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TECHNICAL MEMORANDUM

TO: Hydrogeology Group

cc: B. Kirkpatrick
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FROM: Allan Kirk

DATE: December 3, 2001

RE: Meeting (9/6/01) Notes/Summary
Hydrogeology of the Como Basin, Glengarry Mine and Upper Fisher Creek Drainage, New World District, Montana

EXECUTIVE SUMMARY AND CONCLUSIONS

A meeting of thirteen technical specialists was held on September 6, 2001, in Bozeman, Montana, to discuss the hydrogeology of the Como Basin, Glengarry Mines and Upper Fisher Creek Drainage, New World District, Montana. A list of attendees and the agenda for this meeting is attached. This summary discussion parallels the organization of the agenda.

The primary purpose of the meeting was to review pertinent information and to determine if the technical staff involved with hydrogeologic studies of the upper Fisher Creek drainage (including the Como Basin and Glengarry Mine areas) were in agreement that enough data of suitable quality exists to design technically sound and effective closure alternatives for the upper Fisher Creek drainage area.

My notes and observations on the technical discussion are presented herein. I have tried to represent what was said and hope I have not misstated what others perceived to be the conclusions. In some cases, I have added information based on review of reports and in some other cases, I asked the presenters to prepare a short written summary. I believe that the group:

1. Was impressed with the breadth of our understanding and site specific knowledge in various technical areas including geology, hydrology, ground and surface water quality characterization, metal loading to surface water, underground metal loading in the Glengarry adit and raises, the general character of fracture controlled bedrock ground water flow, contaminant migration pathways, and the impact of ground water additions to surface flow downstream along Fisher Creek.

2. Was in agreement and confident about the identification and characterization of the principal contaminant sources in upper Fisher Creek. The four sources identified by studies included: flow from the Glengarry adit, seepage through the toe of the Glengarry waste rock dump, surface flow in the tributary that drains the Como Basin (northeast of the Glengarry adit

portal) and surface flow in the tributary that drains the northeast (unmined) flank of Fisher Mountain (southwest of the Glengarry adit).

3. Agreed that based on metal loading studies by Kimball with the US Geological Survey, and Amacher with the US Forest Service Intermountain Research Station that somewhere between 60% and 75% of the total metal loading into Fisher Creek could be accounted for from these four sources. There were also other minor surface flow sources (e.g., drainage from Tredennick Mine area down Polar Star Creek) with the remainder of the contaminants entering Fisher Creek in ground water along the upper and middle reaches of the stream.

4. Agreed that we had a fairly good understanding of the migration pathways of contaminants. For example the importance of the massive sulfide ore deposit exposed at the surface in the Como Basin and its direct affect on run off surface water quality from the Como Basin, and also on waters flowing down the Como raises, out the Glengarry portals and through the Glengarry waste rock.

5. Agreed that we had a good fundamental set of data that exhibits considerable geologic control of the hydrochemical setting, and an adequate understanding of the ground and surface water flow regimes and contaminant migration pathways, for example, contaminated water flow along the highly transmissive colluvial/waste rock and bedrock interface in the near-surface of the Como Basin.

6. That no additional data was necessary (although some may be desirable; for example, additional tracer studies) to address the principal sources of contaminants with a broad, logical, and technically sound set of preferred and alternative plans for reclamation and closure on the Como Basin, Glengarry adit, and erosion control in Upper Fisher Creek.

7. Agreed that some "second order" actions may likely be required as future actions to optimize closure effectiveness in the Upper Fisher Creek drainage.

ORIENTATION

Mary Beth Marks, On-Scene Coordinator for the USFS on the New World Mining District Response and Restoration Project opened the meeting with some general comments. Mary Beth summarized **construction activities** on the New World Project site including waste rock removal, repository construction, Glengarry Mine opening and raise rehabilitation, and road construction. She also summarized the **status of the McLaren EECA,** indicating that the draft document had been through agency review, a preferred alternative had been chosen, and was currently out for public review and comments. Finally, Mary Beth indicated that the subject of this meeting was to be focused on the Como Basin, Glengarry Mines and the Upper Fisher Creek drainage (as a collection of elements and their influence) that impacted surface and ground water quality in Fisher Creek. The principal objective of the meeting was to review 2001 progress to date and **identify data gaps in our understanding of the hydrogeology** that might impact closure planning.

