ASSESSMENT AND CLOSURE DESIGN OF THE GLENGARRY ADIT, NEW WORLD MINING DISTRICT, COOKE CITY, MONTANA[1]

M. B. Marks[2], H. Bogert, A. R. Kirk, and M. Cormier

Abstract. The Glengarry adit and two raises were driven in the mid 1920's to early 1930's in the Fisher Creek drainage of the New World Mining District. The USDA-Forest Service rehabilitated the Glengarry adit in 2000 and 2001 for assessment purposes under CERCLA response activities because it is one of the principal sources of metals loading in the headwaters of Fisher Creek. Outflow ranges from 57 to 848 liters per minute of low pH, iron-, zinc-, and copper-bearing water that discharges into Fisher Creek. About 915 meters of workings were surveyed, the geology mapped, and water samples collected for geochemical analysis. Four principal sources of water inflows were identified including two raises, a major crosscutting fracture, and diffuse roof leaks. The main source of contamination is water flowing from the colluvial/bedrock contact in a raise that surfaces in the Como Basin, and contains high concentrations of arsenic, copper, aluminum, cadmium, iron, manganese and zinc. The crosscutting fracture contains the highest concentrations of arsenic, aluminum and cadmium. Mass load analysis provides a basis for identifying significant sources of contamination and quantitative calculations of effectiveness for potential closure options.

Clean-up goals for the Glengarry Adit are based on eliminating or minimizing contaminated inflows and outflows from the adit. Closure alternatives that use engineering controls to plug, contain, or divert water flows were developed and analyzed to meet clean-up goals, and a preferred alternative for closure of the Glengarry Adit was selected. The preferred alternative involves a combination of surface and underground grouting, installation of underground plugs and backfilling a portion of the underground. This combination of closure technologies should eliminate any discharge from the mine. Closure will be implemented in two phases in 2003 and 2004.

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Introduction

The New World Mining District (District) includes both National Forest and private lands in a historic metal mining area located in the Beartooth Mountains, near Cooke City, Montana **(Figure 1).** The District falls within the boundaries of the Gallatin and Custer National Forests and lies adjacent to Yellowstone National Park's northeastern-most corner. This historic mining district contains both mining related and natural features that are pertinent to mine waste cleanup activities. These features include: massive sulfide deposits exposed at the surface; regionally distributed geologic units and deposits enriched in pyrite and chalcopyrite; abandoned mines; hard rock mining wastes; acid discharges from mine wastes and abandoned mine workings; and natural acid rock drainage. Human health and environmental issues are related to elevated levels of metals present in various mineralized geologic units, mine wastes, acidic water discharging from mine openings, and contaminated stream sediments.

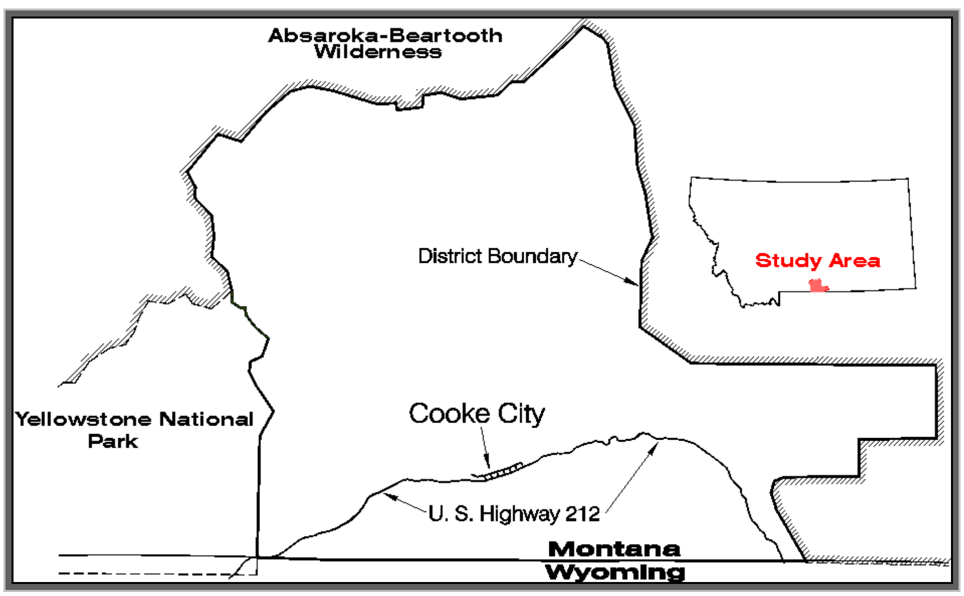


Figure 1. Location Map

Project Background

On August 12, 1996, the United States signed a Settlement Agreement (Agreement) with Crown Butte Mining, Inc. (CBMI) to purchase CBMI's interests in the District. This transfer of property to the U.S. government effectively ended CBMI's proposed mine development plans and provided \$22.5 million to clean up historic mining impacts on certain properties in the District. In June 1998, a Consent Decree (Decree) was signed by all interested parties and was approved by the United States District Court for the District of Montana. The Decree finalized the terms of the Agreement and made available the funds that are being used for mine cleanup. Through the Agreement and Decree, the project officially became known as the New World Mining District Response and Restoration Project.

Mitigation of impacts from acid-generating historic mining wastes has been an objective of investigators in the District since the 1970's. The latest investigative work has been conducted by the United States Environmental Protection Agency EPA from 1995 to 1997, and the United States Department of Agriculture (USDA)-Forest Service from 1999 to present. Site investigation activities have involved installing monitoring wells, collecting surface water and groundwater samples, using surface water and groundwater tracer studies to define pathways of metals loading, mine waste sampling, and rehabilitating certain underground mine workings to allow safe entry of site assessment personnel. Cleanup activities are on-going.

Site Characteristics

The District covers an area of about 100 square kilometers (40 square miles), and is located at elevations ranging from 2,400 meters (7,900 feet) to over 3,200 meters (10,400 feet) above mean sea level in an area that is snow-covered for much of the year. Historic mining disturbances affect about 20 hectares (50 acres). The topography of the District is mountainous, with the dominant topographic features created by glacial erosion and glacial deposits. The stream valleys are U-shaped, broad, and underlain at shallow depths by bedrock, while the ridges are steep, rock covered, and narrow. Much of the District is located at or near tree line.

There are three principle drainages in the District, Fisher Creek, Daisy Creek, and Miller Creek. The Glengarry Adit, which is the focus of this investigation, is located in Fisher Creek. **Figure 2** shows site features in the headwaters of Fisher Creek.

