Analysis of the Potential Effects to Groundwater Resources from the Proposed Golden Meadows Exploration Project
(2015 Revision)

Prepared by John Rygh, PNF Geologist

Analysis of the Potential Effects to Groundwater Resources from the Proposed Golden Meadows Exploration Project
(2015 Revision)

Introduction

This report is organized into three main topic areas: 1) geology and hydrogeology, 2) proposed drilling procedures, and 3) analysis of potential effects to groundwater resources. The project area is located in the Stibnite mining district of central Idaho (Fig. 1).

Geology

Bedrock Geology

The oldest rocks in the project area are Late Proterozoic metasediments, which include quartzite, marble, schist, dolomite, and calc-silicates that outcrop throughout the West End Creek and Midnight Creek drainages. These rocks strike northwest and dip steeply to the northeast. They form a roof pendant overlying Cretaceous granites, granodiorites, and quartz monzonites of the Idaho Batholith. Three major northeast-striking fault zones (West End, Scout Ridge, and Garnet Creek) cut the metasediments. All of these faults intersect the younger Meadow Creek fault zone which trends north-south and swings northeastward near the Yellow Pine pit (see Fig. 2).

The three significant ore bodies in the area are associated with the Meadow Creek and West End fault zones. These are distal disseminated gold-silver deposits (Bookstrom et. al. 1996) that were formed by hydrothermal fluids circulating through highly fractured and brecciated areas of the fault zones. At least four periods of brecciation and mineralization have been identified in the area (Cookro et. al. 1988). Although subsequent cementation and alteration have reduced the bulk permeability of the rock to a certain extent in some parts of these fault zones, it is this pervasive fracturing that makes them much more likely to host aquifers than the less fractured surrounding bedrock.

Surficial Geology

Pleistocene glaciation and subsequent secondary outwash is responsible for alluvial deposition on the valley floors. These deposits consist primarily of sands, silty sands, boulders, cobbles, and gravel, with less frequent silt and clay. The thickness of the alluvial deposits ranges from little or nothing on some side slopes, to over 200 feet in parts of the Meadow Creek drainage as well as parts of the valley floor adjacent to the East Fork South Fork Salmon River (EFSFSR).

