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

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Abstract: The Glengarry adit is an underground gold mine developed between 1925 and 1934 in the New World Mining District of south-central Montana. The adit has been a historic source of metals-laden, acidic water that discharged into Fisher Creek, a major tributary to the headwaters of the Yellowstone River. The adit discharge contributed more than 30 percent of the metals load to Fisher Creek, had an average historical flow of about 363 L/min (80 gpm), Cu and Fe concentrations near 7 and 78 ppm respectively, and a pH of 2.2. The USDA-Forest Service undertook a rehabilitation and closure project to address this adit discharge in 2000, with a goal of minimizing or eliminating this discharge.

Assessment included reconditioning 915 meters of underground workings and characterizing water inflows. Four principal sources of water inflows were identified. Chemical mass loading analysis allowed quantification of the impact of each of these sources to surface water quality, as well as a means of evaluating effectiveness of potential closure options. Closure alternatives considered included plugging, containing, or diverting water-flows. Engineering design work on the selected alternative was completed in 2002 and a contract awarded in 2003. Closure consisted of a combination of surface and underground grouting of water-bearing fractures and faults, selective backfilling of three segments of the underground workings, and strategic placement of five water-tight underground adit and raise plugs. A non-water tight portal plug was also constructed. Closure work was completed in 2005 and resulted in an average metals concentration reduction of 83 percent, a metal load reduction of 99.8 percent and an adit discharge flow reduction of 97 percent.

The closure method used at the Glengarry Mine offers an effective approach considered to be a walk-away solution to handling sources of contamination from adit outflows. No future operational, maintenance, or treatment costs are anticipated. A long-term district-wide program to monitor water quality and aquatic health will be implemented once other reclamation construction projects in the District are complete.

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[1] Paper was presented at the 2008 National Meeting of the American Society of Mining and Reclamation, Richmond, VA, ***New Opportunities to Apply Our Science*** June 14-19, 2008. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502

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Proceedings America Society of Mining and Reclamation, 2008 pp 628-661
DOI: 10.21000/JASMR08010628
http://dx.doi.org/10.21000/JASMR08010628

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 (Fig. 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 mining related and other naturally occurring features related to acid rock drainage (ARD) that are pertinent to mine waste cleanup activities. These features include: massive sulfide deposits exposed at the surface; regionally distributed geologic units and mineral deposits enriched in pyrite and chalcopyrite; abandoned mines; hard rock mining wastes; acid discharges from mine wastes and abandoned mine workings; and various sources of 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. The USDA-Forest Service undertook the assessment and closure of the Glengarry Adit as part of its reclamation activities in the District, by addressing the adits acidic, metal-laden adit discharge to surface water, with a goal of minimizing or eliminating this discharge.

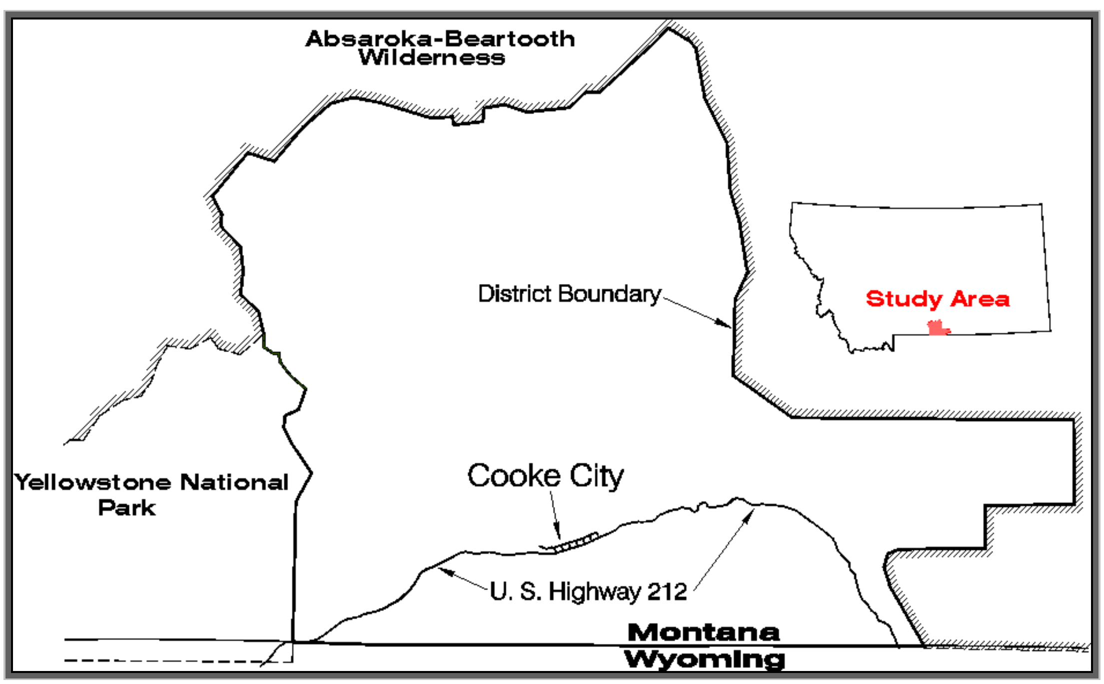

Figure 1. Location Map.

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 funds available 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, analyzing surface water and groundwater samples, using surface water and groundwater tracer studies to define migration pathways, mine waste sampling, metals loading calculations 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 m (7,900 ft) to over 3,200 m (10,400 ft) 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 features created by glacial erosional and depositional features. 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 principal drainages in the District, Fisher Creek, Daisy Creek, and Miller Creek. The Glengarry Adit, the focus of this investigation, is located in Fisher Creek. Figure 2 shows relevant features in the headwaters of Fisher Creek.

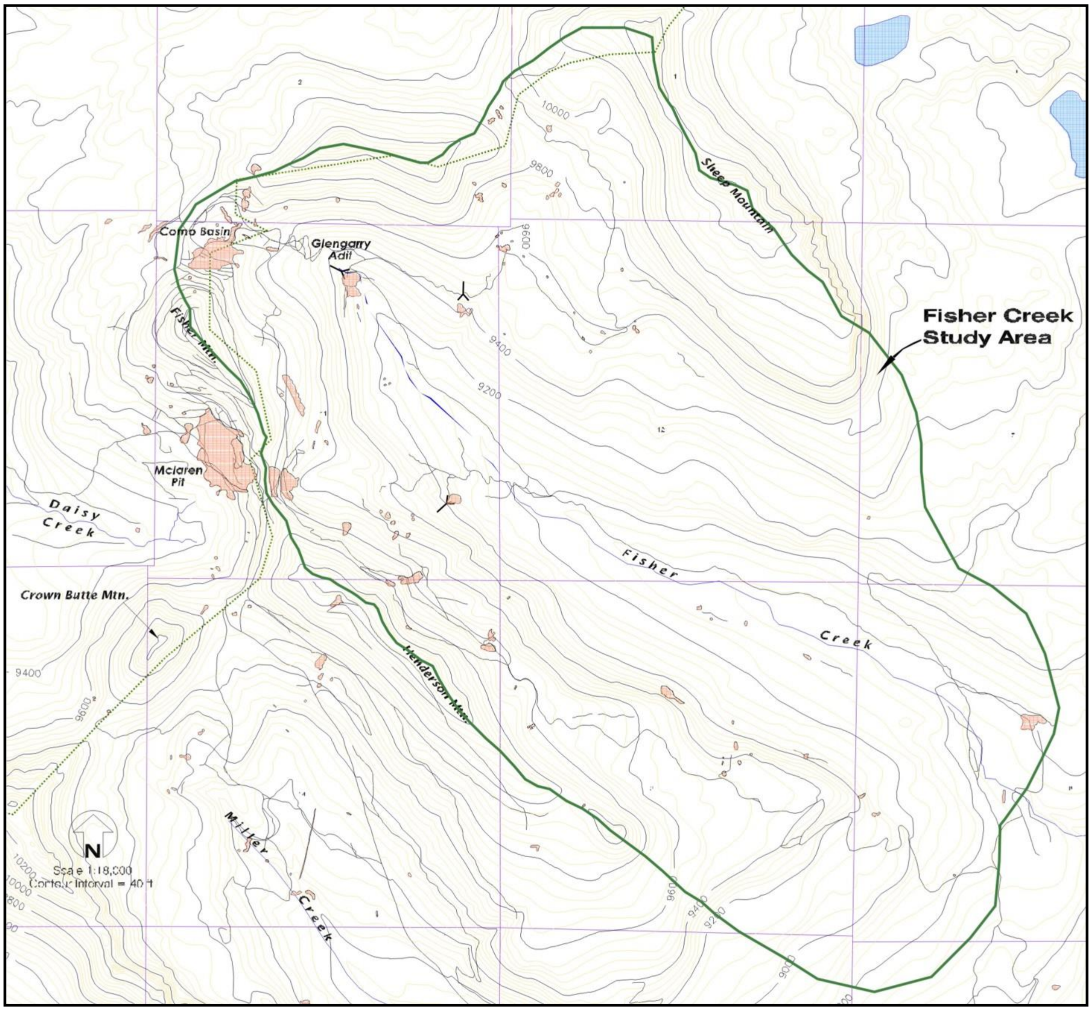

Figure 2. Fisher Creek Vicinity Map. Hatched areas are mine waste deposits.