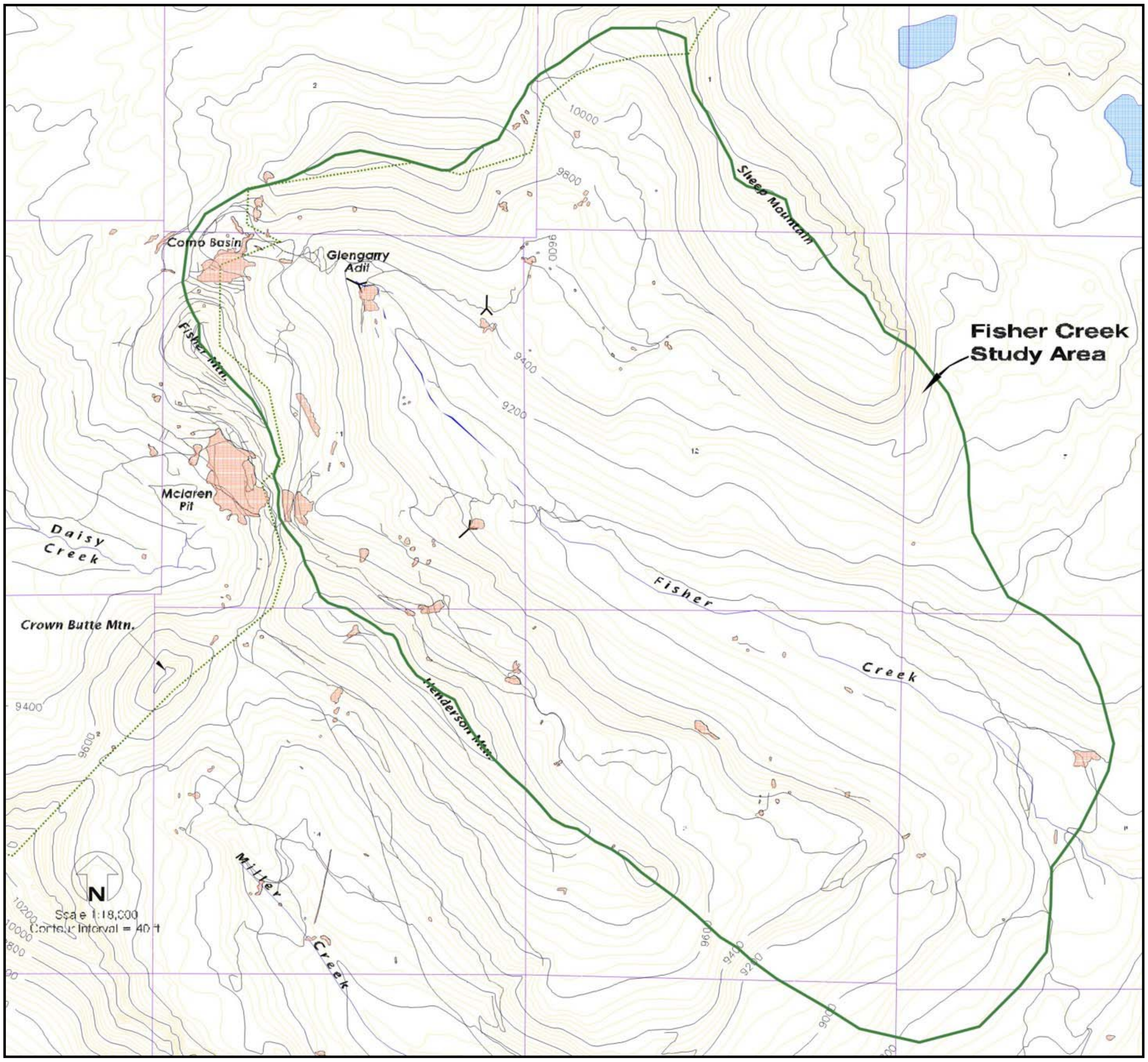


Figure 2. Fisher Creek Vicinity Map. Hatched areas are mine waste deposits.

The Glengarry Adit discharges 57 liters per minute (Lpm) to 848 Lpm (15 to 224 gallons per minute [gpm]) of low pH, iron-, zinc-, and copper-bearing water into Fisher Creek. Current estimates of the contribution of metal loads to Fisher Creek indicate the Glengarry discharge makes up about 30% of the total copper load in the creek, which, during base flow conditions, is 28 milligrams per second (Amacher, 1998); Kimball, et al, 1999). This input, along with other sources, renders poor quality water that is uninhabitable to aquatic life.

District Geology

Precambrian basement rocks, predominantly granitic gneisses, are exposed over much of the northern and eastern part of the District, including the valley floor along upper Fisher Creek (Elliott, 1979). Paleozoic sedimentary rocks consisting of sandstone, siltstone, shale, limestone, and dolomite unconformably overlie these basement rocks. These sedimentary rocks generally dip gently to the southwest and are intruded by Tertiary (Eocene) felsic calc-alkaline stocks, laccoliths, sills, and dikes. Gold-copper-silver deposits in the New World District are of three principal types: 1) tabular, stratabound, skarn and massive sulfide replacement deposits hosted by the Meagher Limestone Formation of Cambrian-age; 2) replacement and vein-type mineralization along high angle faults and fractures; and 3) sulfide and oxide replacement deposits of limestone clasts in diatreme and intrusion breccias (Elliott, et al, 1992). Mineralization in upper Fisher Creek is spatially, temporally, and genetically related to the emplacement and alteration of the Fisher Mountain Intrusive Complex.

Mining History

Mining exploration in the District began in 1864 when prospectors from the mining camp of Virginia City explored the area. The earliest placer and lode deposits were prospected in 1869. In 1876, the Eastern Montana Mining and Smelting Company constructed a smelter in the Cooke City area. In 1883, the Republic Smelter was built for the reduction of silver-lead ore.

Mining activity fluctuated greatly between 1882 and the late 1920's, hampered primarily by the lack of a railroad to ship ore and supplies, and the long and severe winters. Numerous smelters were built, although most only operated for a few years at a time.

The Glengarry Mining Company drove the Glengarry Adit in 1925 (Lovering, 1929) some 700 meters (2,300 feet). No mineralization was found in this drift, so a southwest heading was driven from an underground location about two thirds of the way in from the portal some 183 meters (600 feet) to a location beneath the massive sulfide Como Basin deposit, and two sets of raises driven towards the surface from this drift. The furthest raise terminated near to the surface about 130 meters (425 feet) in the base of the Como deposit (Figure 2). The near raise appears from old maps to have been abandoned after raising some 15 meters (50 feet) above the floor of the drift. **Figure 3** shows a cross-sectional view of the underground workings.

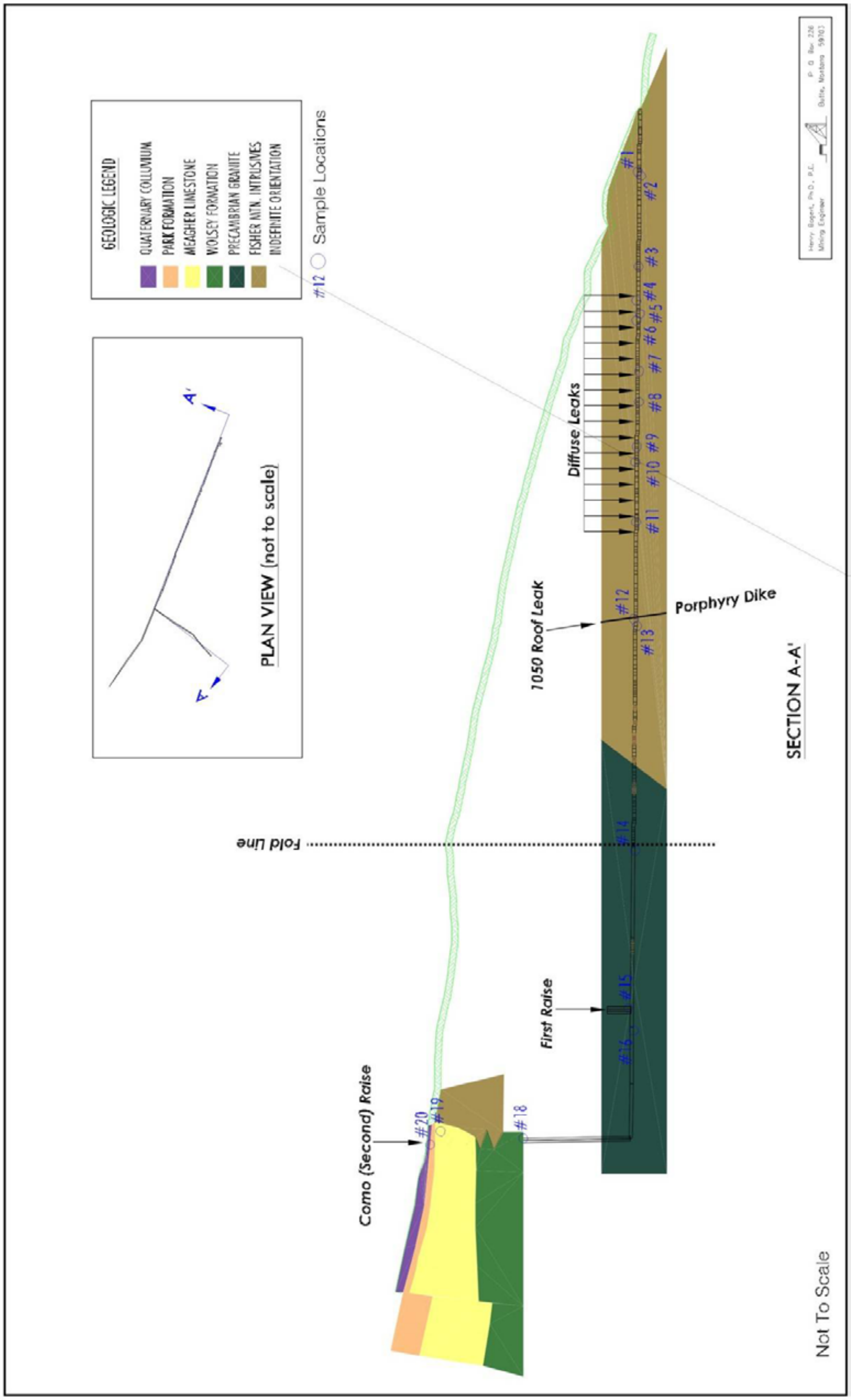


Figure 3. Cross-Section of the Glengarry Mine

Project Objectives

The overall project objectives for the response and restoration project are several. Perhaps the most important for the Glengarry Adit closure project are to assure the achievement of the highest and best water quality practicably attainable and to mitigate environmental impacts that are a result of historic mining. Project cleanup work is accomplished by following the non-time-critical removal process established by the EPA for Superfund projects.

Investigation Methods

The principal objective of this study was to gain access to the Glengarry workings to examine the location and character of groundwater draining into the underground workings. By identifying the principal locations and associated metal loads of inflows into the Glengarry Adit, potential mitigation measures that could be directed at reducing or eliminating the acid discharge from the Glengarry into Fisher Creek could be evaluated.