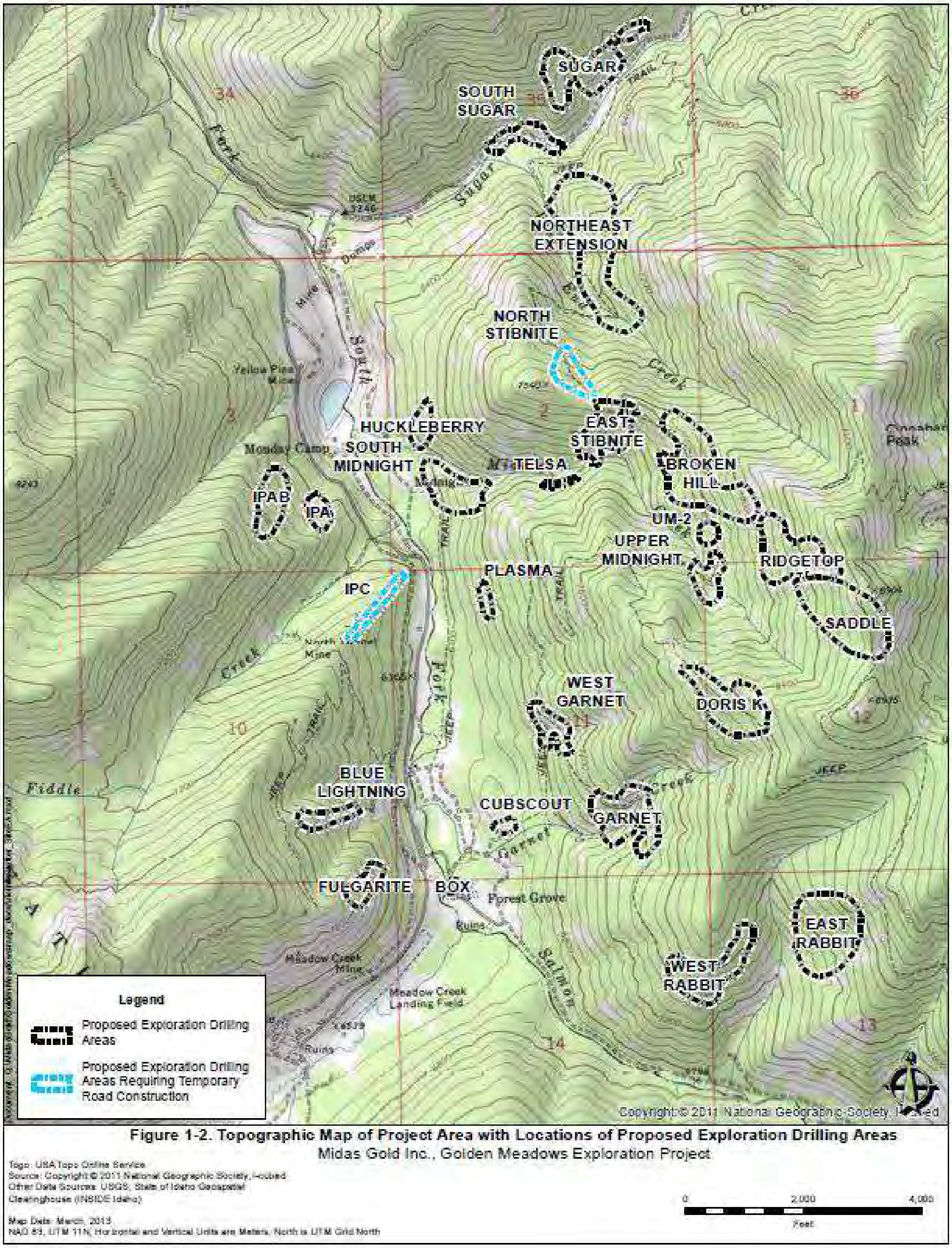


Figure 1: Location map with drill areas.