Allan Kirk, Senior Geologist with Maxim Technologies, indicated that the meeting was going to focus on **three fundamental questions**: 1) What do we know about the hydrogeology of the Upper Fisher Creek drainage? 2) What don't we know? and 3) What do we need to know to effectively scope and define the response actions and design the specific elements needed for closure of various elements affecting Upper Fisher Creek? He reminded the group of the charge placed on the Response and Restoration Project by the Crown Butte Mines, Inc. **Consent Decree**, which was to minimize the impacts from historical mining and exploration activities on District Properties (previously owned in total or in part by Crown Butte and now managed by the National Forest), to the extent practicable. Once all district properties are deemed restored and reclaimed or "closed" by the responsible agencies (USDA Forest Service, USFS, Montana Department of Environmental Quality (MDEQ), and the US Environmental Protection Agency (EPA)) remaining funds can be spent on remediation of historic mining impacts on non-district properties within the New World District.

It was proposed that an outcome of this meeting would be to design **a 3-dimensional block model** depicting the various elements of the hydrogeology of the Upper Fisher Creek drainage. This model will cover the area between Lulu pass and the Gold Dust adit in the middle Fisher Creek Valley. It would include following: topography, drainages, mapped geology from existing company (Crown Butte Mines, 1992), Mine Finders (1975), US Geological Survey, (Elliot, 1985) and Maxim (2001) reports, surface water and ground water quality and flow data, tracer study data, results from underground geology and water source mapping in the Glengarry Mine and raises, and results of USGS and USFS metal loading studies on the Fisher Creek. It is envisioned that a potentiometric map of the area, would be constructed using the limited monitoring well data available in upper Fisher Creek drainage. The limited set of data will restrict the level of detail of the potentiometric surface. The potentiometric map will be developed by factoring in the permeability of different rock units and dominant fractures that are thought to influence flow paths and directions. The mass load model can then be used as a basis for identifying the major sources that contribute metals to the creek and assist in evaluating various remediation options for reducing metals loads and acidity. Perhaps more importantly, however, this block model may help to depict complicated hydrogeologic relations in a manner that can be easily envisioned by people from many different backgrounds.

TECHNICAL PRESENTATIONS

Allan Kirk presented an overview of the geology and ore deposits of the New World District (Kirk, 1994). Much of this discussion was to provide the general and specific geologic setting for New World ore deposits and related alteration as they impact water quality. Critical aspects of this discussion included the following: 1) Rocks underlying the unconsolidated disturbed wastes in the Como and McLaren Pit areas consist of in-place (naturally occurring) massive sulfide ores (30-75% total sulfides) that consist of about 750,000 tons of material in the Como Pit area and 2.1 million tons in the McLaren Pit area, 2) Intrusive stocks that comprise the north end of Henderson Mountain and Fisher Mountain (Homestake stock and Fisher Mountain Intrusive Complex, respectively) are comprised of more than 100,000,000 tons of rock that contain 2-4% disseminated sulfides (15-30 % in fracture zones of high permeability); and, 3) Total sulfide contents as low a 0.3% (that have little or no neutralization potential) have been known to produce acid and waters with elevated metal concentrations. Therefore, there is ample material of sufficient sulfide content that occurs naturally (in unmined deposits and stocks) to account for essentially all of the observed acidic drainage and elevated metal contents as identified for Como Basin and Upper Fisher Creek drainage.

The distribution of aerially extensive ferricrete deposits of the New World District were discussed and the significance of their age (8000 to 300 years before the present) was discussed with respect to pre-mining acid rock drainage (ARD) throughout the district. Kirk mentioned a new section added to the McLaren Pit EECA that summarizes existing data for pre-mining ARD.

Existing data indicates that groundwater occurs in two hydro-stratigraphic units in the Como Basin area: 1) Relatively thin (surficial) unconsolidated alluvial and colluvial material along drainages and in small drainage basins; and 2) Fracture systems within consolidated bedrock. Cambrian-age sedimentary rocks in the Como Basin are primarily fine-grained shale, limestone, dolomite, and quartz-cemented sandstone, which were altered, lithified and compacted into rock masses of relatively low porosity and hydraulic conductivity. There are no true aquifers in the bedrock units themselves and porosity and permeability within the bedrock geologic units is to a large extent fracture controlled. Aquifer tests conducted on bedrock wells completed in intrusive rocks in the Como Basin area indicate hydraulic conductivities range from 3×10^{-4} to 5×10^{-5} cm/sec. Permeability in unconsolidated waste rock materials is on the order of 10^{-2} cm/sec. Therefore, water flow through unconsolidated units is about three orders of magnitude faster than in underlying bedrock. Under similar hydraulic heads, this means that if water in unconsolidated materials is carrying flows of a few gallons per minute (3.0 gpm) (4,320 gallons per day), water flow in underlying bedrock is carrying flows two orders of magnitude lower than the unconsolidated material (0.03 gallons per minute or 43.2 gallons per day).