The Glengarry Mine was rehabilitated for assessment purposes in September and October 2000 (**Figure 3**). Accumulated debris and ferricrete mud 0.6 to 1.5 meters (two to five feet) deep were removed from the drift beginning at the portal and extending back to the "Y" intersection 470 meters (1540 feet) in from the portal (**Figures 3**). **Figures 4, 5, and 6** are photographs of the Glengarry outflow, the portal, and the flooded conditions of the Glengarry workings prior to rehabilitation. Bogert (2001) discusses the rehabilitation efforts in greater detail.

The following year, in June 2001, the second raise that extends into the Como Basin was reopened and repaired to a depth below the base of the Meagher Limestone. The second raise consisted of two square-set compartments. Old ladders and debris were removed from the north compartment. New ladders and landings were installed down to a depth of 65 meters (215 feet) below the surface. Three separate short horizontal workings were encountered in the Meagher Limestone at 10 meters (35 feet), 23 meters (75 feet), and 30 meters (100 feet) below the surface. All of the accessible workings were mapped planimetrically for spatial control, and mapped geologically to identify geologic units, structures, mineralization, and points of water inflow.

Figure 4. Stalactites in the Flooded Glengarry Drift

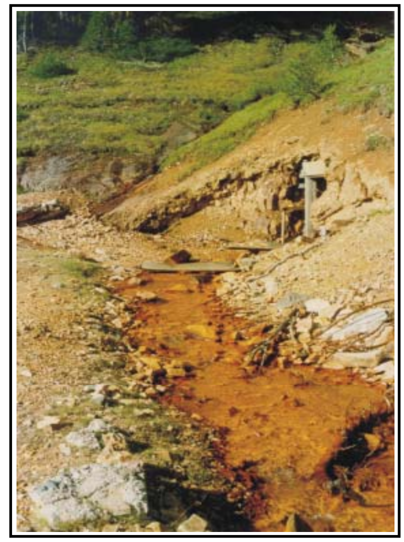


Figure 5. Glengarry Outflow

Figure 6. Glengarry Portal

Underground water quality samples were collected from numerous stations within the Glengarry Mine in the fall of 2000, and water inflows were measured and sampled at the collar of the raise and at each horizontal level during July and August 2001. In the horizontal drift, samples were collected from selected sampling stations in spring (April/May), summer (July), fall (October), and winter (December), 2001. Samples were collected and shipped to the laboratory following standard operating procedures, and the laboratory followed EPA methods for chemical analysis of water and wastes. Analytical parameters included pH, specific conductance, common ions, nutrients, and dissolved and total metals. Samples collected for dissolved analysis were filtered through a 0.45 micron filter. In addition, sediment present on the sill (floor) of the drift was sampled and analyzed for total metals according to EPA methods for evaluating solid wastes. Surface water and sediment samples were collected using standard operating procedures.

Field parameters were also measured at each water sampling station, including pH, specific conductance, temperature, redox, and flow. Flow measurements were made at sample collection stations, as well as up and downgradient of each principal inflow. Flow measurements were made using a bucket method (time to fill known volume) or measuring the height of water in a flume placed on the sill of the drift.

Investigation Results

Glengarry Adit Flow and Chemistry

Groundwater quantity and quality has been measured in outflow from the Glengarry Adit for a number of years. Outflow volume documented since 1989 has ranged from 57 Lpm (15 gpm) to 848 Lpm (224 gpm) and averages about 212 Lpm (56 gpm). Sampling during October of 2000 indicated that the water flowing into the Glengarry Mine comes from essentially three point sources and one diffuse source. **Figure 7** is a graph depicting the various points of inflow into the Glengarry Mine and the cumulative flow curve.

The point sources are the 1050 roof leak (F-8A+12), which is a major roof leak 320 meters (1050 feet) in from the portal; the bulkhead at top of the first short raise about 12 meters (40 feet) above the drift level (first or short raise, F8A+15); and the top of the second raise (Como Raise, F-8A+16) where the raise collars in the Como Basin.

The diffuse source is a collection of small, fracture-controlled roof leaks (F-8A+1, F-8A+2, and F-8A+4) developed in the bedrock between the portal and the major roof leak at 320 meters (1050 feet). Each of these sources is described in detail below and their locations are shown on **Figure 3.**

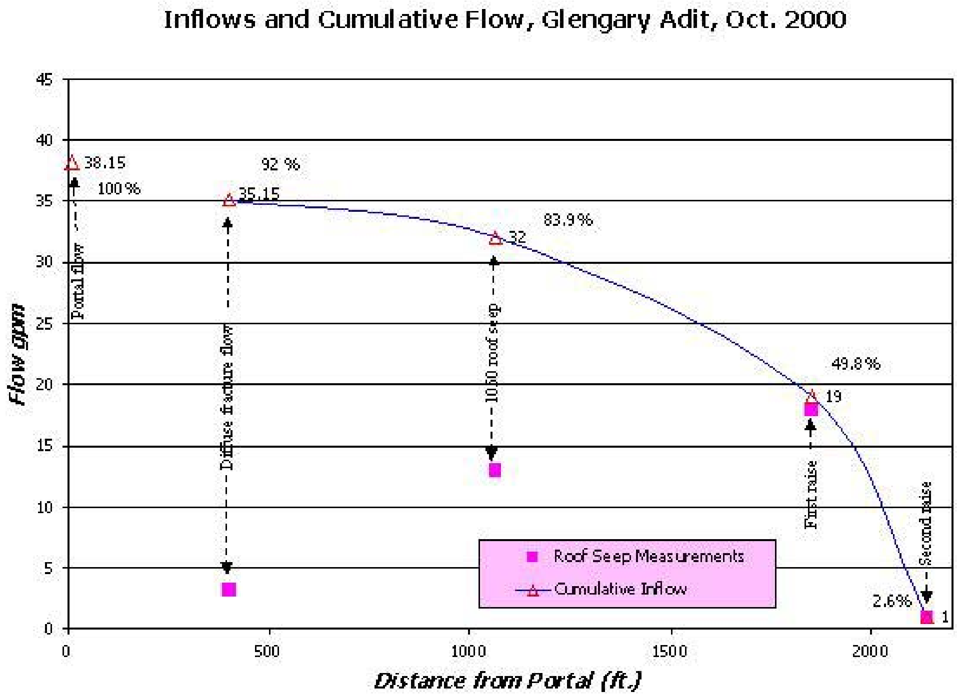


Figure 7. Water Flow in the Glengarry Adit, October 2000

<u>Como Raise</u>. Sample station F-8A+16, which collars in the Como Basin, contributes 3.8 Lpm (1 gpm) to 41 Lpm (11 gpm) of inflow. During snowmelt, most of the flow is derived from water passing through the colluvial material exposed at the surface in the Como Basin and flowing along the bedrock/colluvial surface, into and down the raise. This seasonal water flow is characterized by a pH of 3.0 standard units (s.u.), 100 to 400 milligrams per liter (mg/L) iron, and 8 to 40 mg/L copper.

<u>Short Raise</u>. Sample station F-8A+15 has a fairly constant flow in the range of 26 Lpm (7 gpm) to 68 Lpm (18 gpm) although lower flows occur in the spring prior to snowmelt. The water is characterized by a pH of 3.1 to 3.3 s.u., 47 to 93 mg/L iron, and below detection to 0.32 mg/L copper. Manganese ranging from 5 to 7 mg/L is typical of both raises.

1050 Roof Leak**.** Flow at sample station F-8A+12 varies seasonally from 9 to 49 Lpm (2.4 to 13 gpm) and is characterized by a pH of 4 to 5 s.u., 24 to 123 mg/L iron, and 0.0014 to 0.05 mg/L copper. Concentrations of aluminum (4 to 24 mg/L), arsenic (0.016 mg/L), and cadmium (0.0015 to 0.0032 mg/L), in water discharging from this structure are higher than concentrations in water discharging from the raises or diffuse leaks.

Diffuse Roof Leaks. These structures dry-up in the winter but collectively contribute up to 57 Lpm (15 gpm) during snowmelt. These leaks exhibit a pH of 3 to 6 s.u., 2 to 10 mg/L iron, and 0.001 to 0.006 mg/L copper.

Flow measured in the underground workings in October 2000 and June 25, 2001 was in the upper end of the historic range measured at the portal, ranging from 132 Lpm (35 gpm) to 189 Lpm (50 gpm). Flow measured from the fracture at the 1050 roof leak ranged from 9 Lpm (2.4 gpm) to 49 Lpm (13 gpm) during the five events, with the lowest flow measured in late winter (April 2001). Flow through the raises is more seasonal, with flows that exceed that of the 1050 roof leak during peak recharge and very little flow during the low flow period in late winter. Comparison of flow between stations during the more complete monitoring events shows the adit loses water along two stretches -- near the contact of the Precambrian and intrusive rocks, and in a zone in the diffuse fractures between 400 and 600 feet from the adit portal (**Figure 3**). The magnitude of loss is small relative to total flow from the adit, and is most evident under high flow, recharge conditions.