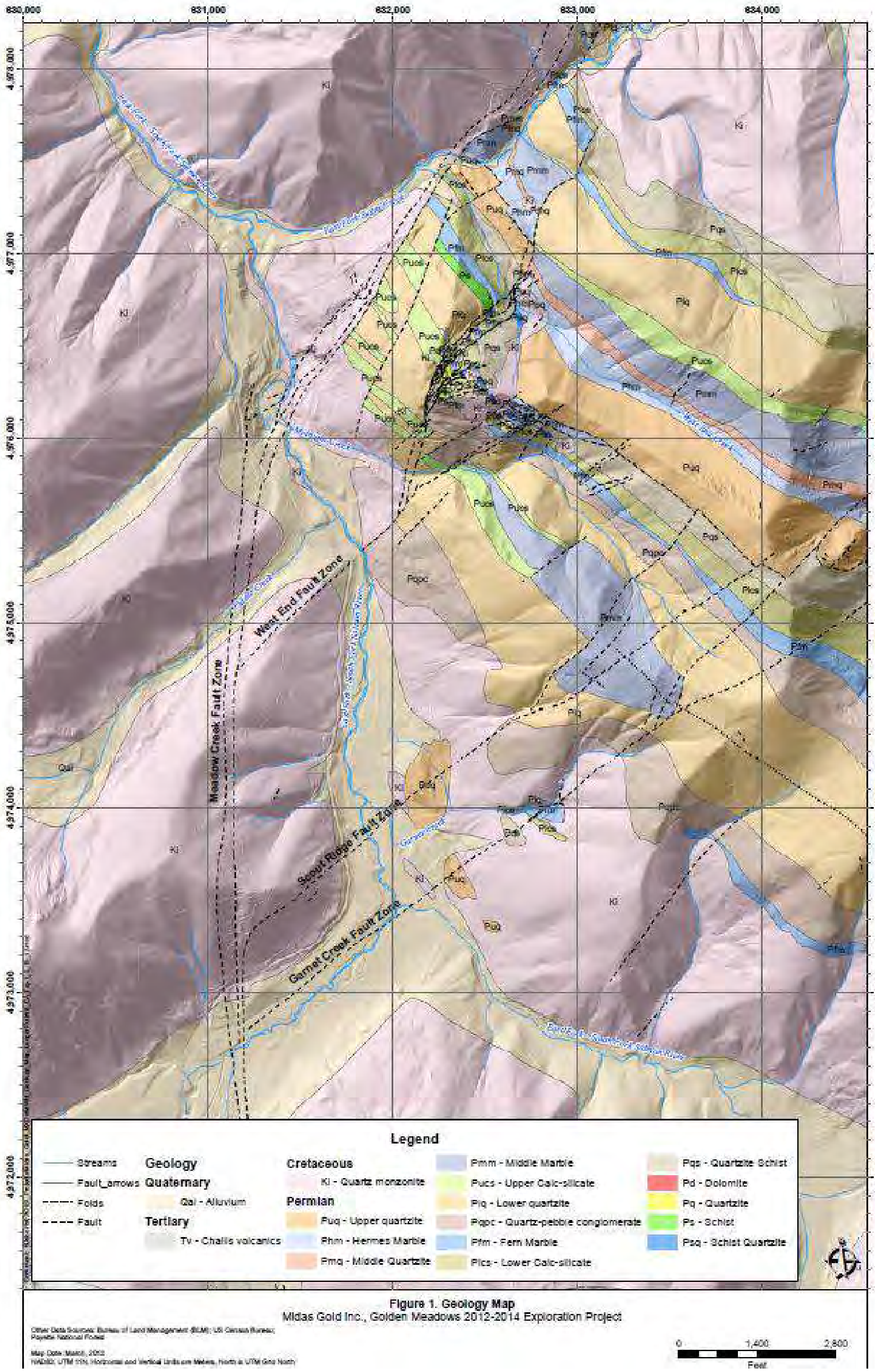


Figure 2: Geologic map.

Hydrogeology

There are two main types of aquifers present in the project area; alluvial aquifers and bedrock aquifers. Alluvial aquifers are relatively shallow and occur in permeable zones (e.g. sand and gravel beds) within the glacial deposits along the valley bottoms. Bedrock aquifers are those that occur within fractures in the crystalline rocks that make up the surrounding highlands and lie beneath the valley alluvium (Fig. 2). The following sections provide a description of existing conditions and constitute an adequate characterization of these aquifers for the purposes of this analysis.

Meadow Creek Alluvial Aquifers

Unconfined aquifers occur within most of the alluvial deposits in the Meadow Creek valley. The alluvium thickness and depth to bedrock in the Meadow Creek valley increase from less than 100 feet above the South Fork of Meadow Creek to over 200 feet in the lower portion of the valley (IDWR well logs, Naylor 2012). The entire depth of the alluvium does not constitute a homogenous aquifer however. As can be expected with the characteristic poor-sorting of most glacial deposits, aquifer permeability has a high degree of both vertical and horizontal variability; some zones are more productive than others.

The water table throughout most of the Meadow Creek valley is quite shallow (0-30 feet). The only well in the valley that had an aquifer pumping test produced more than 100 gallons per minute from an open interval in a sand/gravel zone at 99-109 feet. The productivity of the near-surface aquifer is not likely to be this high. Although there are no records of shallow well tests in the Meadow Creek drainage, aquifer pumping tests of eight alluvial wells in the nearby EFSFSR drainage have given estimated discharges ranging from 1-30 gallons/minute with an average of 10 gallons/minute (Appendix A1).

Recharge to the alluvial aquifers comes from direct infiltration of precipitation on the valley floors, shallow groundwater flow from rainfall and snowmelt that has infiltrated the colluvium on the surrounding hillsides, and groundwater underflow from bedrock aquifers (URS 2000). For the most part, shallow groundwater in the Meadow Creek valley flows obliquely from the valley sides toward the creek to discharge as baseflow (URS 2000). Discharge also occurs by evapotranspiration and flow from seeps and springs. No information is available about possible deeper flow paths below the shallow monitoring wells. Groundwater quality studies (URS 2000) have identified elevated levels of arsenic and antimony that exceeded state standards in groundwater, seeps, and springs in the Meadow Creek valley. State groundwater standards are 50 µg/l for arsenic and 6 µg/l for antimony. Naturally high levels of arsenic up to 2600 µg/l were found in springs near the mineralized Meadow Creek Fault Zone. The highest levels of dissolved arsenic and antimony were associated with groundwater that had been in contact with mill tailings deposited during previous mining activity. Concentrations of arsenic and antimony ranged from 500-13,800 µg/l and 200-2000 µg/l respectively in water samples influenced by the tailings. Reclamation projects have been implemented since the period of these studies (primarily 1996-1997), so although arsenic and antimony concentrations may have changed since then, the baseline groundwater quality study currently being conducted has not noted anything that stands out as dissimilar to the general findings of the URS site characterization report (personal communication, Lauren Perreault, Environmental Scientist, HDR, 2015).

