of annual total (Lynx 8 level)	61 %	26 %	13 %

Figure 4 below compares short-term (one week duration) precipitation events with total flow measured at lynx 8 level. The selected period is from March 22nd to 26th, 1999 when over 83 mm of rainfall was recorded. Note the very close correlation (pairwise correlation = 0.985) of precipitation to flow events.

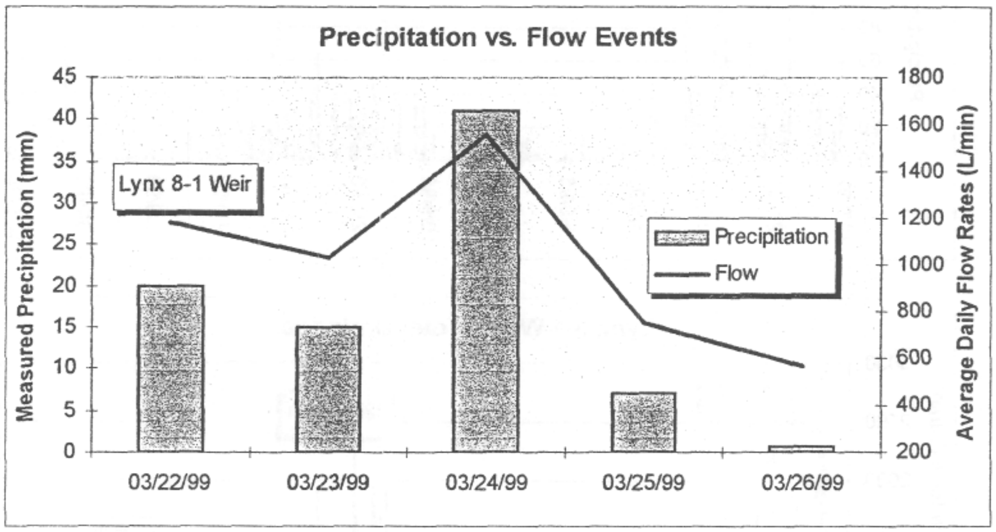


Figure 4: Comparison of precipitation events to flow at Lynx 8 level

The flow contribution of drift 8-567 XCN to the Lynx 8 system averages 87% of the total flow. Thus, drift 8-577 DW does not contribute significant flows to the system. This finding has important ramifications in terms of the proportions of total contaminant loading that discharges from the respective drifts. As well, flows measured in 8-577 DW were not as pronounced and did not fluctuate as did flows from 8-567 XCN. This is because the hydrologie connections to surface are more predominant in 8-567 XCN than in 8-577 DW.

Based on over 2400 individual flow level measurements at Lynx 10E level it was determined that Lynx 8 level's contribution to the total flow from Lynx 10E portal averages ~ 40% (Figure 5). Thus, determining an effective method to reduce the drainage from 8 level will play a large part in mine closure plans.