The Glengarry Adit discharged 57 liters per minute (Lpm) to 848 Lpm (15 to 224 gallons per minute [gpm]) of low pH, Fe-, Zn-, and Cu-bearing water into Fisher Creek. Current estimates of metal loads contribution to Fisher Creek indicate the Glengarry discharge makes up about 30% of the total Cu load in the creek, which, during base flow conditions, is 28 mg s^{-1} (2.4 kg/day)(Amacher, 1998); Kimball, et al, 1999). This input, along with other sources, rendered poor quality water that is uninhabitable or detrimental 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. In 1876, the Eastern Montana Mining and Smelting Company constructed a smelter in the Cooke City area; and, 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.

The Glengarry Mining Company drove the Glengarry Adit (near horizontal mine workings driven from the surface) in 1925 (Lovering, 1929) some 700 m (2,300 ft). No mineralization was found in this drift. Later, in the mid 1930's, a southwest heading was driven from an underground location about two thirds of the way in from the portal some 183 m (600 ft) to a location beneath the massive sulfide deposit of the Como Basin, and two sets of raises (raises are shafts constructed from the bottom up) driven towards the surface from this drift. The furthest raise terminated at the surface about 130 m (425 ft) above the adit level, near the top of the Como deposit (Fig. 2). Based on old maps, the near raise appears to have been abandoned after raising some 12 m (40 ft) above the floor of the drift. Figure 3 shows a cross-sectional view of the underground workings.

Project Objectives

There are several overall project objectives for the response and restoration project. The principal objective of this study was to gain access to the Glengarry Mine's underground workings to examine the location and character of groundwater inflow. 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

By identifying the principal locations and associated metal loads of inflows into the adit, potential mitigation measures directed at reducing or eliminating the acid discharge from the Glengarry into Fisher Creek could be evaluated.

The Glengarry adit was rehabilitated for assessment purposes in the fall of 2000 (Fig. 3). Accumulated debris, including rail and ties, and ferricrete mud 0.6 to 1.5 m (2 to 5 ft) deep were removed from the drift beginning at the portal and extending back to the "Y" intersection 470 m (1540 ft) in from the portal (surface entrance to an adit) (Fig. 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, the raise that extends into the Como Basin was opened and rehabilitated to a depth of 65 m (215 ft), providing access to a point well below the base of the Meagher Limestone, the massive sulfide host unit. 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.

Underground water quality samples were collected from numerous stations within the Glengarry Mine and water inflows were measured and sampled at the collar of the raise and from exploration level drifts off the raise during 2000 and 2001. Field parameters measured at each water sampling station, included pH, specific conductance, temperature, redox, and flow. Flow measurements were made at sample collection stations, as well as up and downgradient of each principal mine inflow. Analytical parameters included pH, specific conductance, common ions, nutrients, and dissolved and total metals. Samples were collected and shipped to the laboratory following standard protocols. The laboratory used various EPA methods for chemical analysis of water. In addition, sediment samples collected from the sill (floor) of the drift were analyzed for total metals.

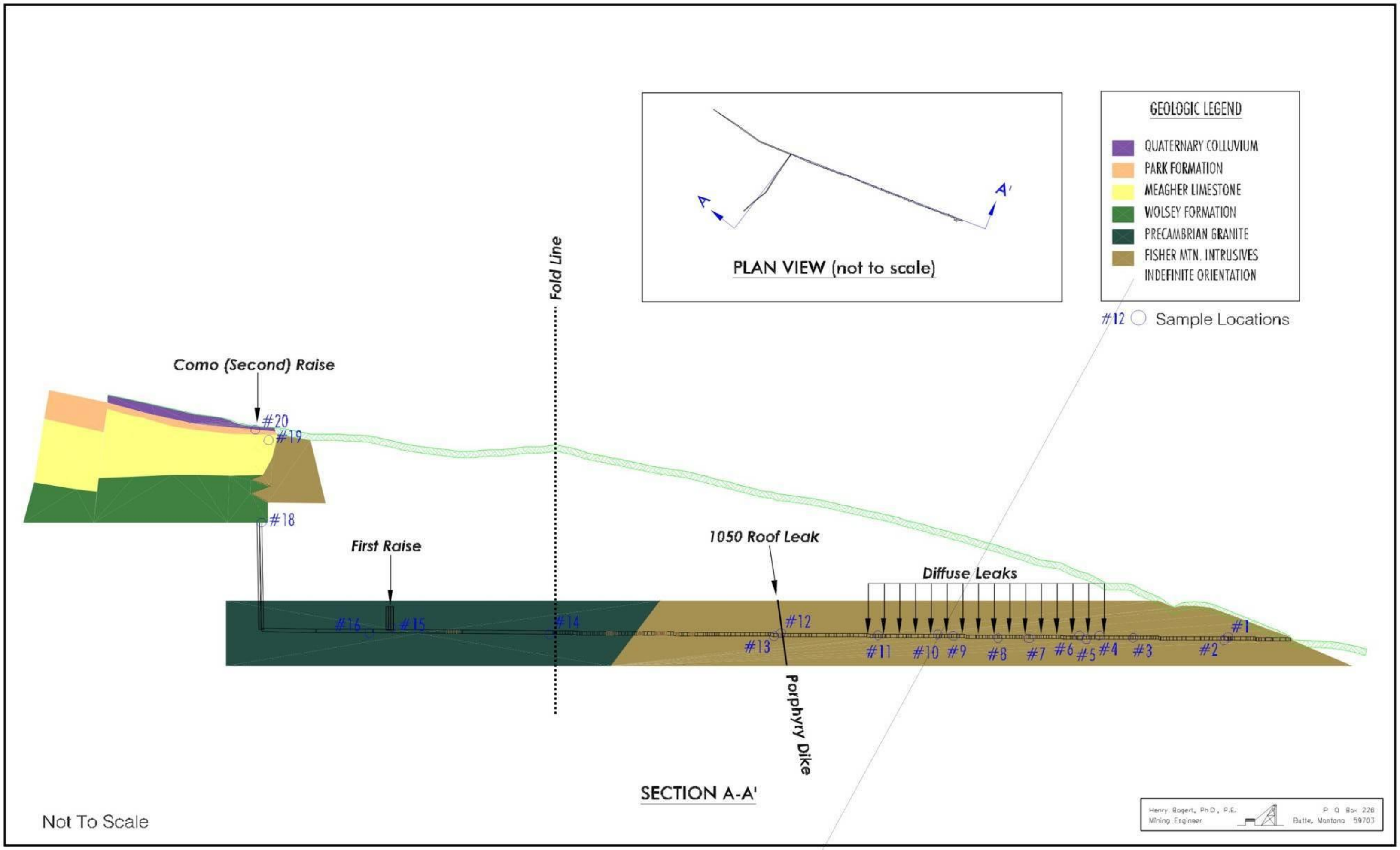

Figure 3. Cross-Section of the Glengarry Mine.

Figure 4. Ferricrete Stalactites in the Glengarry Drift.

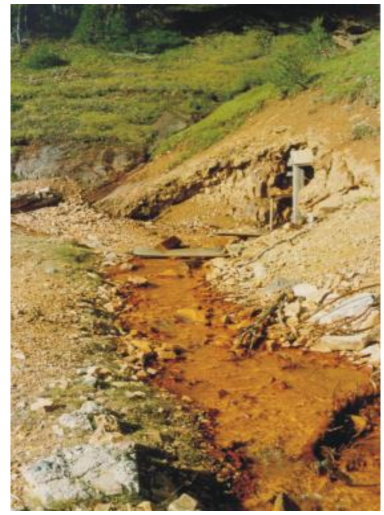

Figure 5. Glengarry Outflow.

Figure 6. Glengarry Portal.

Investigation Results

Glengarry Adit Flow and Chemistry

Groundwater quantity and quality has been measured in outflow from the Glengarry Adit from 1989 to 2008. Outflow volume documented since 1989 has ranged from 57 Lpm (15 gpm) to 848 Lpm (224 gpm) and averages about 363 Lpm (80 gpm). A synoptic sampling event in October of 2000 indicated that the water flowing into the Glengarry Adit comes principally from three point sources and one combined diffuse source. Figure 7 identifies the various points of inflow into the Glengarry Mine and the cumulative flow curve for the synoptic event.