The general direction of groundwater movement in the Como Basin is southeast, down Fisher Creek. Based on a study completed by the USGS (1999), as much as 35% of base-flow in Upper Fisher Creek is attributable to groundwater inflow.

Finally, a number of underground workings exist in the district that act as conduits for the collection and discharge of acidic, metal laden water, including Spaulding Tunnels and the Glengarry adit systems in upper Fisher Creek. However, flow from these adits is very small when compared with groundwater passing through the bedrock mass of Fisher and Scotch Bonnet Mountains.

Henry Bogert, a consultant to Maxim, reported on the **Glengarry Mine water quality and flow** and on the progress of renovating **the raise from the Glengarry Mine to the Como Basin**.

The portal of the Glengarry adit is a source of mine drainage discharge that collects water from fractures and other geologic structures from approximately 2,500 lineal feet of underground workings and two sets of raises. Water flowing into the Glengarry Mine comes primarily from three well defined sources and one diffuse source. The well defined sources are a major roof leak located 1,050 feet in from the portal, bulkheads at top of the first raise about 40 feet above the tunnel level, and the upper portion and top of the second raise where it rises to surface (daylights) in the Como Basin. The diffuse source is the series of small roof leaks that occur between the portal and the major roof leak at 1050 ft.

The short raise (first raise encountered on way into the mine)) has a fairly constant flow in the range of 10 to 20 gallons per minute with the lowest flow occurring prior to snow-melt in the spring. The water is characterized by a pH of 3.2 to 3.3, 75 to 85 milligrams per liter (mg/l) iron, and 0.015 to 0.032-mg/l copper.

The second raise, which surfaces in the Como Basin, seasonally contributes 2 to 10 gallons per minute of inflow. During snow-melt, most of the flow is derived from water moving through alluvium (which is weathered massive sulfide ore), along the bedrock surface and into the raise. This water is characterized by a pH of 2.5, 100 to 400 mg/l iron, and 10 to 40 mg/l copper.

Flow from the major roof leak at 1,050 feet from the portal varies seasonally from 3 to 13 gallons per minute and is characterized by pH 4 to 5, 110 to 135 mg/l iron, and 0.004 to 0.05 mg/l copper.

Diffuse roof leaks virtually dry-up in the winter and contribute a total flow between 1 and 15 gallons per minute during wetter seasons of the year. They are characterized by a pH of 5 to 6, 2 to 10 mg/l iron, and 0.001 to 0.006 mg/l copper.

Thus, the Glengarry adit receives several orders of magnitude more copper loading from the top of the Como raise than from all the other in-flows combined. The two raises and the 1,050-roof leak each contribute at least an order of magnitude more iron loading than do the diffuse roof leaks.

Dan Stanley, a consultant, provided summary information on **surface and groundwater quality in the Como Basin and Upper Fisher Creek**.

A great deal of data has been accumulated on water chemistry of Fisher Creek. The efforts to document and evaluate Fisher Creek water quality began in 1973 when the Montana DNRC began a three year study to assess water quality and discharge characteristics related to mine disturbances at the headwaters of Fisher Creek (Montana DNRC, 1977). Crown Butte Mines, Inc, in conjunction with their application for a hard rock mining permit, began comprehensive surface and ground water quality monitoring and discharge measurements in the Fisher Creek drainage basin in 1989. This work continued through 1996 with the most extensive data base collected during the 1974 - 1975 hydrograph year. The USDA Forest Service, under the direction of Mike Amacher, conducted comprehensive water quality studies from 1989 through 1993. More recently efforts by the USGS, EPA, and the USDA Forest Service continued to build on the database and understanding of Fisher Creek water chemistry.

The conclusions reached by these various studies are complimentary and point to dynamic and complicated water chemistry. In stream water, the chemistry is controlled not only by long term and seasonal climatic events, but by such things as ground water rock interactions at the source of the water entering the stream, discharge from mine-related disturbances, phase equilibrium between precipitants within the water column, and the chemistry and phase state of stream deposited sediments along the Fisher Creek thalweg.

Upper Fisher Creek is characterized by rapidly increasing flow rates and short periods of sustained flow during the snow melt event. As much as 90% of Fisher Creek's discharge volume occurs between mid May and early August. Discharge rates near the upper reaches of Fisher Creek range from less than 1 cfs in late winter to over 50 cfs during the peak of the snow melt event.