The above information is provided as a characterization of an aquifer that is within the area of past operations generally known as Stibnite, but is outside any of the presently proposed drilling areas (with the exception of the west side of the Box drilling area). Since the drilling locations proposed within the Box area are located on the east side of the EFSFSR, they could have effects to the EFSFSR alluvial aquifers described below, but not to the Meadow Creek alluvial aquifers.

EFSFSR Alluvial Aquifers

Unlike the Meadow Creek alluvium, the glacial deposits in the EFSFSR have been subject to more significant post-glacial stream erosion resulting in a shallower depth to bedrock near the stream (50-80 feet), but similar depths (150-180+ feet) on the lower slopes of the canyon (IDWR well logs). The depth to water is roughly 10-20 feet near the EFSFSR and 50-90 feet on the slopes above. Wells in these aquifers produce about 10 gallons/minute on average with a single exception of 100 gallons/minute.

The same pathways for aquifer recharge described for the Meadow Creek alluvial aquifers apply here. Groundwater likely flows a little more directly toward the river from the valley sides where it discharges as baseflow. Discharge also occurs by evapotranspiration and flow from seeps and springs.

Groundwater quality in most of these aquifers appears to be consistent with natural mineralization (URS 2000). Some samples exceeded state groundwater standards for arsenic and antimony. Arsenic values from the 1997 sampling period ranged from 4-266 µg/l with an average of 77 µg/l. Antimony values were 2-138 µg/l with a 39 µg/l average. The samples were all from alluvial aquifers, many of which may be influenced by nearby bedrock fault zones. There are no drilling areas other than the Box area that would penetrate the EFSFSR alluvial aquifers.

Bedrock Aquifers

All of the boreholes have the potential to penetrate bedrock aquifers. Crystalline bedrock in general is usually quite heterogeneous with respect to hydraulic properties. As Gustafson and Krasny (1994) put it:

> The most striking hydrogeological feature of a fractured crystalline rock is the overwhelming variability of its properties. A parameter such as the hydraulic conductivity determined by classical field methods normally varies by several orders of magnitude within the same rock unit and often with short distances. The reason for this is that it is not the rocks themselves which transmit the groundwater, but the fractures and fissures that form conductive openings through the basically impervious rock matrix.

Figure 3 is a diagram of the relative fracture distribution in a massive crystalline rock formation such as granite. As a conceptual model, this may be useful in explaining some of the observed occurrences of bedrock groundwater in the project area. The top of the bedrock is characterized by a zone of relatively dense fractures that tends to be subparallel to the surface topography. This horizon is a result of weathering, lithostatic unloading, and other processes. Any groundwater in this zone tends to flow more or less parallel to the topography. Below this the fracture density declines with depth, with only deep fracture zones providing significant permeability within the basement. It is the deeper lower permeability basement that likely best represents the bedrock conditions where the bedrock monitoring wells mentioned below have encountered groundwater.