The point sources are the 1050 roof leak (#12, Fig. 3), which is a major fault controlled roof leak 320 m (1050 ft) in from the portal; the bulkhead at top of the first short raise about 12 m (40 ft) above the drift level (measured on the sill (floor) of the first or short raise, #15, Fig. 3); and the top of the second raise (measured in 2000 on the sill (floor) of the second (Como) raise #16, Fig. 3) where the raise collars (the top of a raise, in this case at the surface) in the Como Basin.

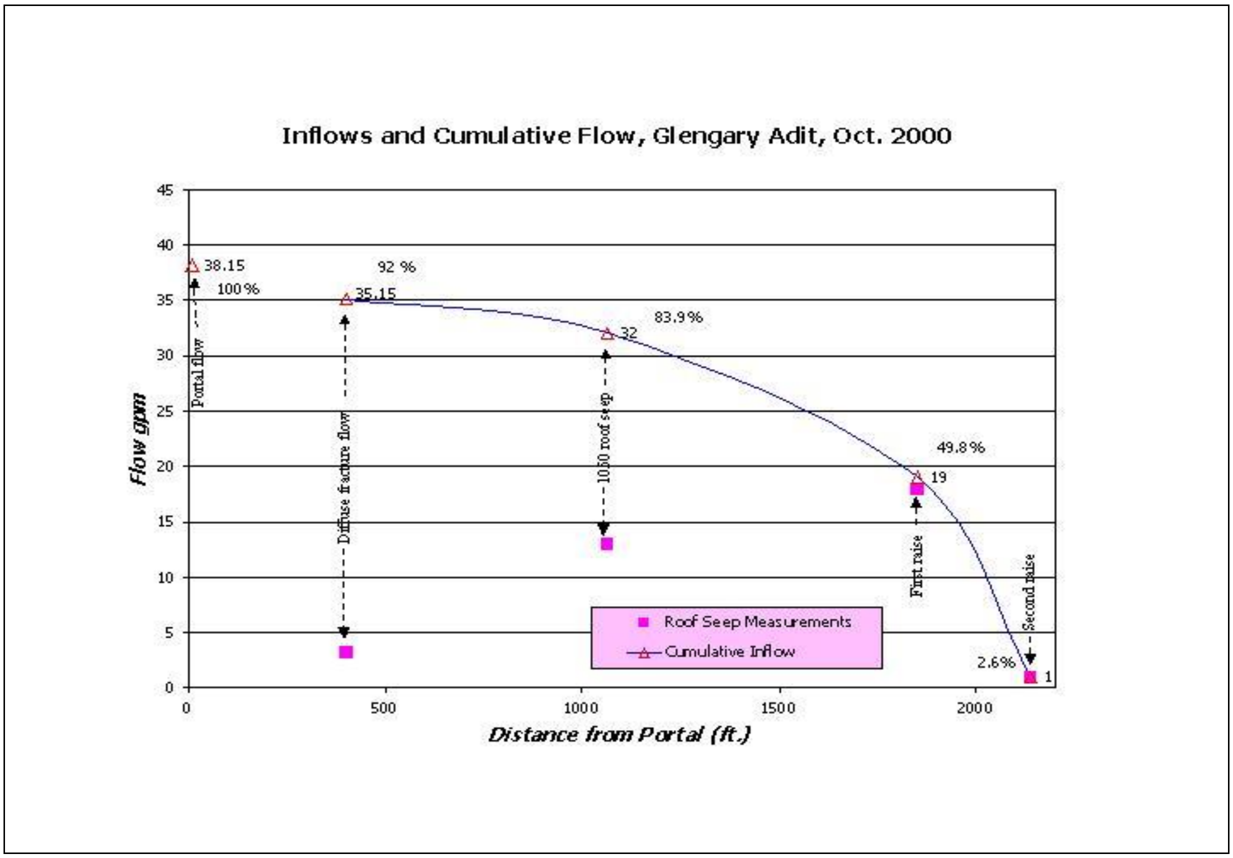

Figure 7. Water Flow in the Glengarry Adit, October 2000.

The diffuse source is a collection of small, fracture-controlled roof leaks (#4 through #11, Fig. 3) developed in the bedrock between the portal and the major roof leak at 320 m (1050 ft). Each of these sources is described below including observed ranges of flow and metal concentration data. The sample locations are shown on Fig. 3**.**

Como Raise. Sample station #20 (Fig. 3) 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) Fe, and 8 to 40 mg/L Cu.

Short Raise. Sample station #15 (Fig. 3) has a 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 Fe, and below detection to 0.32 mg/L Cu. Manganese ranging from 5 to 7 mg/L is typical of both raises.

1050 Roof Leak**.** Flow at sample station #12 (Fig. 3) varies seasonally from 9 to 49 Lpm (2.4 to 13 gpm) with the lowest flow measured in late winter. The water is characterized by a pH of 4 to 5 s.u., 24 to 123 mg/L Fe, and 0.0014 to 0.05 mg/L Cu. Concentrations of Al (4 to 24 mg/L), As (0.016 mg/L), and Cd (0.0015 to 0.0032 mg/L), in water discharging from this fault structure are higher than concentrations in water discharging from the raises or diffuse leaks.

Diffuse Roof Leaks. These relatively near surface fault and fracture structures (#4-11, Fig. 3) dry-up in the winter but collectively contribute as much as 57 Lpm (15 gpm) during snowmelt. These leaks exhibit a pH of 3 to 6 s.u., 2 to 10 mg/L Fe, and 0.001 to 0.006 mg/L Cu.

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 ft from the adit portal (Fig. 3). The magnitude of loss is small relative to total flow from the adit.

Glengarry Adit Concentration Trends

Variation in contaminant concentrations between sampling locations and different sampling events in the Glengarry Adit are shown for Cu in Fig. 8 and Fe in Fig. 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.

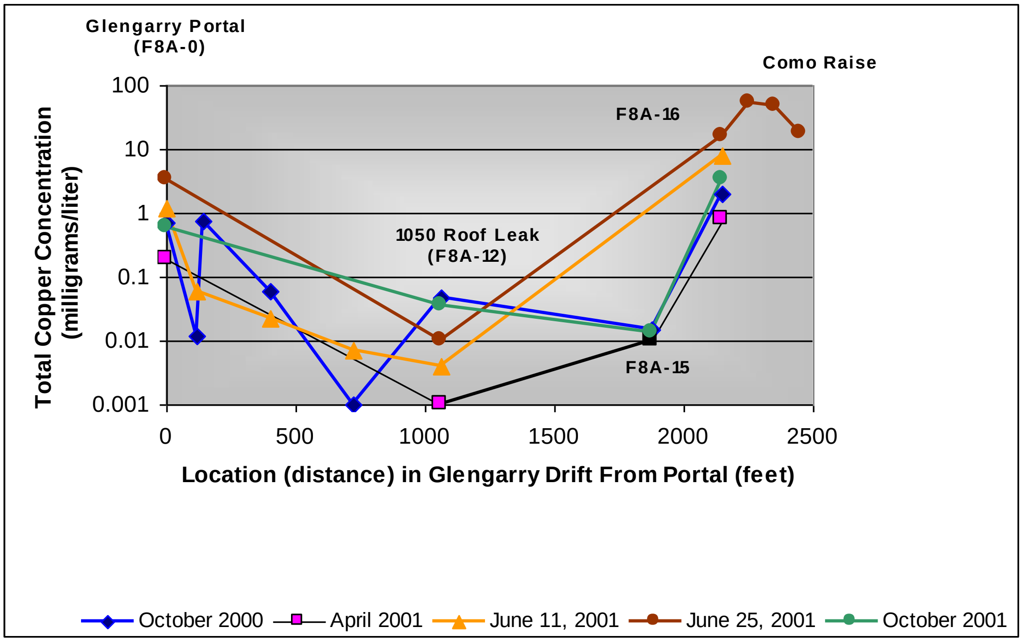

Figure 8. Total Cu concentration in the Glengarry drift versus distance.