Most contaminants entering upper Fisher Creek reach peak concentrations during late winter when flows are at a minimum. At downstream locations, however, concentrations of some constituents rise with increasing discharge rates.

Loading of contaminants to Fisher Creek has been identified from a number of sources. The single largest contributor of these contaminants is the Glengarry adit. This source, however, contributes one third or less of the total load entering upper Fisher Creek during a typical hydrograph year. During low water periods, however, a much greater percentage of in-stream loads of most contaminants can be attributed to the adit discharge.

Ground water chemistry and flow characteristic are not as well documented as is surface water chemistry, but some efforts have been made at comparisons (UOS, 1998). Water level measurements have shown that the potentiometric surface in bedrock wells in the Como basin is directly influenced by the snow melt event. Water levels in some wells may fluctuate by as much as 60 feet over the hydrograph year. Increasing water levels lag behind the snow melt event, and maximum surface water discharge rates in the upper basin, by as little as two to three weeks. Recent ground water tracer studies indicate that bedrock flow is fracture controlled and that flow directions are not necessarily coincident with surface hydrographic divides or other topographic features.

Comparison of ground water chemistry for wells completed in various bed rock units suggest several populations of water, the quality of which is controlled by the host aquifer. Water quality is most degraded in wells completed in the sedimentary rock units within the Como Basin and in the rocks of the mineralized Fisher Mountain Intrusive Complex. Wells completed in late stage tertiary dikes, intruded along fractures, have a distinctive chemical fingerprint with high iron and zinc but low copper values. Wells completed in the Scotch Bonnet diorite show the lowest concentrations of contaminants.

The ground water chemistry in various wells in the Como Basin can be linked to inflows entering the Glengarry adit. Of the three major sources of water entering the adit, the major roof leak at 1035 feet from the portal is most similar to water in wells completed in late tertiary dikes. Water entering the adit from the first blind set of raises (first set) shows characteristics similar to water in wells completed in late tertiary dikes, but may be influenced by a component of water originating from within mineralized sediments during the peak of the hydrograph. Water entering the adit through the second raise compartments that have a direct surface connection has recently been demonstrated to originate mostly within the mineralized unconsolidated and surficial sediments of Como Basin. The chemistry of this water reflects equilibrium with sulfide-rich sediment.

Dan Stanley, a consultant, summarized historical **tracer studies** conducted in the Como Basin area. The EPA proposed a ground water dye tracer study for the New World Mining District Response and Restoration project. This study was designed to map flow patterns of ground water originating in and around mine related disturbances in both upper Daisy and Fisher Creek drainage basins. Possible flow in or along the Crown Butte fault system was also of interest. Maps, illustrating well locations and depicting tracer flow directions can be found in Davies (1998). URS initiated the study in 1996 by supervising the installation and development of 12 wells to be used as dye recovery and water quality monitoring stations. Eleven of these wells were completed in waste rock material and various underlying rock formations within the McLaren Pit disturbed area. Three additional wells were completed in tertiary intrusive rock formations within the Como Basin disturbed area.

In 1997, Cambrian Ground Water Co. designed an organic dye tracer study. Six wells were drilled outside of the disturbed mine areas for the purpose of injecting dye into ground water bearing rock units upgradient of the disturbed mine areas in both the Como Basin and McLaren Pit. Dye injections into these wells were to begin in early August to coincide with the falling ground water hydrograph. Adverse drilling conditions and equipment problems prevented a timely completion of the proposed wells and two abandoned exploration wells located in the study area were injected with dye in order to meet the schedule. The first of these (CBMI 89-170), designated Tracer 1 for the purpose of the study, is located east of the McLaren Pit high wall on the ridge crest of Fisher Mountain. A second well, drilled for this study immediately north of the disturbed area in the McLaren Pit, was injected with suphorodamine. This well is designated Tracer 2.

In the Upper Fisher Creek basin, an abandoned exploration well (BC-12), designated Tracer 7 for this study, located on the east flank of Fisher Mountain was injected with uranine. A second well (Tracer 5) completed for this study below the Como Basin on the northeast flank of Fisher Mountain was injected with suphorodamine. During the 1998 spring melt event, Tracer 5 developed an artesian flow and the dye injected into this well was flushed to the surface.

Three additional wells, Tracers 3, 4 and 6, drilled for injection purposes in 1997, were not injected due to time constraints and a limited number of dyes judged as suitable for this study. Tracer 3 was completed immediately adjacent to the Crown Butte fault trace near the summit of Fisher Mountain. Tracers 4 and 6 were completed upgradient of the Como basin at the south and north ends of the basin respectively.