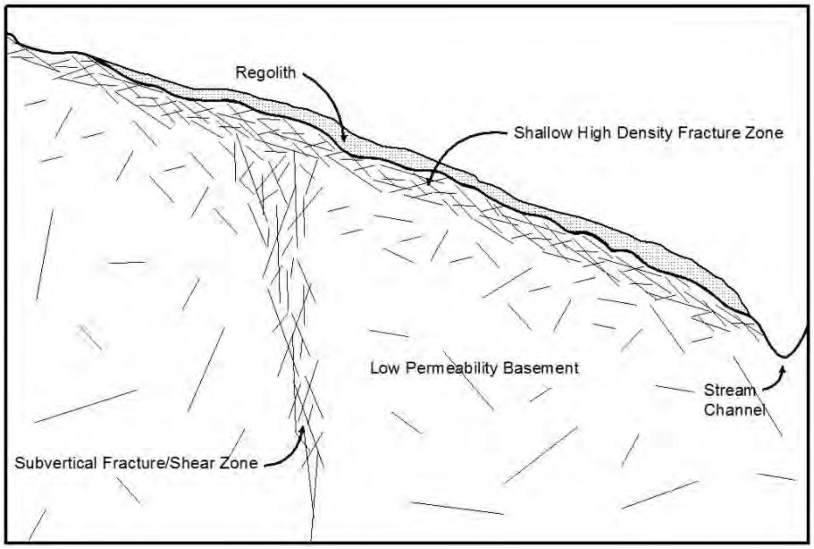


Figure 3: Generalized bedrock fracture distribution. (Dewandel et. al. 2006)

Discussions with drillers and geologists at Stibnite indicate that groundwater within bedrock is generally absent or occurs in limited quantities in fracture zones (Naylor 2012). Although almost all of the 23 existing bedrock monitoring wells in the Stibnite area (Appendix A2) have encountered some groundwater at highly variable depths (25 to 294 feet), those that had aquifer pumping tests had very low productivity. The average estimated discharge from the four holes that were tested is 0.4 gallons per minute. This is even lower than a more regional average of 6.0 gallons per minute, calculated from all domestic water wells that produced water from bedrock aquifers in the Yellow Pine, Johnson Creek, and Big Creek areas (Appendix A3). These areas are located 9, 8, and 12 miles from Stibnite respectively and have very similar bedrock geology.

Fault and fracture zones can form localized regions of much higher permeability within relatively unfractured bedrock. One exception to the generally poor productivity of bedrock monitoring wells is well MWH-B20 which is drilled into the West End Fault Zone. This well has multiple water production zones totaling 50 gallons per minute. In addition, artesian conditions have been encountered in a few previous exploration boreholes that have penetrated through faults in the West End and Yellow Pine pit areas at depths of a few hundred feet (Naylor 2012). Thus it is the fault zones, primarily the Meadow Creek Fault and the West End Fault, and probably to a lesser degree, the Garnet Creek Fault and the Scout Ridge Fault (see Fig. 2) that host the only bedrock aquifers that might be considered significant relative to the local area. It should be kept in mind that relative to other more productive aquifers in the state, these localized fault zone aquifers are of very limited importance from the standpoint of beneficial uses. Since these fault zones have near vertical dips, it is likely that recharge of the aquifers occurs in topographically high areas and flow is parallel to the fault plane toward discharge points at topographic lows.

Water samples associated with these bedrock fault zone aquifers have levels of arsenic and antimony that exceeded state standards in most cases (URS 2000). There are three sources of data in the URS report that support the conclusion that fault zone aquifers in the project area are naturally elevated in arsenic and antimony. Springs and seeps that are likely influenced by fault zones have an average arsenic concentration of 97 µg/l and an average antimony concentration of 48 µg/l (Appendix A4). Bedrock monitoring well concentrations in the vicinity of the West End fault zone average 130 µg/l arsenic and 33 µg/l antimony. Although these two averages agree reasonably well, in no instance can possible influences from alluvial groundwater or previous mining activity be completely ruled out. Probably the strongest evidence for naturally elevated metals concentrations associated with fault zone aquifers comes from sampling that was done in 1978 prior to mining in the West End area. Water samples taken directly from the West End fault zone averaged 700 µg/l arsenic and 13 µg/l antimony, while samples taken at the upgradient edge of the fault contained an average of 45 µg/l arsenic and 7 µg/l antimony (URS 2000).

The association of high arsenic and antimony waters with fault zones is not surprising, since the fault zones acted as the primary conduits for mineralizing fluids during ore emplacement. Arsenopyrite and stibnite are common minerals in the ore zones and the natural oxidation of these minerals releases dissolved arsenic and antimony to the groundwater. It is likely that the more strongly fractured and mineralized portions of these fault zones (e.g. the West End area) have higher concentrations of dissolved metals than those sections that are less so.

Groundwater containing elevated levels of arsenic and antimony would likely be encountered to some extent during the drilling of exploration boreholes that penetrate bedrock fault zones in the area. Drilling procedures described below would minimize the mixing of waters from different sources.