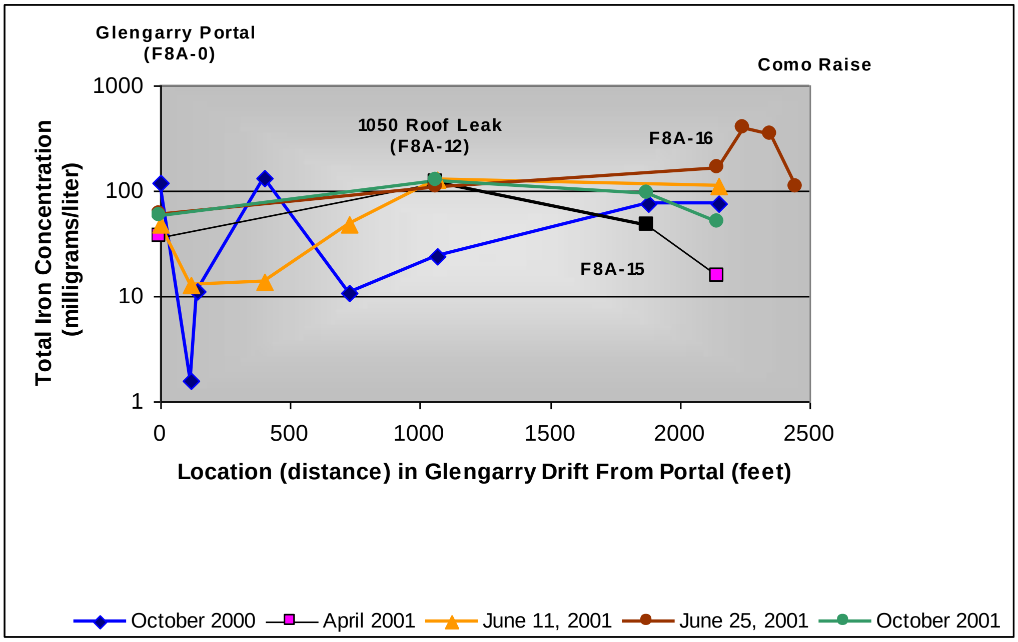

Figure 9. Total Fe concentration in the Glengarry drift versus distance.

Water collected from the raise immediately below the Como Basin at the adit level (#16, Fig. 3) contains high concentrations of Cu (Fig. 8) and Fe (Fig. 9) (also As, Al, Cd, Mn, and Zn; not illustrated), which reflect high rates of oxidation and metal release from the massive sulfide mineralization of the Como deposit and release of Al from clay and feldspar alteration minerals. More 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 some dilution or attenuation occurs between the upper raise workings and the adit level. High concentrations of Cu (Fig. 8) and manganese are observed in flow from the Como raise, and in lower concentrations in the short raise.

With the exception of inflow from the bedrock/colluvial interface to the raise, flow values in the vicinity of the raise collar for near-surface fracture controlled inflows (as measured at various exploration levels driven off of the raise) are very low and range from 0.11 to 0.34 Lpm (0.03 to 0.1 gpm) (#19 and #18, Fig. 3). This low apparent transmissivity may be due to strong silicification and low fracture density observed in the Meagher Limestone.

The metals As, Al, and Cd (not illustrated) are highest in concentration in flows from the 1050 roof leak. Iron (Fig. 9), Pb, and Zn concentrations vary with flow, at times having a higher concentration in water from the Como 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 regional groundwater in wells completed in late tertiary intrusives. Water entering the adit from the first raise also shows characteristics similar to water in wells completed in tertiary intrusives, but appears to be influenced by a component of water originating from massive sulfide mineralization during high flow. Water entering the adit through the second raise has a direct surface connection with the Como Basin massive sulfide deposit and the associated disturbed surface area. The chemistry of this water reflects contamination with acidity and metals released from sulfide-rich sediment hosted deposits.

<u>Glengarry Adit Metal Load Trends</u>

Dynamic changes in metals concentration in water discharging from the adit portal and individual point sources within the mine 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 (flow x concentration), provides a clearer basis for identifying significant sources of contaminants as well as a mechanism for evaluating overall load reduction to surface waters from the adit discharge.

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 Cu from the top of the Como raise than from all the other in-flow sources combined. The raises also contribute a larger Mn load as well. Figures 10 and 11 illustrate this for the Cu and Fe during the June 2001 sampling event.

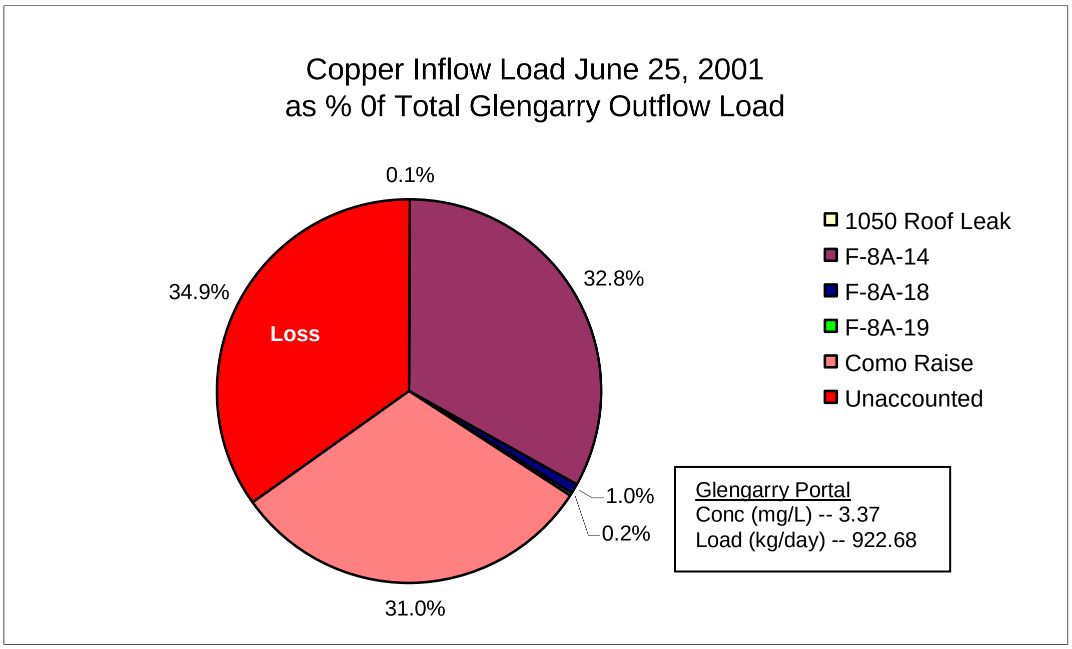

Figure 10. Total copper load as a percentage of Glengarry outflow.

The 1050 roof leak contributes more As, Al, and Cd load than the raises. In addition, the two raises and the 1050 roof leak each contribute at least an order of magnitude more Fe loading than does the diffuse roof leaks (Fig. 11). Comparison of the percent contribution of inflows, relative to outflow, shows that roughly equal loads of Fe (Fig. 11), Pb, and Zn are released by the raises and the 1050 fracture. These results clearly show that control of discharge from the Como raise and the 1050 roof leak are most important in reducing contaminant loading from the Glengarry Adit, especially for Cu and Fe.

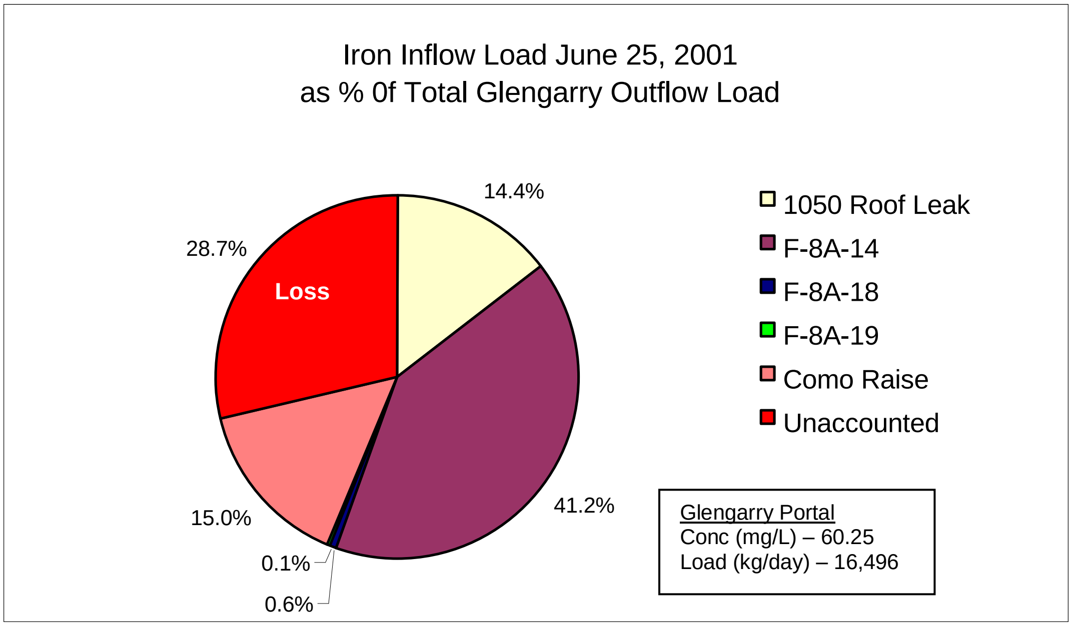

Figure 11. Total iron load as a percentage of Glengarry outflow.