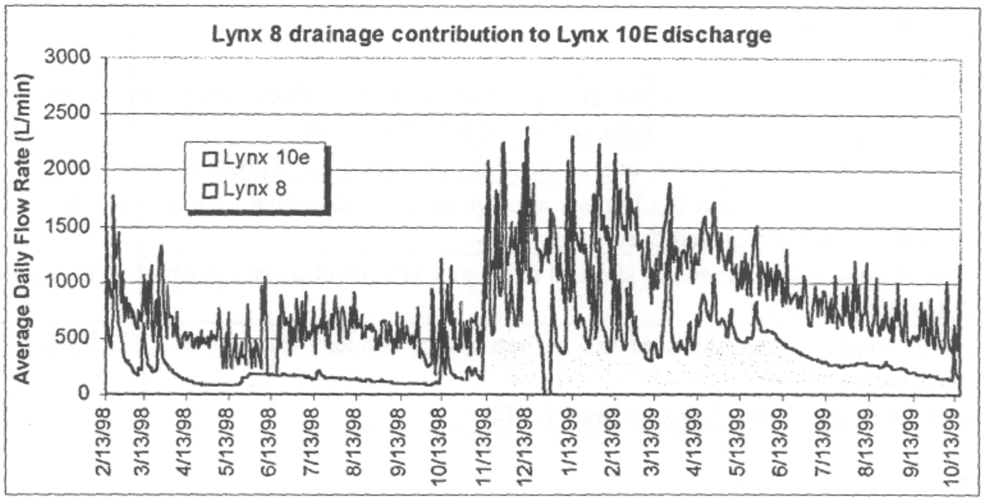


Figure 5: Lynx 8 level's flow contribution to total Lynx 10E portal discharge

3.1 Results Summary

3.1.1 Lynx 8 Level

- Mine drainage flow rates are closely correlated to precipitation events, with fast hydraulic response, indicating strong connections to surface features.
- The largest source of water to the Lynx 8 system is via the upper benches of the Lynx Open pit, wherein precipitation and runoff is funneled into Lynx 8 level mine workings. Stope 8G-53 is hydraulically connected to the surface and is the main source of ARD.
- Lynx 8 level mine drains on average 488 L/min, which equates to 702 m^3/day. The maximum daily flow rate was measured at 3945 m^3/day, the lowest was 108 m^3/day.
- Peak flow rates from Lynx 8, which can exceed 2740 L/min, typically occur in the months of November or December.
- Drift 8-567 XCN contributes, on average, 87% of the flow to Lynx 8 level discharge.
- The majority of Lynx 8 mine waters drain down the Lynx 9/10 ore pass to 10-585 DW, before travelling another 230m to Lynx 10E portal.
- Lynx 8 level contributes, on average, almost 40% of the flow to Lynx 10E level discharge
- Mine drainage from Lynx 8 is seasonally acidic with high metal loads during September, October and November. Trace metal concentrations were found to steadily increase through the summer months; reaching peak concentrations in the early fall months. The lowest pH values (<3 pH in the early fall) preceded the highest flow periods occurring in late fall months.
- Drift 8-577 DW does not contribute acidic water or significant metal loading to Lynx 8 level. Drift 8-567 XCN is the primary source of ARD to Lynx 8 level drainage.
- On an annual average Lynx 8 level mine drainage is considered pH neutral with high metal concentrations, ie. concentrations are above aquatic life limits.
- Significant loadings of Zn, Cu, Cd, Pb and SO_4 discharge from Lynx 8 level.
- Groundwater pressure measurements from DDH 8-53 can exceed 41m of pressure head, but average closer to 30m of head.
- The bulk hydraulic conductivity for Lynx 8 level was calculated to be 1×10^{-6} m/s.
- Correlation equations were developed between electrical conductivity and various metal species. They can be used in the future to infer metal concentrations in Lynx 8 level discharge.

3.1.2 Lynx 10E Level

• On average, Lynx 10E drains 1282 m^3/day. Peak flow rates discharging from Lynx 10E portal can exceed 3432 m^3/day, while the lowest rate measured was 271 m^3/day.
• Mine drainage pH averaged 6.93, or near-neutral. The lowest pH measured was 5.42.
• Lynx 10E drainage recorded the highest average level of electrical conductivity (652 uS/cm) of the five sample locations measured during this study.
• Analyses of mine water chemistry showed that Lynx 10E level discharges high concentrations of trace metals (Al, Cu, Fe and Zn).
• Lynx 10E drainage also recorded the highest mean concentration of SO_4 (251 mg/L) of the five sample sites monitored.
• Estimated pressure head at Lynx 10 level is 100m

4.0 Implications to Closure

Upon mine closure, the current plan to mitigate Lynx mine drainage is to seal all infiltration routes and install concrete plugs at all surface portals. However, according to BC government authorities, plugs used to flood underground mine workings have often been unsuccessful. It is hoped that future research and experience will allow plugs to become a more reliable form of long-term ARD and metal leaching prevention (Price & Errington, 1998). For now, concrete plugs have important shortcomings making them an unsuitable longterm option as summarized in Table 3.