Glengarry Adit Concentration Trends

Variation in contaminant concentrations between sampling locations and different sampling events in the Glengarry Adit are shown for copper in **Figure 8** and iron in **Figure 9**. Changes in concentration occur between inflow sources due to differences in the chemistry of each inflow. Changes in concentration also occur seasonally within each source and the relative volume contributed by each source changes over time. Although these variations contribute to dynamic and complex trends in concentration, some general conclusions can be drawn.

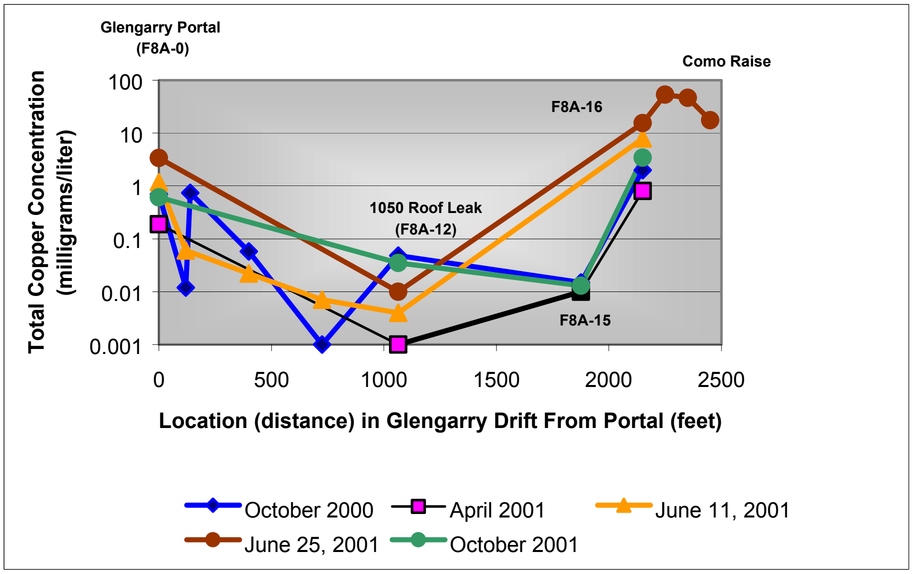


Figure 8. Total copper concentration in the Glengarry drift versus distance.

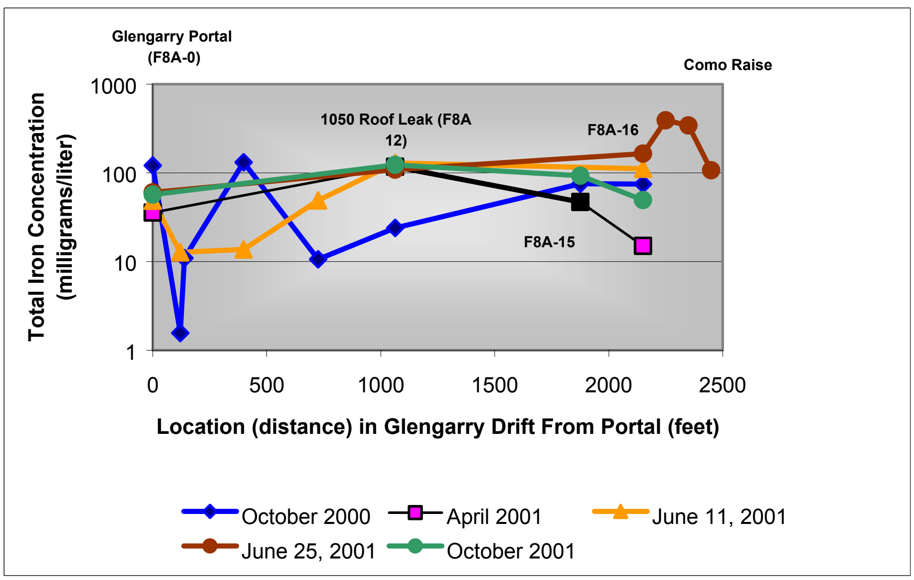


Figure 9. Total iron concentration in the Glengarry drift versus distance.

Water collected from the raise immediately below the Como Basin (F-8A-16) contains very high concentrations of arsenic, copper (**Figure 8**), aluminum, cadmium, iron (**Figure 9**), manganese, and zinc, which reflect high rates of oxidation in the massive sulfide mineralization of the Como deposit and release of aluminum from clay and feldspar alteration minerals. With the exception of inflow from the surface to the raise, flow values for these near-surface fracture controlled inflows are very low and range from 0.11 to 0.34 Lpm (0.03 to 0.1 gpm). This low apparent transmissivity may be due to strong silicification and low fracture density observed in the Meagher Limestone. Elevated concentrations of metals in water at the top of the raise do not correspond directly to metal concentrations measured at the base of the raise, however, suggesting that significant dilution or attenuation occurs between the upper workings and the adit. The metals arsenic, aluminum, and cadmium are highest in concentration in flows from the 1050 roof leak. High concentrations of copper (**Figure 8**) and manganese are observed in flow from the Como raise, and in lower concentrations in the short raise. Iron (**Figure 9**), lead, and zinc concentrations vary with flow, at times having a higher concentration in water from the raise than the 1050 roof leak, and at other times having lower concentrations than the roof leak.

Groundwater chemistry in various wells in the Como Basin can be linked to water entering the workings of the Glengarry Adit. Of the three major sources of water entering the Glengarry Adit, the 1050 roof leak is most similar to water in wells completed in late tertiary dikes. Water entering the adit from the first raise also shows characteristics similar to water in wells completed in late tertiary dikes, but appears to be influenced by a component of water originating from mineralized sediments during peak flow. Water entering the adit through the second raise has a direct surface connection with the Como Basin disturbed area. The chemistry of this water reflects equilibrium with sulfide-rich sediment.

Glengarry Adit Load Trends

Dynamic changes in metals concentration in water discharging from the adit make it difficult to evaluate potential improvements in water quality in the long term. A mass load approach, which evaluates the mass of metals in water discharging from each source over time, provides a clearer basis for identifying significant sources of contaminants.

Load analysis shows that the vast majority of loading into the adit comes from the raises and the 1050 roof leak, and not the diffuse fractures. Comparison of loading sources between elements shows that the Glengarry receives several orders of magnitude more copper from the top of the Como raise than from all the other in-flow sources combined. The raises also contribute more manganese load as well. **Figures 10 and 11** show examples of this for the copper and iron during the June 25, 2001 sampling event.

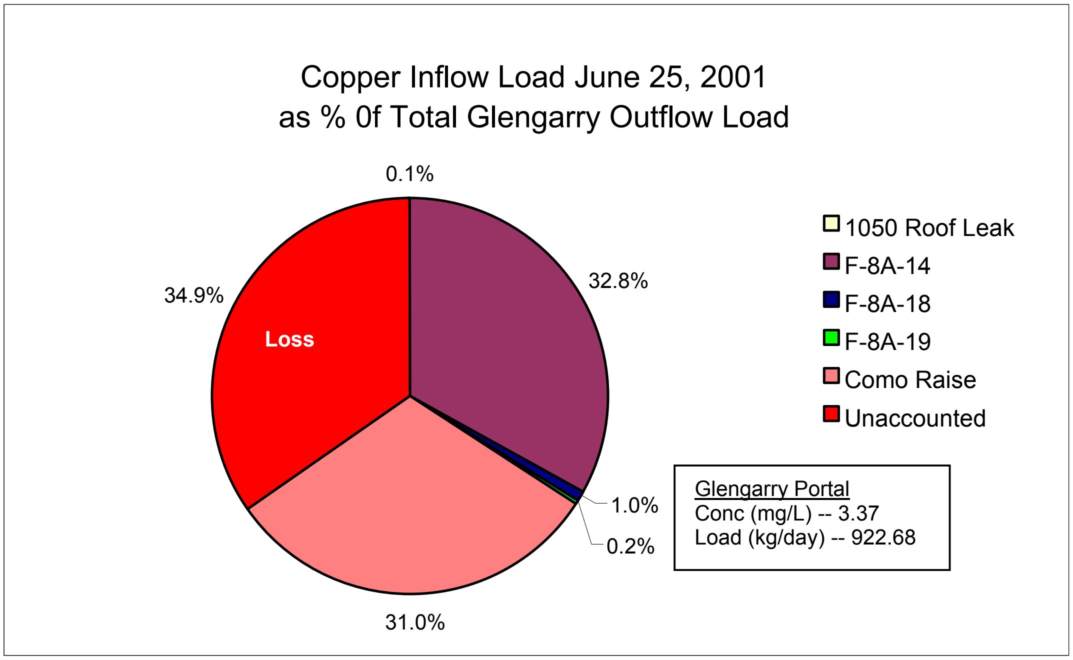


Figure 10. Total copper load as a percentage of Glengarry outflow.