Figures 10 and 11 plot the Fe and Cu mine inflow loads as a percentage of mine outflow loads and document that a considerable amount of load (34.9% for Cu and 28.7% for Fe) is lost in the mine workings before the water is 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 m (5 ft) in places, a majority of this portion of the total load appears to precipitate as iron oxides and hydroxides that likely adsorb other metals to their surfaces.

Development and Evaluation of Closure Alternatives

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 project team developed conceptual alternatives 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 compiled 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.

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.

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.

Selected 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 selected 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 the portion of the raise above the plug.
- 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 contaminate water entering and flowing down the Como raise. The grout curtain encircling the raise collar provides 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 water 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 Lpm) and flow from the 1050 fracture system (10 to 50 Lpm). These two inflow sources contribute two orders of magnitude less metals concentrations than the Como raise, but contribute a considerable Fe and Zn load that exceeds water quality standards. Grouting of the 1050 roof leak, Alternative GA-4, considerably reduces 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

The estimated combined cost for the preferred alternative (GA-2, GA-4, GA-5A, and GA-6) at the design phase was about $2.7 million (US).

Implementation of Closure Alternatives

Closure of the Glengarry Mine was proposed as a two-year construction project. A contract was awarded to Hayward Baker, Inc. (HBI) of Denver, CO on April 1, 2003, based on a best value determination associated with the bid price of $2,949,623. Construction was completed over a three-year period, with the first phase completed in 2003 with the grouting of the Como Raise collar at the surface and grouting a major fault in the main Glengarry tunnel. Construction work completed in 2004 and 2005 involved pouring a watertight cement plug in the Como Raise, backfilling the raise, and placing four watertight plugs and three backfilled segments in the main Glengarry tunnel. A portal plug consisting of earthen backfill was placed at the surface and graded to blend with the surrounding topography. The final contract amount was $3,281,597. Details of the project's construction activities, differences between design and actual implementation, and contract changes are presented in the following sections.

Grouting the Como Raise Collar

The purpose of the Como Raise grouting program was to place an impermeable grout curtain in the colluvial soils and upper portions of the fractured bedrock around the raise collar. The raise grout curtail was constructed during August and September of 2003. The contract's proposed method of installation of the grout curtain called for drilling 7.5 cm (3 in) diameter holes through the colluvium and fractured near surface bedrock and then using permeation grouting or jet grouting. Due to the nature of the clay rich colluvium, these grouting techniques were not viable, and a different grouting program was implemented. The construction of the raise grout collar curtains is described below and illustrated in Fig. 12.

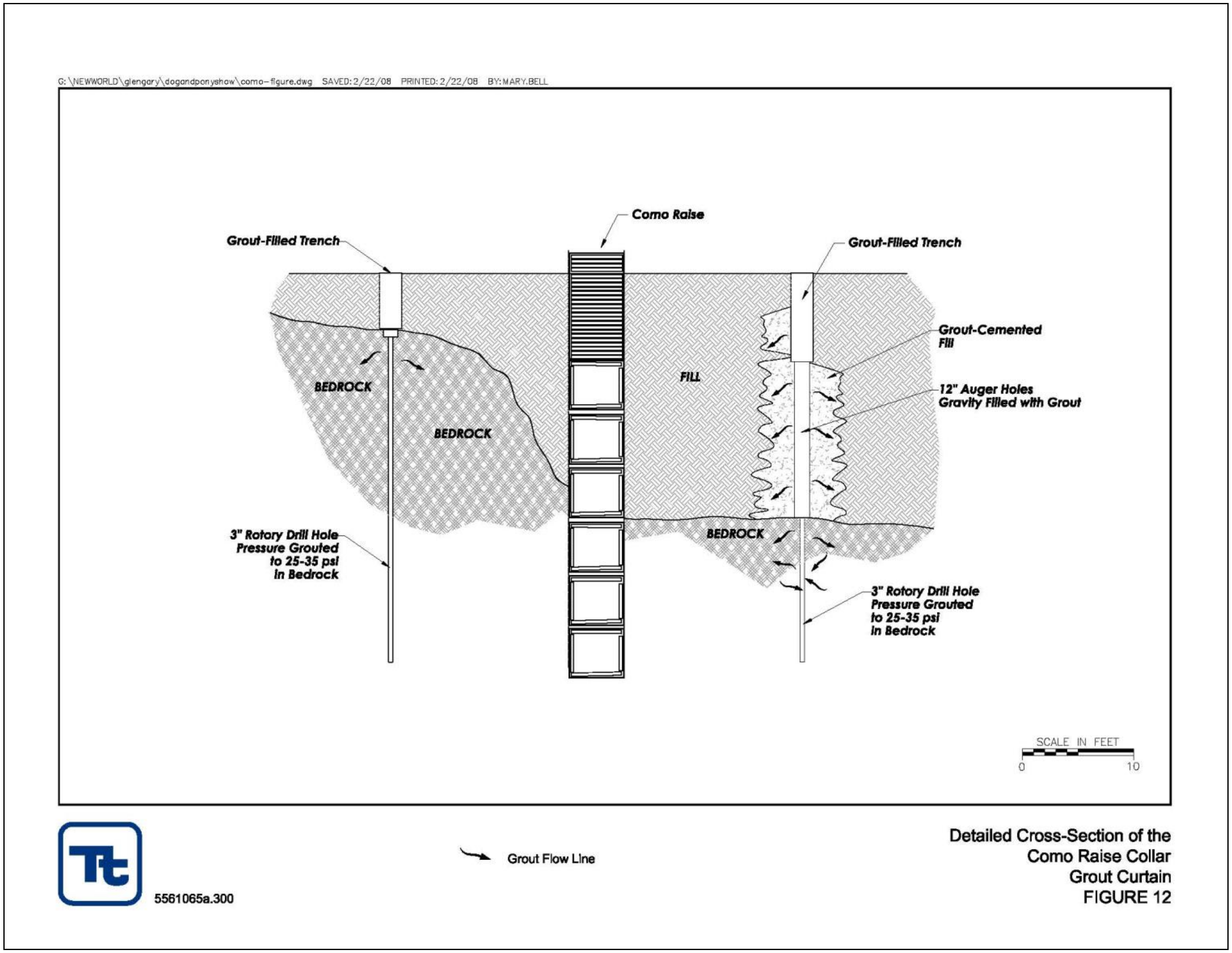

Figure 12. Detailed Cross-section of the Como Raise collar grout curtain.

A 0.61 m (2 ft) wide trench was excavated around the raise collar. The depths of the trench either went to bedrock, one meter deep (3 to 4 ft deep) or as deep as the backhoe could dig and still maintain an open trench (approx. 1.8 m [6 ft]). The trench was filled with grout to the surface and allowed to set for 48 hours resulting in a grout ring-wall surrounding the raise collar (Fig. 13). Next, thirty nine 0.3 m (12 in) diameter auger holes were drilled through the grout wall, colluvium and compacted backfill into the uppermost portion of the underlying bedrock in areas of the wall that had not been excavated to bedrock (Fig. 14). These holes were filled with grout in stages into the adjacent unconsolidated materials. This completed the grout ring-wall into the uppermost portion of the underlying bedrock.

Figure 13. Como Raise collar grout trench.

Figure 14. Como Raise collar auger holes for caisson wall.

Once the grout ring-wall was completed, thirty 10 cm (4 in) diameter and 0.9 m (3 ft) deep rotary holes were drilled on 0.9 m (3 ft) centers along the centerline of the ring-wall. Steel standpipes were cemented in place at the collar of the holes. Fifteen of these holes were designated as primary holes and were deepened by drilling into the underlying bedrock (Fig. 15). These holes were pressure grouted at 15 to 34 pounds per square inch (psi) until refusal. Once completed, secondary holes were drilled and grouted in the same fashion. The purpose of these holes was to grout the colluvium/bedrock interface.

Grouted primary holes were re-drilled to a depth of 10 m (35 ft) below the surface, well into the underlying bedrock and pressure grouted. Primary holes were initially pressure grouted with microfine grout; if grout takes were large; grouting was finished with Portland cement grout. All primary holes were pumped to refusal at 25 to 30 psi. Once all primary holes were grouted, secondary holes were drilled and grouted in the same fashion to complete the infill grouting of the primary holes. Many of the secondary holes only took as much grout as was required to fill the holes, indicating good grout continuity between primary holes. The purpose of this grouting was to provide a downward extension of the grout wall into the underlying bedrock, further preventing the migration of near-surface water into the raise.