Table 3: Limitations of concrete plugs for sealing mine portals

• Estimated life for concrete plugs is only 50-100 years. Long term maintenance will be costly to future generations.
• Acidic and sulphate rich groundwaters occur in the Lynx mine. These waters will chemically attack and eventually weaken concrete and grouting materials.
• High pressure heads will likely cause high-energy failure of the weaker, fractured rock zones surrounding the plugs. Significant pressure (>30m of H_2O) head was measured in Lynx 8 level, while pressure head at Lynx 10 level is estimated at 100m. Also, Phillips Ridge is situated almost 1000m (sub-vertically) above the Lynx mine workings - producing significant pressure head on mine structures.
• Extensive fractures and faults in the Lynx mine will be difficult to seal adequately. Bulk hydraulic conductivity for Lynx 8 level was measured at 1×10^{-6} m/s.
• The Lynx mine is located within a region of extreme seismic instability, earthquakes are common and can be large (eg., >7.0 on the Richter Scale) causing water hammer against static plugs and structures connected to fractured and faulted rock.

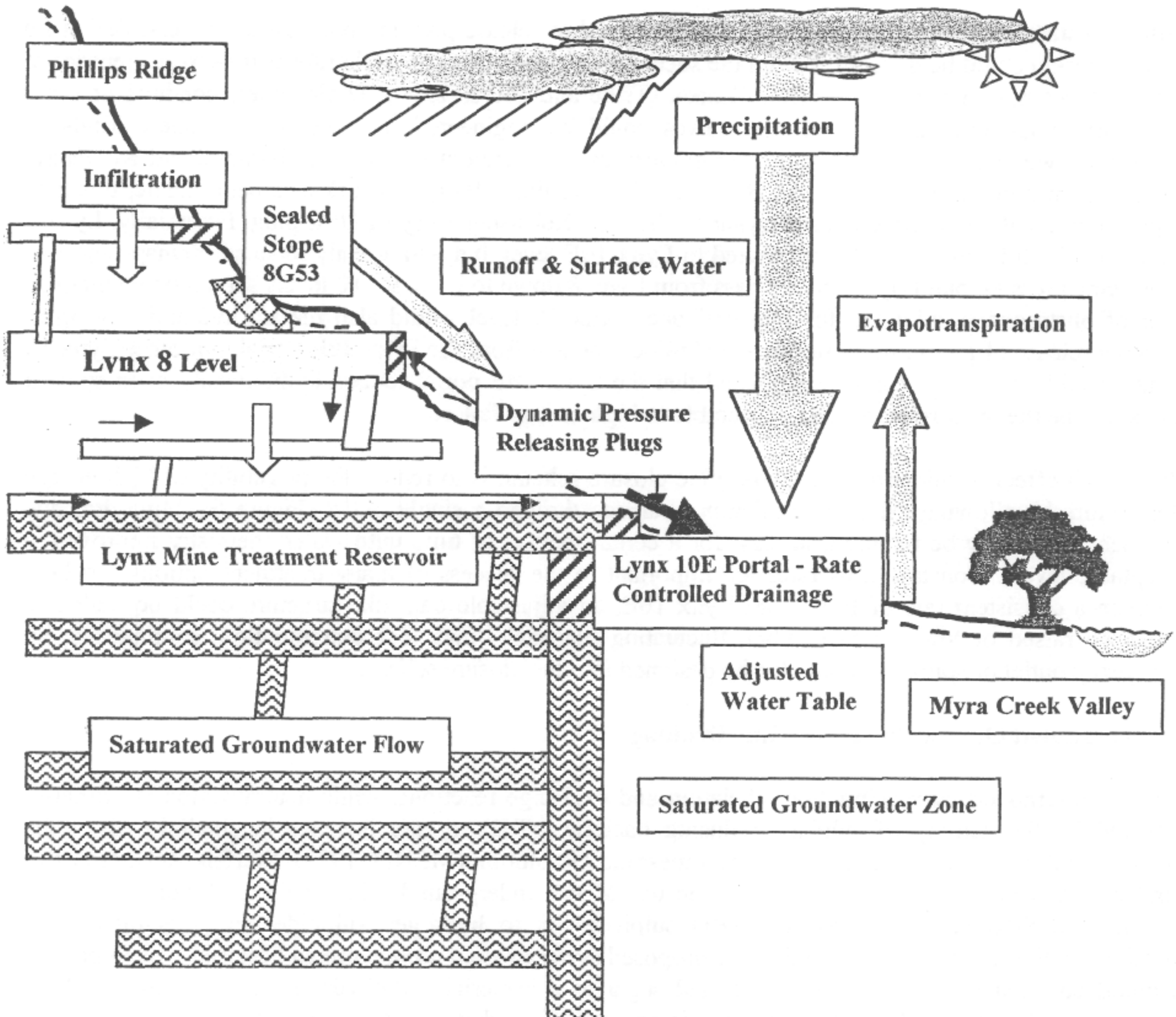
build-up - install a permanent structure that is designed to release pressure but obstruct access. Perhaps a suitable design could be developed from the successful designs using flexible rubber tires to seal entries to over 150 old mine portals in Alberta, Canada (Tribe and Tribe, 1999). Drain pipes, conduits or other means of maintaining pressure release valves could be engineered into the design. These kinds of implements were recently part of mine portal closures conducted at the historic Highland and Kootenay-Florence mines in Ainsworth, B.C. by Boliden Ltd. (Mchaina, 1999). For lack of a better name, this type of portal plug will be referred to as a 'Dynamic Pressure Releasing' plug, or DPR plug. Essentially, Lynx 8 level would still be hydraulically connected to Lynx 1OE level, but with greatly reduced drainage and risk of extreme pressure build-ups. The ore pass from Lynx 8 down to Lynx 9/10 levels should be maintained clear of obstructions, allowing for free drainage. Lynx 10 level would also remain hydraulically open, allowing release of groundwater pressure and mine drainage from the Lynx 10E portal. All other Lynx 10 portals could be sealed. It is recommended that the Lynx 10E portal remain hydraulically open since it appears to be the most fractured and vulnerable to high-energy failure.