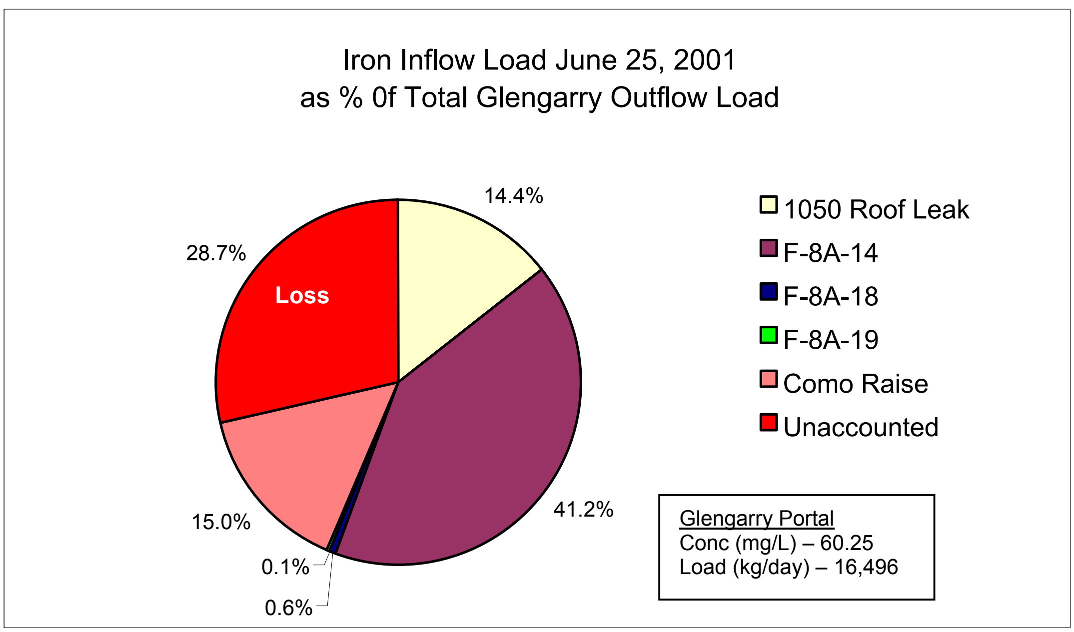


Figure 11. Total iron load as a percentage of Glengarry outflow.

The 1050 roof leak contributes more arsenic, aluminum, and cadmium load than the raises. In addition, the two raises and the 1050 roof leak each contribute at least an order of magnitude more iron loading than do the diffuse roof leaks (**Figure 11**). Comparison of the percent contribution of inflows, relative to outflow, shows that roughly equal loads of iron (**Figure 11**), lead, and zinc are released by the raises and the 1050 fracture. These results clearly show that control of discharge from the Como raises and the 1050 roof leak are most important in reducing contaminant loading from the Glengarry Adit, especially for copper and iron.

Figures 10 and 11 also show a considerable amount of load (34.9% for copper and 28.7% for iron) is lost in the mine workings before being discharged from the adit. Based on sediment sampling results and the accumulation of sediment along the sill (floor) of the mine workings, which was as deep as 1.5 meters (five feet) in places, a majority of this portion of the total load appears to precipitate as iron oxides and hydroxides.

Development and Evaluation of Closure Alternatives

The project team developed conceptual alternative for reducing or eliminating metal-laden flows from the Glengarry Adit by following EPA guidance for non-time-critical removal actions (EPA, 1993). Potential response technologies and process options were identified, screened, and then assembled into potential response alternatives in an Engineering Evaluation/Cost Analysis for the Glengarry Adit source area (Maxim, 2002). Response action alternatives for the Glengarry Adit were developed by combining cleanup technologies and process options into several alternatives that, in whole or part, fulfilled project goals and objectives for the project.

Issues associated with the Glengarry Adit source area are contaminated inflow into the underground mine workings from four specific sources. The principal impacts are contaminated outflow to both surface and groundwater in the Fisher Creek drainage. The scope of the response action was defined by the USDA-Forest Service to eliminate or reduce the uncontrolled release of metals from the Glengarry Adit. Therefore, all of the proposed alternatives for the Glengarry Adit source area involve controlling flow into and out of the mine.

Alternative Description

Table 1 summarizes the alternatives that were considered to mitigate metals loading to Fisher Creek. These alternatives are discussed in more detail below.

Table 1. Response Action Alternatives for the Glengarry Adit Source Area

Alternative	Response Technology/Process Options
GA-1 No Action	None
GA- 2 Grouting and Backfilling the Como Raise	Construct a grout curtain around the Como Raise using drilling and pressure grouting. Plug and backfill the raise.
GA-3 Grouting the Short Raise	Construct a grout curtain around the short raise using drilling and pressure grouting.
GA-4 Grouting the 1050 Roof Leak	Construct a grout curtain around the 1050 roof leak using drilling and pressure grouting.
GA-5 Backfill Various Portions of the Glengarry Drift	Backfill with cemented backfill for structural support and strength to protect grout curtains and reduce or minimize flow along a particular portion of the drift. • 5A – backfill the drift in the Fisher Mountain Porphyry • 5B - backfill the drift in the Precambrian Granite. • 5C- backfill the entire drift.
GA-6 Plug the Glengarry Drift at Critical Locations	Construct watertight concrete plugs within the Glengarry Drift.

Alternative GA-2 – Como Raise Grouting and Backfilling. Water quality data collected during 2001 shows that, during seasonal snowmelt, nearly all copper loading measured in water exiting the Glengarry Adit enters the Glengarry Mine through the Como raise. Water that enters the raise flows along the colluvial/bedrock contact, within a few meters of the surface. The purpose of Alternative GA-2 is to prevent acidic and metals-laden colluvial groundwater from entering the Como raise.

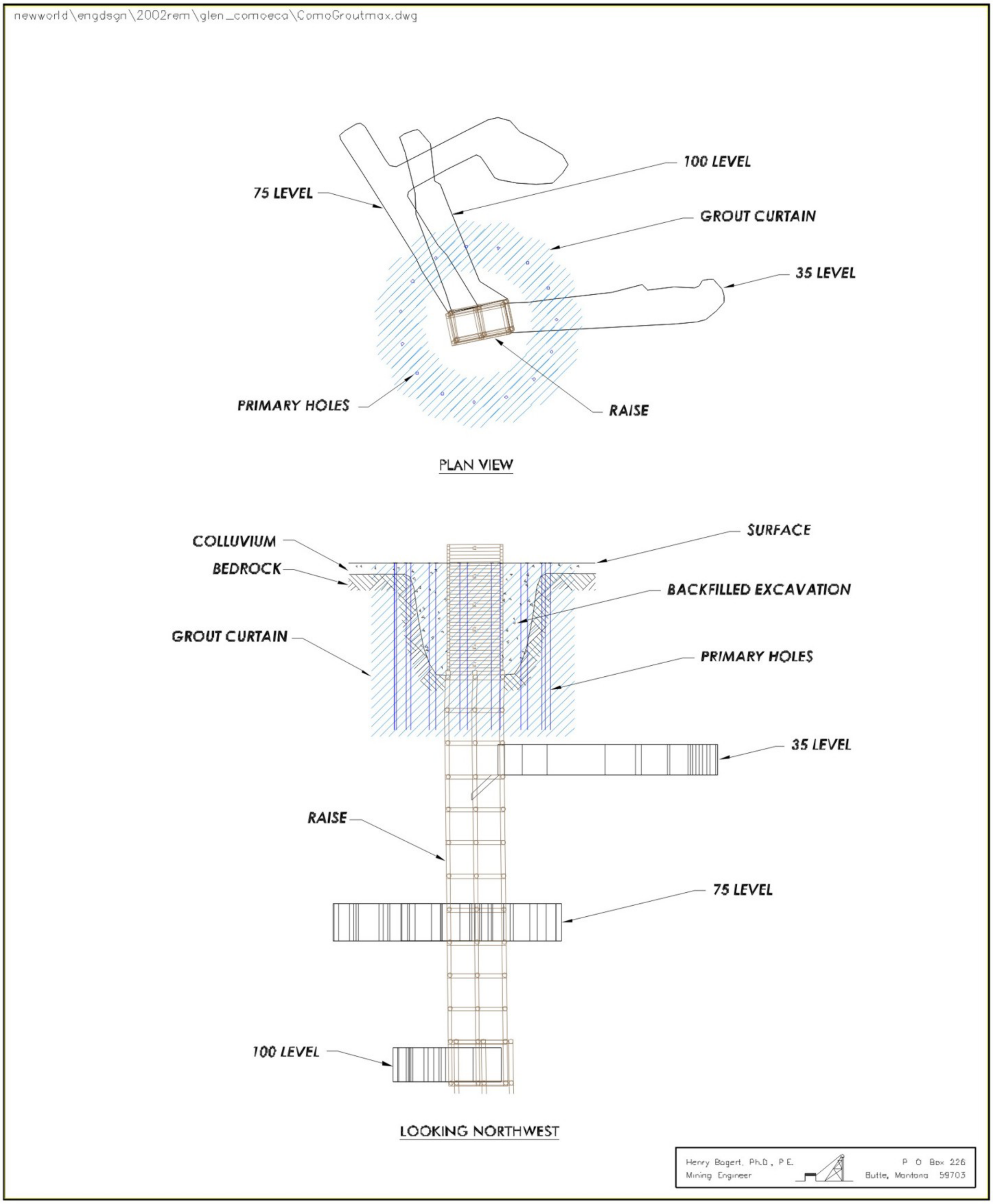
Alternative GA-2 includes drilling a ring of vertical holes three to six meters away from the raise collar, each approximately 10 meters deep (**Figure 12**). The holes will be drilled into the Meagher Limestone Formation, and grout will be pumped under pressure into the holes to form a nearly water-tight, cylindrical grout curtain around the collar of the raise. With this alternative, water flow along the colluvial/bedrock contact and into the Como raise will be significantly reduced. Upon completion of the grout curtain, the timbered Como raise will be filled with cemented backfill and a cement plug to provide structural support to the raise and to provide a second barrier to water flow down the raise (**Figure 13**).