Figure 15. Rotary drilling primary (Red) and secondary drill holes into bedrock.

Plugging and Backfill of the Como Raise

The purpose of plugging the Como Raise (Fig. 16) was to eliminate any water discharge down the raise that might enter below the grout curtain constructed at the raise collar. The purpose of backfilling the raise was to provide for long term stability for the plug. Work began on the Como Raise in 2004 and was completed largely in accordance with the contract. There were two changes to the original plans; a change in the vertical location of the backfill interval and raising the location of the plug site. These changes were incorporated due to the conditions of the underground workings which would result in difficult and dangerous working conditions.

Considerable work went into the rehabilitation of the workings to allow for safe working conditions and preparation of the plug and bulkhead sites. To support the cemented backfill, a 15 cm (6 in) steel I-beam bulkhead was constructed in the raise. The raise was backfilled with a cemented backfill material with a 28-day uniaxial compressive strength greater than 1,800 psi and a slump greater than 15 cm (6 in). Concrete was placed from a continuous, 15 m^3 (20 cu yd) per hour batch plant (Fig. 17) at the surface in a series of lifts.

The water tight raise plug (Fig. 16) was constructed as per the contract in at a higher elevation. First a 4.6 vertical meters (15 ft) concrete plug was placed as a continuous pour at the timber stripped plug location in the raise and allowed to cure for 48 hours. Next a 1.2 meter (4 ft) thick layer of bentonite clay pellets was placed on the concrete plug. An open-latticed wooden mat was placed on top of the clay pellets to prevent the additional cemented backfill from displacing the bentonite chips. The remainder of the raise was backfilled with concrete to within about 3 m (10 ft) of the raise collar. A total of 487 m^3 (637 cu yd) of concrete backfill were placed in the Como Raise. The collar area was backfilled and graded to drain away from the raise. There was no water flowing or dripping at the bottom of the raise after placement of the plug and backfill. Previous flow rate had been as much as 11 gpm.

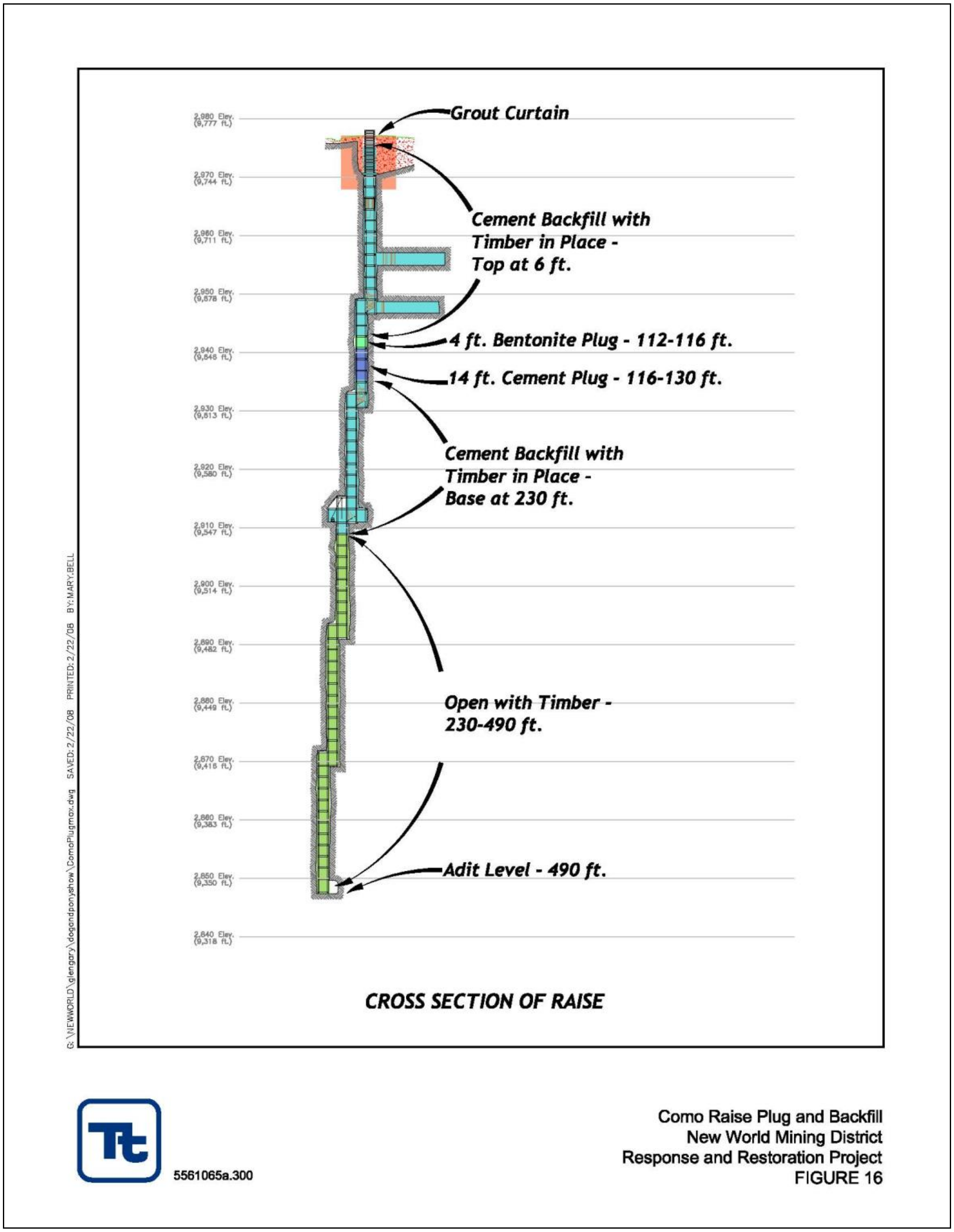

Figure 16. Como Raise Plug and Backfill.

Figure 17. Continuous 15 cubic meter/hour concrete batch plant at the Como Raise.

Grouting the 1066’ (1050) Fault Zone

The 1066 roof leak area (called 1050 roof leak above and renamed after more precise surveying) in the Glengarry drift had been previously mapped as a Tertiary porphyry dike that cut the adit at an oblique angle trending N 35 W. The initial design called for drilling this structure and placing an impermeable grout curtain around the drift from two drill stations, one on either side of the structure. During construction in 2003, rib lagging was removed from the timber sets through the 1066 zone and the structure was observed to be a fault that crossed the adit at about right angles rather than the originally reported obliquely-oriented dike. Because of the different type of structure (fault vs. dike) and different orientation, the initial plan for drilling the zones was changed to construct one drill station in the drift instead of two. The drill station was cut on both sides of the adit to drill the structure at right angles to the drift. This change resulted in significant cost savings.