The overall effect of this proposed Lynx mine closure scheme is to reduce the possibility of high-energy plug failure by allowing the release of mine drainage through a single outlet (Figure 6). Mine drainage treatment will likely be required, at least for a certain period of time until water chemistry improves to acceptable levels. Constant flow rates are important to the success of many treatment options. To help maintain a consistent rate of flow from Lynx 10E, an adjustable dam-like structure could be built that would be raised or lowered to regulate fluctuating seasonal flows. For extreme flow contingency, an emergency outlet or spillway could also be designed into the closure scheme.

4.2 Treatment Options for Lynx Mine Drainage

Metals are removed by precipitation, chelation and exchange reactions, while neutralization is primarily achieved by the activity of sulphate reducing bacteria (SRB), or the increase in alkalinity from the chemical and microbial reactions including limestone dissolution (MEND, 1999). Steffen, Robertson and Kirsten (B.C.) Inc. (1991) have proposed the use of the underground mine at Faro, Yukon, as a giant underground SRB reactor to convert ARD sulphate ion to hydrogen sulphide, and precipitate zinc contained in the ARD as zinc sulphide. The proposed system would use the mixed bacterial system present in liquid cow manure as an SRB source, and sugar as a bacterial carbohydrate (energy) source (Mills, 1998). According to another recent study, this process of sulphate ion to hydrogen sulphide conversion was the first stage of a NTBC Research Corporation pilot plant that operated in 1996 at the former Britannia mine site in British Columbia. The second stage utilized the hydrogen sulphide generated to precipitate copper (Cu^{2+}), zinc (Zn^{2+}), and cadmium (Cd^{2+}) ions from ARD as metallic sulphides (Warkentin and Rowley, 1994).