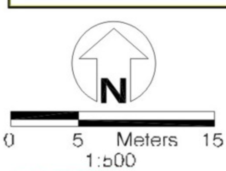
Alternative GA-3 – Grouting the Short Raise: The short raise beyond the "Y" in the Glengarry drift is a three compartment, vertical raise extending vertically upward to a bulkhead about 12 meters above the track level in the drift. Between 38 and 64 liters per minute of metals- laden water rains down through the bulkheads. Alternative GA-3 targets what is most likely a geologic structure in bedrock by drilling several holes from a drill station within the drift (**Figure 14**). The water-bearing structure will be grouted to diminish or stop the inflows from entering the top of the raise.

Alternative GA-4 – Grouting the 1050 Roof Leak: Approximately 320 meters in from the portal, water flows into the Glengarry drift at a rate of 10 to 50 Lpm through a cross cutting geologic structure. The geologic structure is completely covered by timber sets, lagging, and ferricrete deposits up to 30 centimeters thick. Geologists entering the Glengarry Mine in 1973 reported the structure as a porphyry dike with an approximate N. 35 W. strike (Kennecott, 1973).

The purpose of Alternative GA-4 is to construct a grout curtain around the drift where it passes through the porphyry dike to reduce the inflow of metals-laden water. Alternative GA-4 includes excavating two drill stations, one on each side of the porphyry dike (**Figure 15**). Holes would be drilled from the stations to intersect the dike, and grout would be pumped into fractures and voids in the dike and surrounding fractured rock mass to form an impermeable grout curtain around the Glengarry drift.

Alternative GA-5: This alternative involves filling the Glengarry drift with cemented backfill to provide structural stability to the 1050 roof leak grout curtain and to reduce water movement through the drift (**Figure 16**). There are three variations to this alternative:





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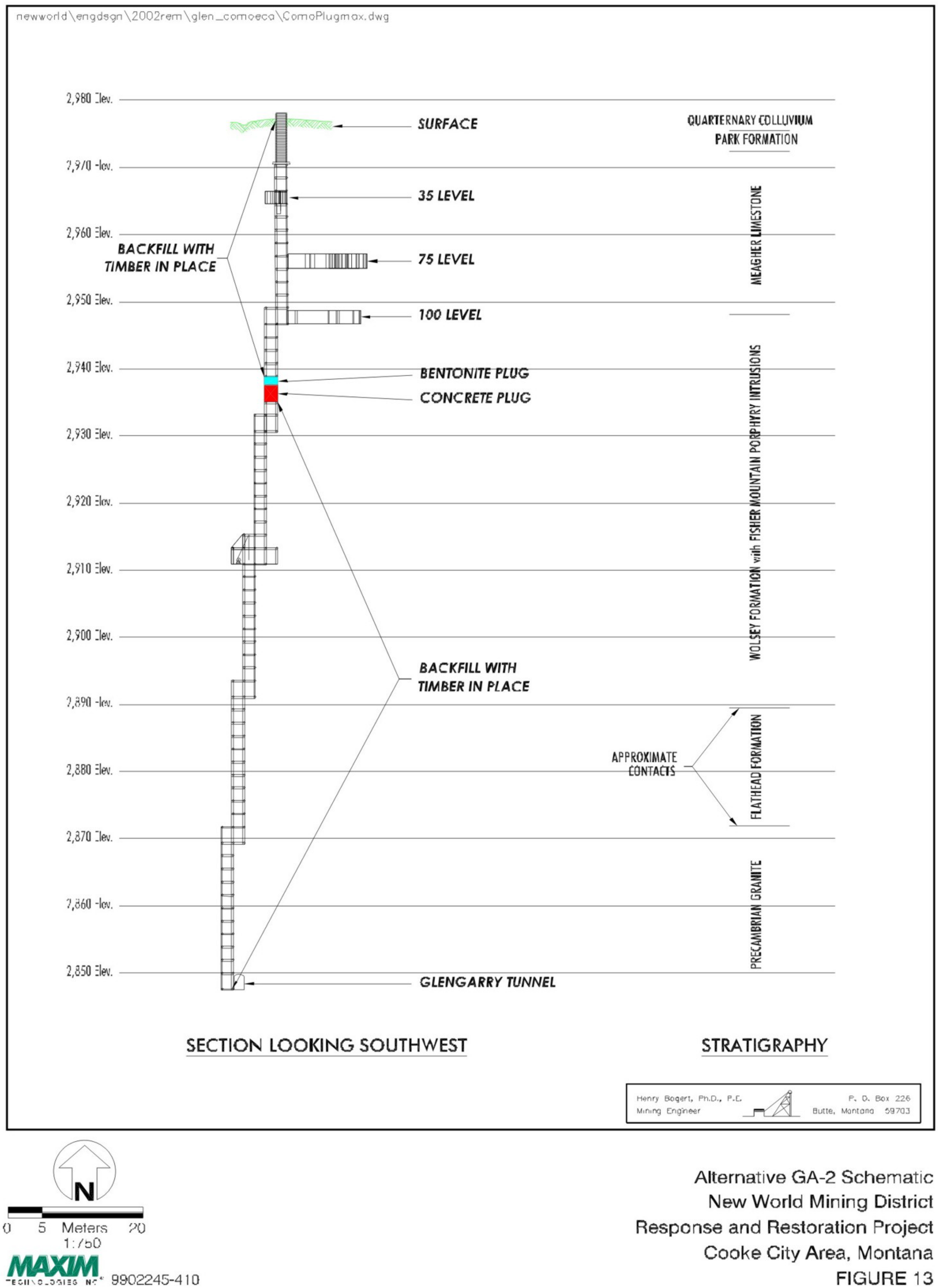
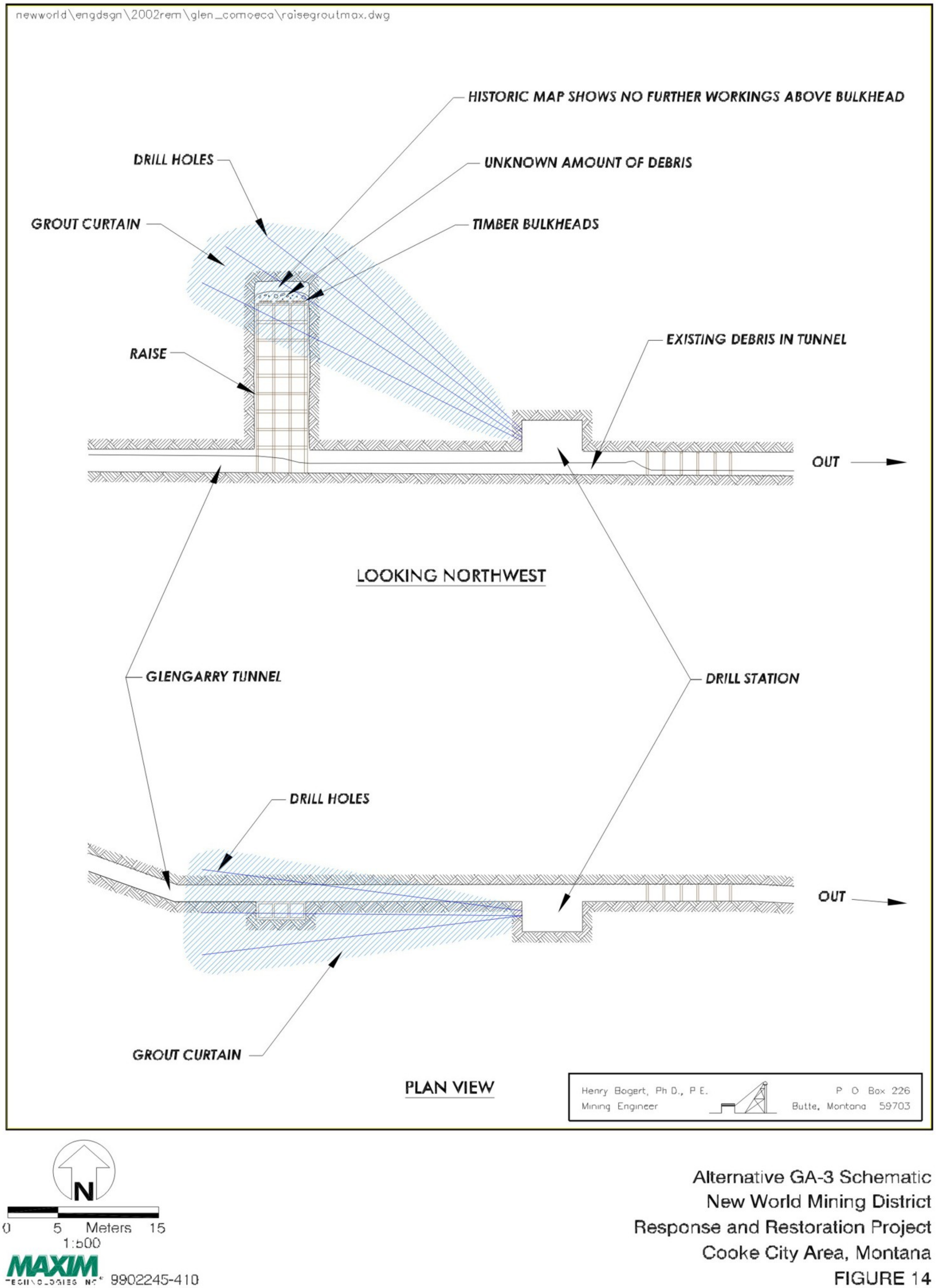
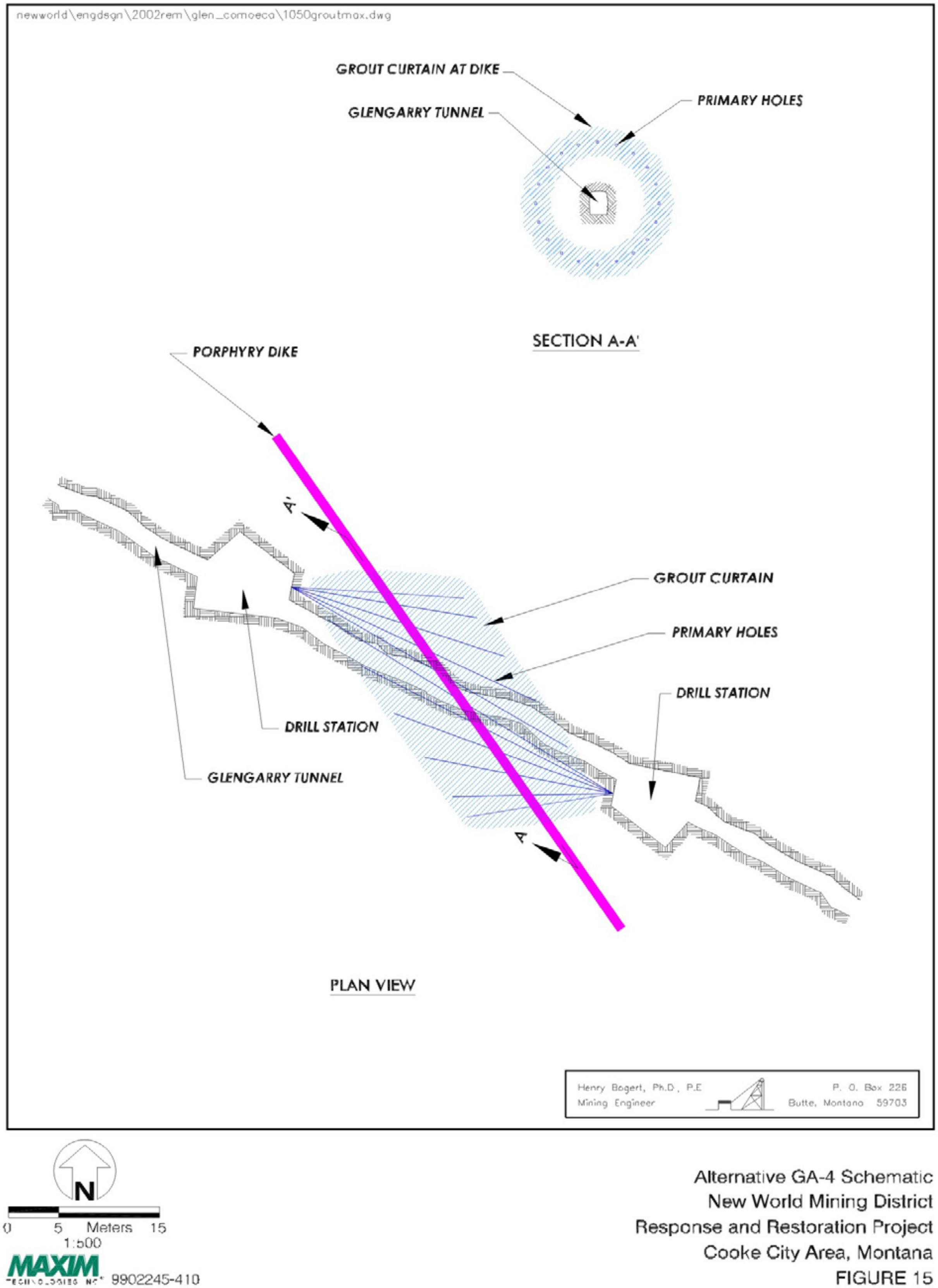
Alternative GA-2 Schematic
New World Mining District
Response and Restoration Project
Cooke City Area, Montana
FIGURE 12