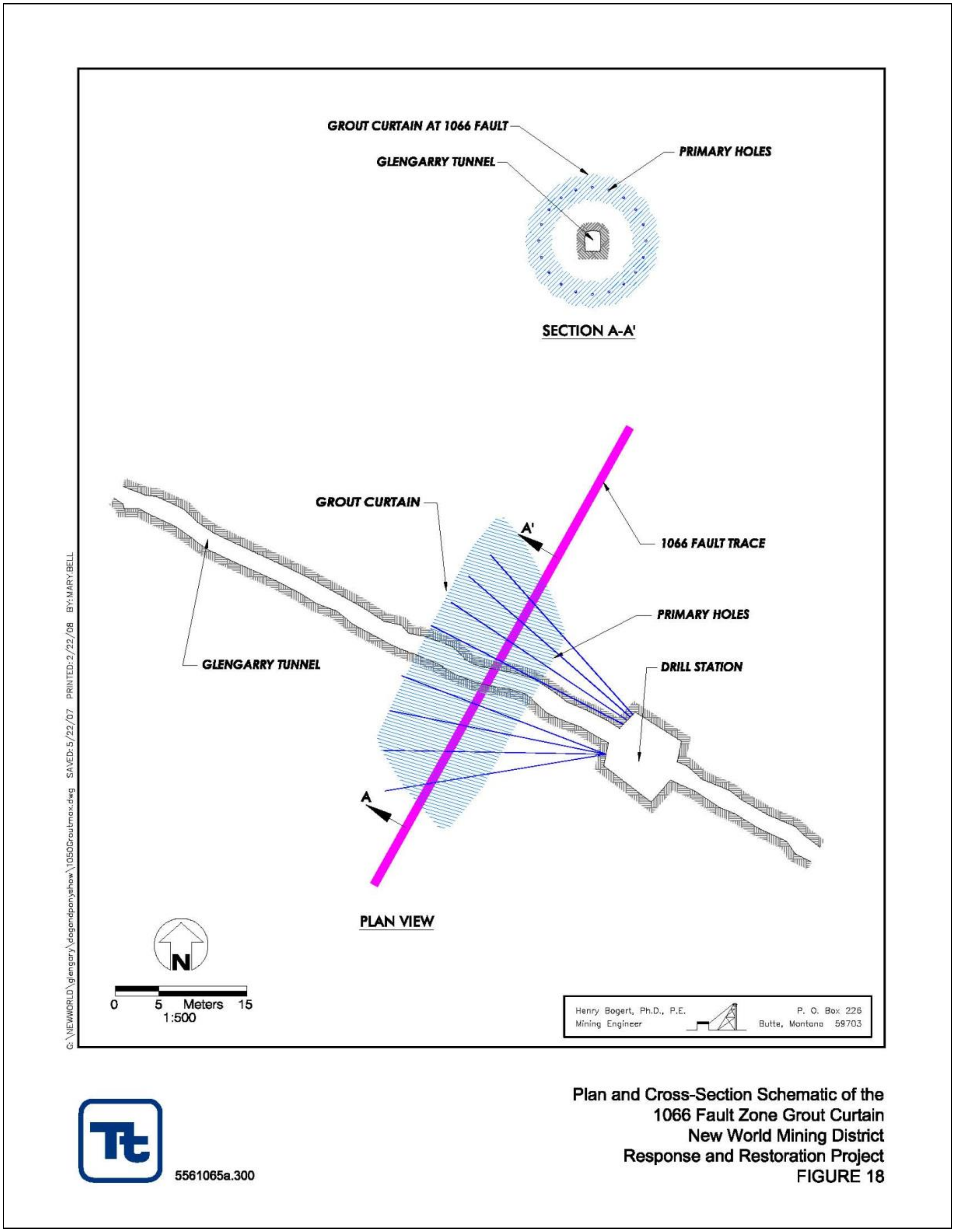

Figure 18. Plan and cross section schematic of the 1066 fault zone grout curtain.

With the exception of changing the drill station layout and grouting a caved area along the fault by bulk-heading and cementing the back of the adit, the grout curtain around the fault was constructed as per the contract. Core holes were drilled to cut the fault zone structure at a point on a circle 9.1 m (30 ft) in diameter centered on the adit drift. The hydrostatic head was measured on each of the holes by placing a valve and gage on each hole. The fifth core hole drilled intercepted a preferential flow path and captured 100% of the flow from the fault zone.

While initial core drilling was being completed, the remainder of the timber sets and lagging from the fault zone were removed. This area had caved and opened a hole into the ceiling of the drift about 4.6 m (15 ft) in height. This collapse created a problem for the grouting of the fault zone as there was not adequate, competent rock between the drill holes for the grout curtain and the drift. To solve this problem, the fault zone was re-timbered and bulk-headed, and the open space was backfilled with cement. A total of nine primary and nine secondary drill holes were used to place the grout curtain around the fault zone. These holes were initially grouted with microfine grout and then were finished with Portland cement grout to refusal. During grouting of the fault zone, flow at the cemented bulkhead went from 19 Lpm (5 gpm) to less than 0.5 gpm.

<u>Watertight Plugs and Backfill of Glengarry Tunnel</u>

In general, the construction of the plugs and backfills in the Glengarry drift went as specified in the contract. Plugs were placed in the underground workings at strategic locations to block water flow into the through the workings. Segments of the underground workings were backfilled to provide a structural fill for ground support around and between the watertight plugs in case the workings collapsed.

Four plug site locations and three drill stations were excavated and constructed in the Glengarry drift (Fig. 19). Three holes were drilled upward from the underground workings to the surface at the most of these sites (Fig. 21). Two of the drill holes were for cement fill delivery (one for primary and second in the event the primary hole plugged) and the third hole was the breather hole to allow for displacement of air and water during plug placement. Watertight plug stations were 5 to 6 m (16 to 20 ft) long and constructed in an arched configuration between 4.6 to 5.5 m (15 and 18 ft) in height, to allow the cement plug a place to into the bedrock (Fig. 20). Plug stations were filled sequentially from the back of the workings toward the portal.

Steel I-beam supported and timbered bulkheads were constructed at each end of the watertight plug stations (Fig. 22). Four watertight plugs were poured with high-strength cement from the surface to fill the plug to the top of the arch. Portland cement mix averaged 8-sacks Type II per cubic yard (18% by weight), used a sand aggregate and was delivered with about an 8-inch slump. Cement was allowed to set for 24 to 48 hours after which cement grout was injected into the top of the plug to infiltrate bedrock and any shrinkage fractures.

Two segments of the workings in between watertight plugs were filled with long, cemented – fill plugs to provide a lower-strength structural-fill for long term stability of the watertight plugs (Fig. 20). Placement of the cemented-fill was accomplished with a 3-inch HDPE pipe along the drift and a series of wooden stop dams. These long plugs were filled for the most of the plug interval to within 30 to 45 cm (12 to 18 in.) of the back. Portland cement mix averaged 4-sacks Type II per cubic yard (9% by weight), using a sand aggregate and was delivered with about an 8-10 in. slump. One long structural fill plug, in a dry section of the mine, was constructed of rock generated from drill station construction. A portal plug was constructed to allow for final surface revegetation of the portal pad site (Fig. 20). A thick layer of rounded cobbles were placed on the floor as a drainage layer, covered with non-woven geotextile fabric, and then backfilled with leftover cement aggregate and compacted. Adit work was completed on August 30, 2005.

A monitor well was drilled from the surface to a location behind plug #6 near the "Y-intersection" within the Glengarry adit (Fig. 20). The well depth was 118 m (386 ft). The purpose of this well was to provide data from which to determine the rate and ultimate height of the water column that would back up behind the plug system and to calculate the hydrostatic head behind the deepest plug (#6). Within 60 days of the installation of the deepest plug (#6), the water levels rose to the ground surface and the monitoring well had artesian flow from the collar of approximately 2.3 Lpm (0.5 gpm). These factors suggest that the fracture controlled permeability of the rock in the vicinity of the mine is low with limited interconnectivity of fractures that have a limited storage capacity for groundwater.

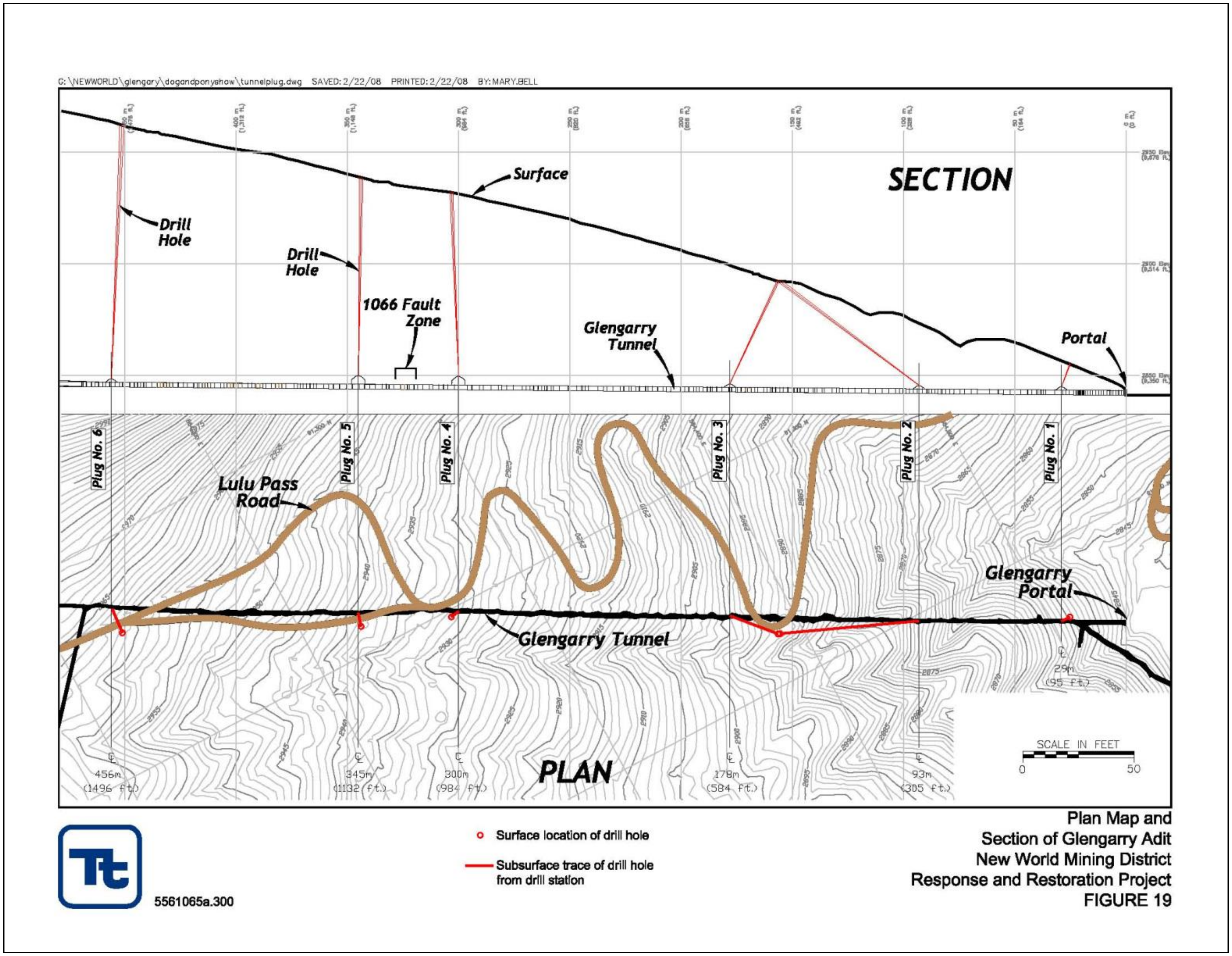

Figure 19. Plan map and cross section of Glengarry adit plugs, backfill segments, and borehole locations.