Drilling procedures related to groundwater resource protection

Core drilling is a mineral exploration technique designed to recover subsurface rock samples used to determine the extent and quality of an ore deposit. The method has been in use by the mining industry for over one hundred years. Core drilling has many similarities to water well or oil and gas well drilling, but there are some important differences. Probably the most important difference that is relevant to groundwater protection is the objective of creating the borehole. A successful water, oil, or gas well is primarily designed to allow fluid to be removed for an extended period of time from an underground rock formation. A core hole is simply a conduit to remove a rock sample from underground. It has no long-term use and is plugged shortly after completion (see abandonment section). Core drilling rigs are substantially smaller than oil and gas rigs and the capacity of their mud pumps is correspondingly smaller.

A core drilling rig uses a cylindrical, diamond-studded bit (Fig. 4) to drill through rock. The hole is deepened by adding sections of pipe to the drill string. The resulting cylinder of rock (the “core”) is retrieved from the bottom of the hole periodically by means of a cable and liner tube system. During drilling operations, drilling fluid or ‘mud’ is continuously circulated by means of pumps in a “closed loop” system. The mud is so called because it is a mixture of a naturally occurring clay (sodium bentonite) and water along with minor amounts of additives. The mud travels from the pump down the hollow center of the drill string to the bit, where it exits the drill string through radial slots in the cutting surface of the bit. It then travels up the outside of the drill string through the space created by the slightly larger diameter bit. This space between the drill string and the outside wall of the borehole is called the “annular space”. The mud returns to the surface through the annular space (or the casing if it has been set) where it runs into either a sump or a portable recirculation tank that allows the drill cuttings to settle out before the mud is recirculated down the borehole. Sumps are the preferred method of drilling fluid storage at most locations, while portable tanks are an option that may be used for drilling sites located in RCAs or on very steep slopes.

Figure 4: Diamond core drill bits.

A sump is an unlined excavated pit adjacent to the drill pad. A typical sump is approximately 6 feet wide, 12 feet long, and 3 feet deep. Drilling fluid containing cuttings from the drill hole returns to the surface where it flows through a short ditch to the sump. The sump is divided into compartments in order to slow the flow of drilling fluid from the point of inflow to a mud pump on the other end of the sump. This allows the drill cuttings to settle out. The cleaned mud is then pumped back to a mixing/holding tank where it is recirculated back down the hole. When the sump is first used there is a short period when drilling fluid will infiltrate into the surrounding material before the bentonite seals the pit in the same way that it creates filter cake down the hole. Infiltration rates and volumes will depend upon the permeability of the soil at each drilling location. Once the hole is completed, all the mud is pumped into the sump for disposal. The mud and cuttings are allowed to dry out (primarily by evaporation, since most infiltration has ceased by this time) and then the sump is backfilled with the excavated material.

For drilling pads located on very steep slopes or in RCAs unlined excavated sumps would not be used. Instead, a small lined sump (approximately 3 feet square and 2 feet deep) would be located adjacent to the drill hole casing. A mud pump would then transfer the mud either to a remote unlined excavated sump or a portable recirculation tank. The decision to use either of these options on very steep slopes is made in the field prior to moving a drill rig in. The primary consideration is reducing the risk of a slope failure due to saturation of soils. A number of factors including slope angle, soil permeability, and soil depth are taken into account when making the decision to use an unlined excavated sump or not. On slopes greater than 35%, the selected locations would be reviewed and approved by Forest Service personnel.

If a remote sump is used, mud is transferred to and from the sump location via pumps and double-jacketed hydraulic lines. The remote sump location would be located outside any RCAs and in an area of stable ground (generally old road beds or localized areas having a low slope angle). If a tank is used it is located on the pad or platform and mud is recirculated back down the drill hole from the tank. Final disposal of drilling mud from a tank is done by pumping it to a location where it can be collected by a pickup-mounted vacuum tank and then transported to a large collective sump.