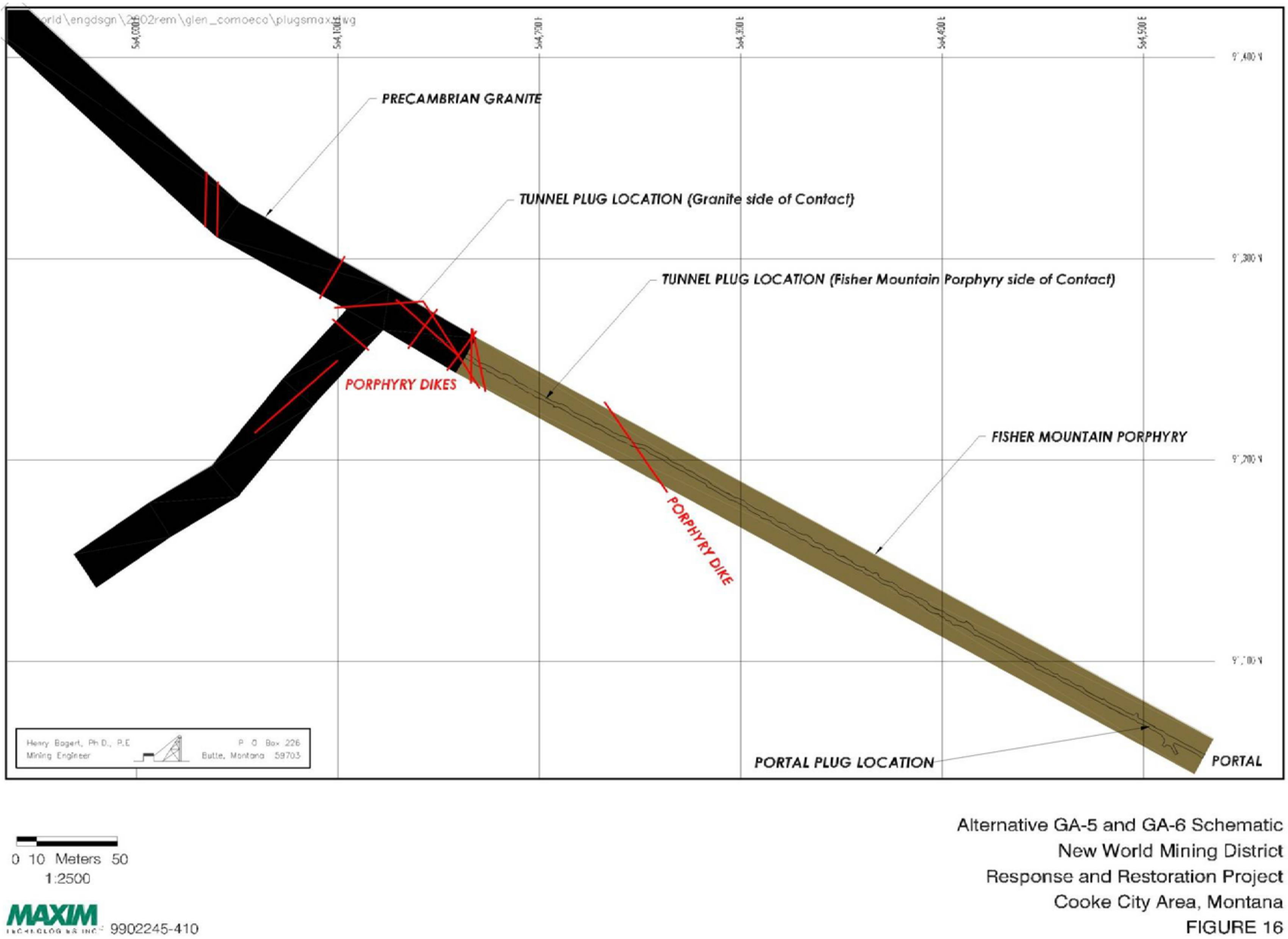
Alternative GA-2 Schematic
New World Mining District
Response and Restoration Project
Cooke City Area, Montana
FIGURE 13



Alternative GA-3 Schematic
New World Mining District
Response and Restoration Project
Cooke City Area, Montana
FIGURE 14



Alternative GA-4 Schematic
New World Mining District
Response and Restoration Project
Cooke City Area, Montana
FIGURE 15



Alternative GA-5 and GA-6 Schematic
New World Mining District
Response and Restoration Project
Cooke City Area, Montana
FIGURE 16

- GA-5A - filling the drift in the Fisher Mountain Porphyry only
- GA-5B - filling the drift only in the Precambrian Granite section.
- GA-5C- filling the entire drift.