Quite possibly, the Lynx mine too could act as an underground SRB reactor - as a primary treatment reservoir that discharges to final surface treatment facilities. Drainage could be treated, if necessary, by existing lime treatment or possibly constructed wetlands. However, a proposal for passive drainage treatment must demonstrate that collection and treatment systems are sustainable for as long as is necessary and during and after extreme climatic events (Price & Errington, 1998). According to BCMEM, experience to date in British Columbia has shown that most forms of passive drainage treatment are incapable of handling high metal loads or high flow rates and reliably meeting low discharge concentrations. Nevertheless, further research or pilot-scale studies could be undertaken to assess the effectiveness of constructed wetlands and other passive treatment options. At this stage, the recommended approach to treating Lynx mine drainage would be to attempt to utilize the potential of in-situ SRB treatment within the mine workings, followed by active conventional lime treatment.



This drawing represents a conceptual model of the complex flow patterns after closure of the Lynx mine using the proposed approach. There are two key components: 1). Seal all infiltration routes as well as possible, particularly the Stope 8G-53 area and 2). Allow for pressure relief. The key is that while the vertical shaft and upper levels (5 & 6) are plugged, Levels 8 and 10 are maintained hydraulically open, allowing for relief of pressure and/or mine drainage. Level 8 would be plugged using a Dynamic Pressure Relief (DPR) design that allows for emergency pressure relief only. The relief is not likely to be needed since all Lynx 8 flows would continue down ore passes to Lynx 9/10 levels. Lynx 10 level portals could all be sealed with DPR plugs except for 10E portal, which would remain open, allowing mine drainage and pressure to escape. A portal dam could be constructed at the 10E portal, with a modification that automatically baffles or controls the height of water. This would enable the moderating of flow to a more consistent rate, which in turn would help the water treatment system function more effectively. The mine could also act as a SRB pre-treatment reservoir prior to discharging to an external treatment system.

Note that the drawing is not to scale, nor are all Lynx workings shown.

Figure 6

5.0 Recommendations

The data from this study and re-interpretations of previous research efforts indicated that the existing conceptual Closure Plan options for decommissioning the Lynx mine would not likely be sufficient to effectively seal the portals and mitigate mine drainage. Some of the proposed work suggested can not be undertaken until the mine is closed down. However, other work could be accomplished now in anticipation of the eventual mine closure. Ultimately, the proposed long-term management option is to isolate or eliminate the ARD source. This may tie achieved by the following methods:

1. Remove the ARD source to Lynx 8 level by mining it out or reduce the infiltration causing metal transport by sealing the major routes to die reactive ARD zones.

2. Minimize water inflow to the Lynx underground mine as soon as possible, so that effectiveness of this drainage abatement method can be tested while the mine is in operation. This recommendation involves sealing the inflow to Stope 8G-53 from the upper Lynx open pit bench.

3. Further research is recommended to determine the potential groundwater pressure heads that could develop within the Lynx mine workings in a post-closure environment. Fracture and fault zone identification is necessary.

4. Sample and monitor Lynx 10 level for changes (reductions) in water chemistry. Measure pH and conductivity monthly. Use correlation equations established between metals and pH/conductivity parameters from this study to estimate metal concentrations. Sample major parameters every two months at Lynx 10E portal.

5. Continue treating Lynx mine drainage by cost-effective, conventional methods. However, investigate the potential of establishing bio-remediation "pilot-scale" test projects to treat Lynx 10E drainage. Recommended options include in-situ Lynx mine SRB treatment and constructed passive wetlands.

6. Toxicology studies of the Lynx mine effluent are also recommended to determine the short and long term environmental impacts of mine drainage.

Acknowledgements

Funding for this project was jointly provided by Boliden-Westmin (Canada) Ltd., the Geological Survey of Canada (GSC) and the B.C. Technical and Research Committee on Reclamation through their Jake McDonald Memorial Scholarship award. I am grateful to the late Dr. Dan R. Boyle (1948-2000), Dr. Alec Desbarats (GSC), Steve Januszewski (MFO) and to my Royal Roads University (RRU) thesis advisors, Dr. Stephen Grundy and Dr. Anthony Hodge for lheir important comments and guidance.