Two wells (Tracer 1 and Tracer 7) located on the eastern flank of Fisher Mountain were injected with uranine dye in 1997. Two other wells, one immediately north of the disturbed area in the McLaren Pit (Tracer 2) and one on the northeast flank of Fisher Mountain (Tracer 5) were injected with suphorodamine. Both the dyes used in this first phase (1997 injection) of the study were recovered in monitor wells in the down gradient portion of the McLaren pit, in monitor wells and surface water stations in Upper Fisher Creek drainage basin, and in a single monitor well in the Upper Miller Creek drainage basin. As the same dye was used in wells in both the Daisy Creek and Fisher Creek drainage basins, at first it was not clear where some of the recovered dye originated. After careful review of the data, it was concluded that all the recoveries could most likely be attributed to dyes injected above the McLaren pit high wall.

In May of 1998, a second injection of suphorodamine was made into Tracer 2 and a new injection, using phloxine B dye, was made into well EPA-5, approximately 125 feet south of

Tracer 2. These injections were used to confirm the ground water movements inferred and mapped by the first injections and to test for new pathways, which might be intersected by the rising ground water levels responding to the snow melt event. Both of these dyes were also recovered in wells or surface water down gradient in the McLaren pit, in surface water and monitor wells in the Upper Fisher Creek drainage basin, and in a single well in the Upper Miller Creek drainage basin.

The study confirms that topographic features or potentiometric surface mapping cannot predict ground water movement in the study area. It also suggests that conventional aquifer testing may lead to erroneous interpretations of the direction of ground water movements and flow velocities.

Dye injected into wells developed in intrusive porphyry rock units located topographically above the McLaren pit migrated rapidly in divergent directions to all three adjacent drainage basins. This would seem to indicate that the flow system in bedrock within the district is predominantly fracture controlled in fracture systems that cross-cut lithologic boundaries. It further suggests that most of the major and most rapid flow must be occurring through fractures or faults that are interconnected between drainage basins. Furthermore, flow paths appear to be seasonally dependant and reflective of a fluctuating ground water table that allows for ground water to intersect various discrete flow paths as the potentiometric surface moves up and down in response to the recharge/discharge event. The study further demonstrates that ground water hydrographic divides do not necessarily coincide with surface water hydrographic divides.

When evaluating the results of both years injection studies, it is apparent that most of the water from the Fisher Mountain Intrusive drains into Fisher Creek, with only a small percentage reporting to Miller and Daisy Creek during the higher stages of flow. Almost all of the water from the sedimentary bedrock in the vicinity of the McLaren Pit reports to monitor wells and surface springs and seeps at the lower edge of the pit, to Daisy Creek, or to MW-5 located on the Crown Butte fault in Miller Creek.

It is interesting to note that no tracer dyes were recovered in any of the adits (McLaren adit, Glengarry adit, or Gold Dust adit) suggesting that they are fed during even base flow conditions by relatively slow moving ground waters flowing through bedrock fractures. Although outflow from each of these three adits is significant (10-60 gpm,) this water apparently enters the adits through a relatively small number of fractures that apparently are not well connected to fractures that are controlling the rapid flow path of the tracers.

The overall tracer study was not carried to completion in that wells installed up gradient of the Como Basin and in the Crown Butte fault zone proper were not tested with dye. It should also be noted that all of the injections made in the 1997/98 study were in wells east of the Crown Butte fault system. The Como disturbed area straddles a fault that is the likely northward extension of the Crown Butte fault. Indeed, mineralization in this area may be locally controlled by the fault structure and further to the north, the Spaulding mine workings clearly occur within and along this structure.

A more detailed description of this study is available in URS (1998).

<u>Mike Cannon, a hydrogeologist with the US Geological Survey</u>, contributed significantly to the discussion period (below) and summarized the work by Kimball (1997), also with the US Geological Survey, on **Metal Loading and Spatial Water Quality Data Studies in the Fisher Creek drainage**.

Kimball and associates undertook a metal loading study in August of 1997. The two main objectives of this study were to identify and quantify the sources of metal loading in Fisher Creek and to describe the geochemical processes that affect metal concentrations in the creek. This was accomplished by combining tracer injection with synoptic sampling.