Mine backfilling is a means of returning the underground workings as near to the pre-mining conditions as possible. Cemented backfill placed tightly to the back (roof) will eliminate future subsidence and the loosening of fractures within the rock mass adjacent to the underground opening. Backfill with a low hydraulic conductivity will limit movement of water into, within, or along backfilled mine workings.

Alternative GA-6: The primary purpose of Alternative GA-6 is to isolate the raise water from the Fisher Mountain Porphyry water, and to prevent raise water from flowing through the Glengarry drift. Alternative GA-6 also stops Fisher Mountain Porphyry water from exiting the Glengarry Adit and discharging into Fisher Creek. Alternative GA-6 includes several water-tight concrete grout plugs within the Glengarry drift (**Figure 16**). Plugs will be constructed near the Precambrian Granite/Fisher Mountain Porphyry contact, one on the Granite side and one on the Fisher Mountain Porphyry side of the contact. Another plug, located near the portal, will block Fisher Mountain Porphyry water that drains into the drift between the portal and the contact.

Preferred Alternative

The most effective means of closure for the Glengarry Mine involves a combination of alternatives that attempt to minimize mobility of contaminants as inflow and outflow from the mine. The following alternatives comprise the combined preferred alternative for the Glengarry Source Area:

- GA-2, a surface grout curtain around the Como raise collar with a concrete plug in the raise below the Meagher limestone and backfilling a portion of the raise.
- GA-4, a grout curtain around the 1050 roof leak.
- GA-5A, backfilling of the drift with cemented backfill in the Fisher Mountain Porphyry portion of the drift.
- GA-6, placement of watertight plugs and a portal plug in the Glengarry drift.

Alternative GA-2 effectively reduces the influx of metal-laden water into the Glengarry Mine and Fisher Creek by providing multiple barriers to contaminated water entering and flowing down the Como raise. The grout curtain encircling the raise collar will provide a barrier to keep shallow subsurface water flowing along the colluvial/bedrock contact from entering the raise, and cement and bentonite plugs will provide a very tight seal within the raise and below the massive sulfide-bearing portion of the Meagher Limestone. Backfilling the raise will also act as a barrier to water movement, and will eliminate the chance of future collapse of rock around the grout curtain and plug areas that could result in leakage past the plugs or failure of the grout curtain.

Other significant sources of inflow are the flow from the top of the first raise (38 to 64 liters per minute) and flow from the 1050 fracture system (10 to 50 liters per minute). These two inflow sources contribute two orders of magnitude less metals concentrations than the Como raise, but contribute a considerable iron and zinc load that exceeds water quality standards. Grouting of the 1050 roof leak will considerably reduce water inflows to the mine. Grouting of flows from the first raise is unnecessary because Alternative GA-6 seals the underground workings with a series of plugs. Water draining down the raises and entering the Glengarry drift will be stopped in the dry, low permeability rock of the Precambrian granite. A third plug located near the portal will block Fisher Mountain Porphyry water that drains into the drift between the portal and the porphyry contact.

Implementing Alternative GA-5A (backfilling various portions of the underground workings) provides structural stability and support to areas grouted and plugged under Alternatives GA-4 and GA-6. The relative impermeability of backfill will also significantly reduce flow through the backfilled portions of the workings.

Cost

Table 2 lists the costs of the Glengarry Source Area Alternatives. The combined cost for the preferred alternative (GA-2, GA-4, GA-5A, and GA-6) is about $2.7 million (US).

Table 2. Glengarry Source Area Alternatives Cost Summary

Alternative		Cost
GA-1	No Action	**$ 60,000**
GA-2	Como Raise Grouting and Backfilling	**$ 532,000**
GA-3	Grout Short Raise	**$ 694,000**
GA-4	Grout 1050 Roof Leak	**$ 620,000**
GA-5A	Backfill the Fisher Mountain Porphyry	**$ 725,000**
GA-5B	Backfill the Precambrian Granite	**$ 1,079,000**
GA-5C	Backfilling Entire Workings	**$ 1,531,000**
GA-6	Plug Glengarry Drift at Critical Locations	**$ 792,000**

Conclusion

Water quality sampling and loading analysis proved the major sources of inflow to the Glengarry Adit are the 1050 roof leak and the Como raises. The visual confirmation of these flows and the chemical loading analyses allowed the project team to develop specific alternatives to reduce or eliminate flows from a source control approach. The loading analysis was done by determining the range of reduction in flow for each alternative, and multiplying the flow reduction by analyte concentrations to determine the annual load of each analyte in kilograms per year. This load reduction was then divided by the total existing load by analyte to determine the percent decrease in load that could be attributed to each alternative.

If the preferred closure method works as planned and eliminates contributions of metals from groundwater in the vicinity of the underground workings, nearly all copper and iron loading to Fisher Creek will be eliminated during low flow periods. Under high flow conditions, which occurs from about mid-May to mid-June, when other sources of groundwater and tributary flows contribute metals loading to Fisher Creek, effectiveness of the Glengarry Adit closure may drop to 25% for copper and 60% for iron. If the closure does not eliminate all flows, the effectiveness of the closure on reducing copper and iron loads to Fisher Creek could drop to as low as 20% for both metals under low flow conditions.

A design for the preferred alternative was completed in December 2002, and a construction contract is expected to be awarded in spring 2003. The project will be completed over two construction seasons, with completion scheduled for fall 2004. Following implementation of the preferred alternative, monitoring will be conducted to document project success. Depending on the results of monitoring, further response actions may be evaluated to ensure project objectives are met.

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Literature Cited

Amacher, M.C., 1998. Metal Loadings and Metals in Sediments and Wetland Soils in the Fisher and Daisy Creek Catchments in the New World Mining District, Montana. A Draft Assessment Report Prepared for USDA-FS Region 1 and the USEPA. Forestry Sciences Laboratory, USDA-FS-RMRS, Logan, Utah. January.

Bogert, 2001. Technical Memorandum: Reopening and assessment of the Glengarry Mine in 2001 and Assessment of the Glengarry Dump as Potential Backfill. Prepared for USDA Forest Service, Northern Region, Missoula, Montana. November 15.

Elliott, J. E., Kirk, A. R., and Johnson, T. W., 1992, Gold-Copper-Silver deposits of the New World District in Elliott, J. E., ed., Guidebook for the Red-Lodge-Beartooth Mountains – Stillwater area, 17th Annual Field Conference: Missoula, MT, Tobacco Root Geological Society, p 1-19.

Elliott, J. E., 1979, Geologic Map of the southwest part of the Cooke City quadrangle, Montana and Wyoming, US Geological Survey Miscellaneous Investigation Series, no. I-1084, scale 1:24,000.

Environmental Protection Agency (EPA), 1993, Guidance on Conducting Non-Time-Critical Removal Actions Under CERCLA, EPA/540-R-93-057, Office of Emergency and Remedial Response, Washington, D.C.

Kennecott Exploration Inc. - Exploration Services, 1973, "Geologic Sketch Map of Lower Glengarry Adit, New World District, Park Co., Montana."

Kimball, B.A., D.A. Nimick, L.J. Gerner, and R.L Runkel, 1999. Quantification of Metal Loading in Fisher Creek Using Tracer-Injection and Synoptic Sampling Studies, Park County, Montana, August 1997. Water Resources Investigations Report 99-4119. U.S. Geological Survey. Prepared in cooperation with the USEPA.

Lovering, T. S. 1929, The New World of Cooke City Mining District, Park County, Montana; US Geological Survey Bulletin 811, p. 1-87.

Maxim Technologies, Inc., 2002. Como Basin/Glengarry Adit/Fisher Creek Response Action Engineering Evaluation/Cost Analysis, New World Mining District Response and Restoration Project. Draft. Prepared for USDA Forest Service, Northern Region, Missoula, Montana, June.