Opinions and options discussed in this paper do not necessarily represent the policies or opinions of Boliden-Westmin (Canada) Ltd. The data interpretations and conclusions are solely the views of the author.

References

Bedherer, M. (1992). *Grade Control and Mining Methods in the Lynx Mine - Myra Falls Operations.* Abstract prepared for Westmin Resources Limited.

Desbarats, A., D. Boyle, M. Stapinsky, and M. Robin. (1999). *A dual-porosity model for water level response to atmospheric loading in wells tapping fractured rock aquifers.* Water Resources Research. 35(5). p. 1495-1505.

Desbarats, A. and D. Boyle, (2000). *Physical Hydrogeology of the Price and Myra Mine Areas.* Unpublished internal report prepared for Boliden Westmin (Canada) Ltd., Myra Falls Operations. Geological Survey of Canada, Ottawa, Ontario.

Juras, S., M. Robinson and *C.* Godwin, (1994). *Major Lithologies of the Battle Zone, Buttle Lake Camp, Central Vancouver Island (92F/12E).* Geological Fieldwork 1993, Paper 1994-1. British Columbia Geological Survey Branch.

Knight Piesold Ltd. (1989). *Lynx Open Pit - Phase 1 - Water Management Study.* Internal report prepared for Westmin Resources Limited - Myra Falls Operations. January 9/89.

Mchaina, D. (1995). *Myra Falls Conceptual Decommissioning Plan.* Report prepared for Westmin Resources Limited and BC Government Agencies, December 20, 1995. Vancouver, B.C.

Mchaina, D. and W. Weirmeir (1999). *Reclamation of Mine Openings at the Historic Highland Mine and Kootenay-Florence Mines Ainsworth, B.C.* Proceedings of the 23rd Annual British Columbia Mine Reclamation Symposium. Kamloops, B.C. p. 224-239.

Mills, C. (1998). *Acid Rock Drainage.* URL document: http://www.enviromine.com.

Mine Environment Neutral Drainage Program (MEND) (1999). *Review of Passive Systems for Treatment of Acid Mine Drainage. Report 3.14.1 -May 1996, Revised 1999.* Natural Resources Canada, Ottawa.

Morin K. A. and N.M. Hutt (1997). *Environmental Geochemistry of Minesite Drainage - Practical Theory and Case Studies.* MDAG Publishing, Vancouver, B.C. Canada.

Northwest Geochem (1992). *Physical and Chemical Hydrogeology of the Lynx Area of the Westmin Myra Falls Operation.* Internal report prepared by Northwest Geochem, a division of C.E. Jones and Associates. October 1992.

Phipps, G., (1998). *Hydrochemical and Isotopic Characterization of Ground Waters in the Myra-Price Hillsides and Thelwood Valley, Myra Falls Mining Camp, Vancouver Island, British Columbia, Canada.* Ph.D. Thesis, Ottawa-Carleton Geoscience Centre and University of Ottawa, Canada.

Price, W. A. & Errington, J.C. (1998/ *Guidelines for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia.* Ministry of Energy of Energy and Mines, Victoria, B.C.

Steffen, Robertson and Kirsten (B.C.) Inc. (1991). *Sulphate Reduction as a Water Treatment Alternative at the Faro Mine.* Report for Curragh Resources Inc., 64p.

Tribe, N.L. and LJ. Tribe (1999). *A Successful Method of Reclaiming Subsidence in Abandoned Mining Areas.* Proceedings of the 23rd Annual British Columbia Mine Reclamation Symposium. Kamloops, B.C. p.212-222.

Warkentin, D.D. and Rowley, M. V. (1994). *Britannia Minesite A.R.D. Biosulphide Demonstration Project* - Interim Report - Laboratory Testing, NTBC Research Corp., Richmond, B.C., 21p.