According to Kimball, water in Fisher Creek changes in response to the chemistry of the inflows and can be divided into three distinct study reaches. First, upstream from the Glengarry adit, Fisher Creek is acidic, indicating that there are acid sources in the upstream reaches of the drainage. Natural weathering of the intrusive porphyritic rock high in the watershed may be one source of this acid drainage. Acidic inflows downstream, however, have a greater affect on the resulting stream chemistry. The second geochemical reach defined by USGS begins at 263 m, where the Glengarry adit inflow causes the lowest pH and the highest metal concentrations. This stretch extends downstream to about 1,715 m. Combinations of acidic stream flow and near-neutral pH inflow in this second reach results in a gradual increase in pH along gradient. In the final study reach of the stream, located downstream of 1,715 m, pH increased substantially (pH>5) in response to the inflow of neutral pH water from wetlands adjacent to the stream and water draining carbonate rock sources.

Among the inflows, the Glengarry adit was the most acidic and had the highest concentration of metals. Three samples draining from the waste rock dump in front of the adit were also found to have a pH of 4 and very high concentration of metals. A third group of inflows, which had a slightly less acidic pH (pH of 5) and lower metal concentrations, may represent more natural drainage of the porphyritic country rock.

Two groups of inflows had higher pH values. The first group included inflows that had low metal concentrations; these inflows appeared unaffected by mining and occurred along much of the study reach between 492 m and 1412 m. A second group of higher pH inflow waters exists downstream from 1,750 m and included flows from the Gold Dust Mine and inflows at the start of the wetland area adjacent to the stream that is rich in calcium (Ca> 30,000 ppm). Regulated metal concentrations decrease downstream as a result of dilution and co-precipitation with ferrihydroxides.

The two largest sources of iron loading into Fisher Creek were the Glengarry adit and FCT-11, the tributary stream draining the Como Basin. Iron precipitation is widely observed along the creek and plays an important role in controlling the concentration in the downstream reaches where higher pH is observed. In Kimball's study, about 60 % of the Al, Cu, Mn and Zn loads can be accounted for by concentrations in surface inflows. The remaining 40% is assumed to be coming in from diffuse subsurface (groundwater) flows. Almost the entire load from surface inflows enters Fisher Creek in the upper 700 m. The increase in load in the reach between 1,582 m and 1,750 m is primarily due to subsurface flows. Further downstream, between 1,876m to 1,936 m, there is a considerable increase in Ca, Al and Cu. This area likely drains carbonate outcrops on the southwest side of the valley, but the sources of Al and Cu are not clear (perhaps surface run-off from the Homestake Mine area, Kirk speculation).

Geochemical data available from the USGS indicate at least 60% of the sources contributing metal loading into Fisher Creek are surface water sources. The Glengarry adit and the waste rock dump in front of the adit are two major sources of metal loading. Runoff from the Como pit (FCT-11) is another major contributor. While there is metal loading from diffuse subsurface ground water flows (40%), the origin of these flows is not necessarily in the upper reaches of Fisher Creek. Subsurface flows may prove difficult to characterize, as these don't appear to be associated with mining related activity and may represent natural acidic drainage, for example, from the tributary draining the unmined northeast side of Fisher Mountain (FCT-12).

Mike Amacher, a research scientist with the US Forest Service Intermountain Research Station at Logan Utah reported on his studies **of Metal loading in the Fisher Creek drainage**.

Amacher compiled water quality data and flow data for various springs, seeps, adits, tributaries and the main channel of Fisher Creek that were collected from 1989 to 1996 as part of the baseline studies for the CBMI project. A metal loading study was conducted on this data and 20 direct inputs to Fisher Creek were identified. The studies indicate that the major in flows for metals loading into Fisher Creek are the Glengarry adit, the runoff from Fisher Mountain adjacent to the Glengarry adit, the runoff from the Como Pit up-gradient of the Glengarry adit, and leachate from the waste rock dump in front of the adit (Table 1). These four sources contribute nearly 70% of the copper load, 67% of the aluminum load, 75% of the manganese load, and 95% of the iron load into Fisher Creek at base-flow conditions. Two additional tributaries from Fisher Mountain (FCT-1 and FCT-14) contribute an additional 20% of the copper load.

Table 1. Mean Contributions from Major -Sources

Source	Description	Mn%	Fe%	Cu%	Al%	SO_4%
F-8A	Glengarry adit	39.9	65.3	20.2	15	9.3
FCT-12	Runoff from Fisher mountain	1.1	0.4	14.3	6.4	1.8
FCT-11	Runoff from the Como Pit	19.7	16.8	21.1	25.5	8.2
FC-2	Leachate from waste rock dump in front of Glengarry adit	14.4	12.9	13.8	20	8.6
	Total	**75.1**	**95.4**	**69.4**	**66.9**	**27.9**