The following is a detailed description of the drilling of a core hole and explains how the standard operational procedures (SOPs) are protective of groundwater. All of the SOPs described are designed to assure compliance with relevant regulatory standards. The primary ones pertaining to groundwater protection are:

- The Idaho Ground Water Rule (IDAPA 58.01.11)
- Idaho Rules Governing Exploration, Surface Mining Closure of Cyanidation Facilities (IDAPA 20.03.02)
- The Idaho Well Construction Standards Rule (IDAPA 37.03.09)

The Well Construction Standards Rule is indirectly applicable in that mineral exploration boreholes are not considered to be wells and therefore are not subject to the standards of the rule. However the rule does require that the construction of such boreholes meets the intent of the regulations which is "to protect the ground water resources of the state against waste and contamination", implying that the exact letter of the rule need not be strictly followed as long as the intent is met. All of the SOPs meet the intent of the rule and in almost every instance meet or exceed the standards.

First the drill pad is prepared prior to and during the moving in of a drill rig. The site is leveled (or a wooden platform is built) and graded to drain surface runoff to a point where the water can be managed. Depending upon the location, mud sumps are excavated or mud tanks are placed as described above. Silt fencing, straw bales, and/or sediment traps are used for water management and erosion control on the pad. Petroleum products are kept in containment and spill prevention kits are available on site in order to minimize the risk of a surface spill of hazardous materials infiltrating a shallow aquifer. The drill itself is placed on an impervious material (such as HDPE liner material) to retain any petroleum products. Lubricants, such as pipe thread lubricant, are a food grade vegetable product.

Once drilling commences, the first formations to be penetrated are usually unconsolidated or semi-consolidated alluvial or colluvial material. In upland locations this is often a thin layer overlying bedrock and may not contain any perennially saturated zones that would constitute an aquifer. On the lower slopes and on the valley floors (e.g. at the Box drilling area), the thickness increases and alluvial aquifers may be present.

As the drill string passes through the alluvium, it is the mud that serves to prevent inflow or outflow of significant volumes of fluid to or from the borehole. Mud has a higher density than plain water and contains large quantities of extremely fine clay particles. When drilling through an unconfined aquifer, the pressure exerted by the column of mud in the borehole (the hydrostatic head) always exceeds the water pressure in the aquifer. Because of this pressure differential, the mud can seep out of the borehole into the formation. The interconnected pores of the alluvial sediments act as a filter that traps the bentonite particles along with the entrained drill cuttings (sand sized particles) to form a coating on the surface of the borehole known as "filter cake"(Fig. 5, Campbell and Gray 1975). It is the filter cake that confines most of the drilling mud to the borehole. Seepage of fluid through the filter cake is discussed in the groundwater chemistry effects section.

Water can also flow into a borehole from the formation if the hydrostatic head in the aquifer exceeds that of the mud column, as could be the case with a confined aquifer. Minor gains in water similar in volume to the seepage losses through the filter cake are ignored. More substantial inflows to or outflows from the borehole are sealed off (see fluid loss/gain section). In order to stabilize the alluvial section of the borehole and further minimize fluid losses or gains during drilling, casing is advanced simultaneously behind the core drill. Casing is a steel pipe that has a slightly larger diameter than the core drill. A casing "shoe" (essentially a hollow diamond impregnated bit) is used on the leading edge of the casing string to advance it by means of rotational drilling. The casing is advanced incrementally down the hole by using the core drill to drill a pilot hole, drilling the casing down to the bottom of the pilot hole, then repeating the process until solid bedrock is reached. This "drill-within-a-drill" method creates an annular space between the outside of the casing and the borehole wall.