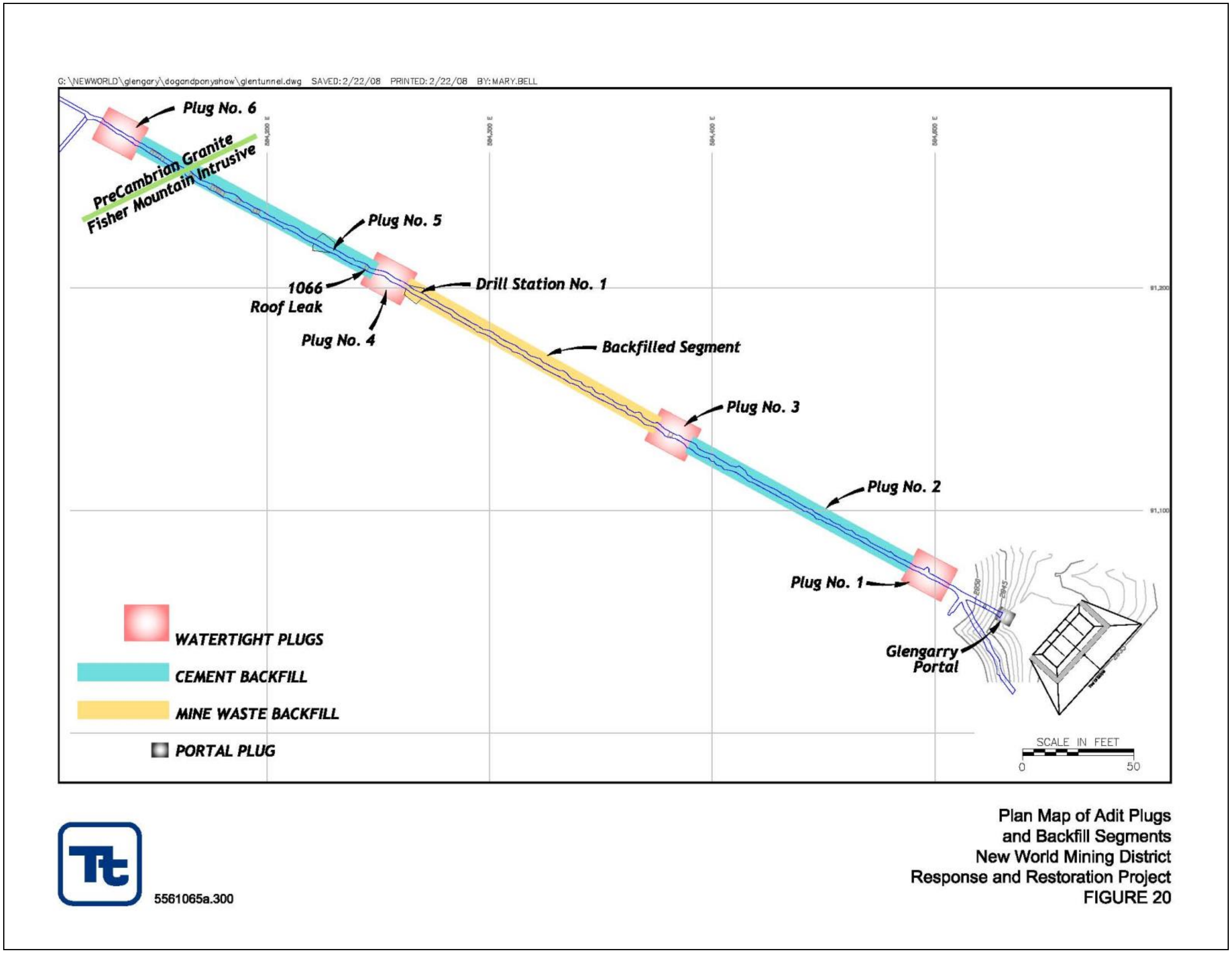

Figure 20. Plan map of adit plugs and backfill segments.

Figure 21. Watertight plug station with Hagby core drill drilling borehole to surface

Figure 22. I-beam and Timber Constructed Bulkhead for Plug Station

Conclusion

Flow and water quality sampling data from specific groundwater discharges into the rehabilitated Glengarry Mine were used to identify and characterize the magnitude, and assess the relative importance of these inflows as sources of metal loading to the adit. The characterization of these inflows allowed the project team to develop and analyze specific underground engineering source control alternatives to reduce or eliminate the risk of contamination of surface waters by a subsequent adit discharge to surface waters of Fisher Creek.

Underground closure work in the Glengarry Mine at the New World Project site was completed during three short construction seasons during 2003 and 2005. The work consisted of a combination of identified alternatives including surface and underground grouting of water-bearing fractures, faults and the Como raise collar; selective backfilling of three segments of the underground workings; and strategic placement of five water-tight underground adit and raise plugs. A non-water tight portal plug was also constructed.

Monitoring of the quantity and quality of the Glengarry adit discharge since 2005 indicates an overall reduction in flow from the reclaimed portal of 97.3% from an initial average value of 268 to 7.1 Lpm (59 gpm to 1.57 gpm) (Table 2). Geochemical analysis of water quality data since 2005 indicates an average metal concentration reduction of 83.3% and an average metals load reduction of 99.8%. Individual metal concentration and load reduction values are presented in Table 2.

The method of closure used at the Glengarry Mine offers an effective approach that is considered to be a walk-away solution to handling sources of contaminated groundwater discharges from adit portals. In addition, it can be used to eliminate point source discharges that are often problematic from both a permitting and water quality points of view. No future operational, maintenance, or treatment costs are anticipated.

Table 2. Glengarry Adit Water Quality Data –Pre and Post-Closure.			
Measured Values and Concentrations			
Parameter	**Average 1989-2000**	**Average 1989-2000**	**% Reduction**
Flow (gpm)	58.9	1.57	97.3
pH (s.u.)	Range 2.6 – 3.2	6.3	
Sulfate (ppm)	430	144	66.4
Aluminum (ppm)	9.09	0.50	94.5
Cadmium (ppm)	0.002	0.0003	83.1
Copper (ppm)	2.8	0.24	91.3
Iron (ppm)	52.3	11.4	78.3
Lead (ppm)	0.022	0.0037	83.6
Manganese (ppm)	4.14	0.50	87.8
Zinc (ppm)	0.41	0.08	81.3
Average Metals Reduction %			**83.3**
Load in kilograms/day			
Parameter	**Average 1989-2000**	**Average 1989-2000**	**% Reduction**
Sulfate (ppm)	136	1.18	99.1
Aluminum (ppm)	2.88	0.004	99.9
Cadmium (ppm)	0.018	0.000X	99.9
Copper (ppm)	0.68		100
Iron (ppm)	0.08	0.000X	100
Lead (ppm)	0.001	0.0000X	100
Manganese (ppm)	0.03	0.000X	100
Zinc (ppm)	0.00005	0.0000X	100
Average Load Reduction %			**99.8**

Acknowledgements

The authors would like to thank the USDA-Forest Service Northern Region staff, especially Bob Kirkpatrick, for providing continuing direction and support for this project. Other notable support for this project came from: Tetra Tech's (previously Maxim Technologies) scientists and engineers located in Helena, Billings, and Bozeman, Montana; the engineering staff of the Gallatin National Forest Supervisor's office, particularly Frank Ehernberger; Henry Bogert independent consulting mining engineer for the Glengarry Mine project; and the construction contractor Hayward Baker Inc., of Denver, CO. The authors acknowledge in sorrow the recent and unexpected death of their coauthor, dedicated fellow scientist and friend, Mike Cormier.

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