Amacher noted a marked temporal variation in the relative contribution of the four major sources from snowmelt to base-flow conditions. In May, under base flow conditions, the Glengarry adit accounts for most of the dissolved copper load to Upper Fisher Creek. As snowmelt begins in June and proceeds into July, runoff from Fisher Mountain and the Como Pit account for most of the dissolved copper load. In the fall, the Glengarry adit again accounts for majority of the copper load. Through the snowmelt season, the load contribution for metals from groundwater is significant. Thus, reduction of flow from the Glengarry adit will only result in significantly lowering metal concentrations at base-flow conditions. It is also possible that reduction in flow from the Glengarry adit may result in an increased flow of more highly contaminated water from the Como Basin. Remediation of the mine spoil on the Como Pit is needed to reduce runoff inputs from this area. Amacher suggests a combination of limestone addition and soil cover would provide a suitable media for establishing vegetation and reducing metal loading. Limestone additions reduce metal loading by lowering the pH of the soils and the water that passes through them and thereby decrease the solubility of metals. Vegetative cover decrease the amount and rate of water infiltration.

Amacher further speculated that due to the high acidity in the upper reaches of Fisher Creek, metals might continue to leach from stream sediments and precipitates. Studies by Amacher also show that in-stream iron concentrations are controlled by ferrihydrite precipitation, aluminum concentrations are controlled by aluminum hydroxide precipitation (above pH 5.5), and copper is controlled by sorption on ferrihydrite. There is a large temporal variation in iron speciation in the stream that results in changes in dissolved metal concentration during the day in Fisher Creek.

During a working lunch break; **Allan Kirk** presented a slide show of **historical pictures from the McLaren Pit, Como Basin, and Glengarry Mine areas.** These photos show mining and exploration disturbances from a period of time prior to the reclamation activities of Crown Butte Mines (1989 - 1992).

DISCUSSION

The following were discussed (not necessarily in this order) during the afternoon discussion session.

Amacher pointed out and Cannon agreed that, in general, both the loading studies are in agreement with regards to the major inflow sources that are contributing metals to Fisher Creek. At least 60% of the sources contributing metal loading into the creek have been identified as surface sources. The Glengarry adit and the waste rock dump in front of the adit are two major sources of metal loading into Fisher Creek. Runoff from the Como Pit is another major contributor as is the tributary that drains the northwest slope of Fisher Mountain (unmined area). While there is metal loading from diffuse subsurface flows, it is not necessarily in the upper reaches of Fisher Creek. The subsurface flows will prove difficult to remediate, as they don't seem to be associated with any particular mining-related activity, and could very well represent natural acidic drainage. A substantial effort would be required to try to identify all the subsurface diffuse flows. If these subsurface flows prove to be natural drainage, there might not be much that can be done to control these sources.

Amacher and Kirk discussed that a phased approach should be taken for remediation of this site. As four major sources have already been identified, these four sources should be addressed and the effects on Fisher Creek observed prior to taking any additional action.

Amacher reiterated that it is important to keep in mind that equilibrium processes control metal concentrations in the stream and so a simple mass balance will not be able to accurately predict the effect of remedial actions. For example, eliminating the Glengarry adit as a source will lead to a decrease in copper-loading in the upper reaches, an increase in pH, and a reduction of iron loading in the stream. These changes will effectively change the dynamics of copper sorption on ferrihydrite colloids. With such chemical complexities at work, eliminating this major source might not lead to an acceptable water quality in the downstream reaches of the creek.

Mike Cannon and Pat Dunlavy, Maxim Senior Hydrologist, stressed the importance of the fact that the cross-sectional area and distance represented by the Glengarry adit as it intercepts fracture-flow through the subsurface of Upper Fisher Creek is trivial when compared with the overall mass of rock through which water is flowing. Both agreed that considerably more water was flowing through the rock mass as a whole, some of which is discharged to Fisher Creek from ground water sources.

Joe Gurrieri, Hydrogeologist with the USFS, seconded this understanding of groundwater flow.

Kirk emphasized that we have very good control of the subsurface geology in the vicinity of the pit (from mapping and drill data), and good control of the surface geology of Upper Fisher Creek and the Glengarry adit from several rounds of geologic mapping. In addition, we have a very complete record of surface water flow and geochemistry from Upper Fisher Creek and the Glengarry adit. He further pointed out that while groundwater data is somewhat lacking, we do have water quality data and piezometric data from a number of wells in Upper Fisher Creek, over a number of years. He also thought that the 3-D block model of the hydrogeology of Upper Fisher Creek drainage would be a useful exercise for the group and would provide us with an excellent graphical tool to present to various agency personnel and the public as an aid in understanding the complexities of the Upper Fisher Creek drainage. This should be completed and available in late winter of 2001.

Kirk reiterated the point discussed earlier in the day and at previous meetings that it was unlikely that Montana water quality standards would be met in Upper Fisher Creek because the identified major sources of contamination are not the only sources of contamination in the drainage basin. He also emphasized that water in Upper Fisher Creek and flowing from the Glengarry adit was more than 2 orders of magnitude greater than the standard, and when these facts are combined with the conclusions of Amacher above (concerning remobilization of copper and other metals from ferric hydroxides), standards probably cannot be met in the upper reaches of Fisher Creek until reaching a point downstream where they are diluted by tributary and groundwater sources. (This presently occurs about 1.5 miles below the Glengarry adit at the confluence of Fisher Creek with Lady of the Lake Creek). We do not really know where this point might be if the four major sources are significantly reduced. But, if we could make some estimates of reduction, we might be able to calculate equilibrium for the creek.

Bill Botsford, a hydrogeologist with the Montana Department of Environmental Quality (MDEQ), indicated that not meeting water quality standards was probably not going to be acceptable to the state, and mentioned a nearly completed draft version of Total Maximum Daily Load (TMDL) standards for Daisy and Fisher Creeks in the New World District that was being crafted by the state (Soda Butte Creek standards were temporarily on hold).

At this point, **Kirk and Marks** asked that we review two of the original three questions, What don't we know? and, What do we need to know to effectively implement closure plans? In general there was agreement that we had the information we needed to know to design our conceptual and alternative plans for closure of the Glengarry Mine and Upper Fisher Creek (Como Pit and downstream erosion channels). There was some concern by **Stanley and Botsford** that there was a lack of understanding of groundwater flow and quality that may be able be addressed by additional tracer studies. The group discussed this at some length. I do not believe that there was a general consensus reached on the merits of addition tracer and groundwater flow studies. Unfortunately **Mr. Bob Wireman, US EPA Denver** – a proponent of tracer studies – was not present at the meeting. **Marks** suggested that we defer the discussion of tracer studies for a separate meeting of concerned technical people at a time when Mr. Wireman could attend.

REFERENCES

Amacher, Brown, Sidle, and Kotuby-Amacher, "*Effect of Acid Mine Drainage on Headwater Streams in the Beartooth Mountains, Montana*," Poster Presentation at the SSSA 1991 Meeting, Oct 27-Nov1 1991, Denver, CO.

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Kimball, Nimick, Gerner and Runkel, " *Quantification of Metal Loading in Fisher Creek Using Tracer-Injection and Synoptic Sampling Studies, Park County, Montana*," USGS Draft Report, August 1997.

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URS, 1998, Site Assessment and Sampling Activities Report, New World Mine, Cooke City, Montana: START Report delivered to the EPA, Region VIII, 107 p

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Meeting Agenda

Hydrogeology of the Como Basin, Glengarry Mine and Upper Fisher Creek Drainage New World District, MT

10:00 AM to 4:00 PM City Center - Best Western Motel Bozeman, MT

Introduction (Updated status of the New World Reclamation/Construction Activities) Como Basin /Glengarry EECA, Overall Objectives) Mary Beth Marks	10:00
Meeting Objectives and Reclamation Program Goals, Allan Kirk	10:15
Geology, Allan Kirk	10:20
Glengarry Mine: Water Quality and Flow, Henry Bogert	10:40
Surface and Groundwater Quality, Upper Fisher Creek, Dan Stanley	11:00
Tracer Studies, Dan Stanley and Mike Wireman (?)	11:30
Working Lunch (ordered in) - Historic Site Photography, Allan Kirk	12:00
Metal Loading in Fisher Creek (Spatial Water Quality data), Mike Cannon USGS	12:45
Metal Loading in Fisher Creek (Spatial Water Quality), USFS (Amacher or Kirk?)	1:15
Surface and Groundwater Flow (lead in to discussion), Dan Stanley and Pat Dunlavy and USGS (may lead directly into discussion below)	1:30
Discussion, Group (What we know, what we don't know, what we need to know)	2:00
Conclusions, Summary and Lessons Learned	3:50
Adjourn	4:00

All discussions are informal (not necessarily expecting a lot of preparations and graphics support), and designated leaders of discussions (above) may not be the only speakers, indeed they may not be the speakers at all. Presentations are to review what we know. Discussions will be focused on our understanding of the Upper Fisher Creek drainage, its geology, hydrology and resulting water quality. They will also focus on what we need to know and how it might or might not affect or possible closure options.