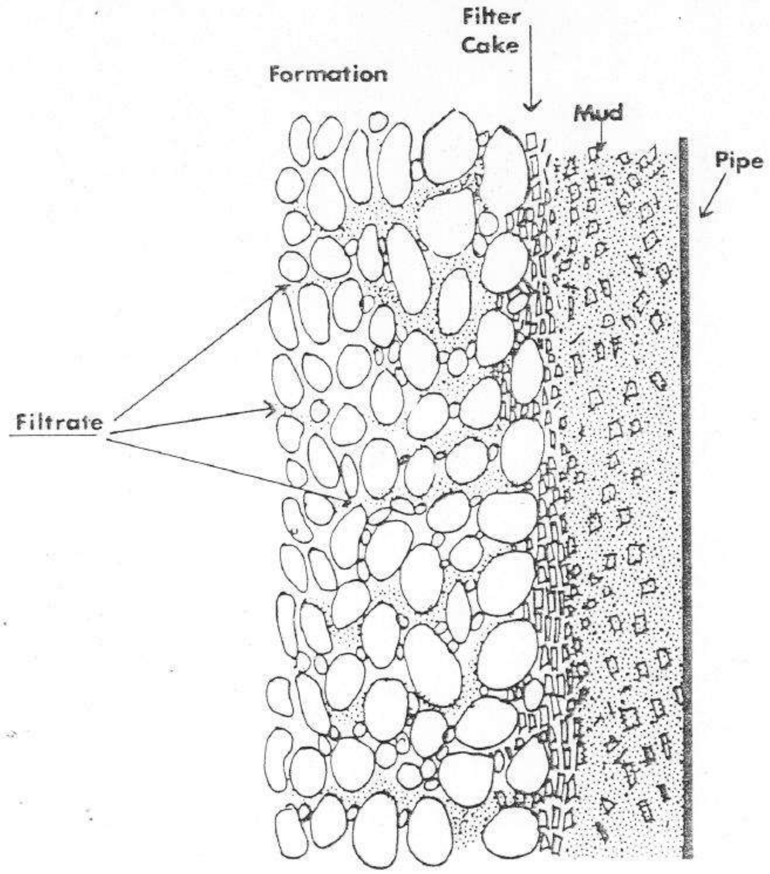


Figure 5: Formation of filter cake (Campbell and Gray 1975)

Once the alluvium has been drilled through and the hole has penetrated sufficiently into solid bedrock, surface casing is set in place by sealing the annular space. For this project bentonite or neat cement would be used as sealants. Sealing is done by removing the drill string and pumping the grout mix down the inside of the casing. The grout is mixed (using a roughly 150% estimated volume) in a separate tank and pumped down the hole with a rubber plug behind it (between the grout and the regular mud). As the grout rises inside the annular space the casing is rotated to ensure a more even distribution of grout within the annular space and prevent the formation of any linear voids due to preferential flow paths. After the grout begins flowing at the surface from the annular space around the casing, pumping continues until the pressure spikes. This indicates that the plug is on bottom. If bentonite grout is used the top three feet filling the annular space is removed and replaced with neat cement. After the annular grout has set up, the plug is drilled out and drilling continues into bedrock. Any aquifers within the alluvial formations are now completely sealed off from each other, from surface water, and from any aquifers that may be encountered deeper in the bedrock. All mud circulation above the casing bottom takes place within the casing.

Drilling in the bedrock continues in the same manner as in the alluvium. The only difference is that bedrock permeability is controlled primarily by the aperture size and density of interconnected fractures, rather than interconnected pore space as is the case in alluvial formations. Under normal drilling conditions filter cake forms on the borehole walls in the same manner as when drilling through alluvial formations. The higher permeability fault zones and fracture zones that would be encountered in some of the proposed holes are the most likely areas to produce drilling fluid losses or gains.

Drilling Fluid Loss/Gain

Normally the development of filter cake is quite rapid, however if a zone of very high permeability and low relative pressure (e.g. a coarse gravel lens, or highly fractured bedrock) is encountered, the drilling fluid flows farther into the formation before a filter cake can form. This is referred to as “lost circulation”. It is necessary to prevent substantial fluid losses to lost circulation zones (LCZs) otherwise there is an increased risk of problems such as binding of the drill string from sloughing and an inability to circulate cuttings out of the hole.

Lost circulation can be recognized by the driller who is watching the mud return flow at the top of the hole and the mud pump pressure gauge. If the flow rate drops off and the pressure drops, then lost circulation is occurring. Generally a gain or loss of 10% (approximately 25 gallons in a 1000’ hole) or more of the drilling fluid alerts the driller to an inflow/outflow condition (Tim Rygg, Midas Gold Drilling Supervisor, personal communication). The speed and duration of mud loss are dependent upon the formation permeability and the pressure differential. If mud flow is still present at the surface, drilling continues and full flow often returns as the lost circulation zone is sealed.

Several mechanisms act to promote sealing in these instances of moderate circulation loss. As the drill cuttings in the mud are carried into the formation, individual particles or aggregates become stuck at points where they form bridges spanning various apertures in the flow paths. These plugs then act to filter out the even smaller bentonite particles to form localized areas of filter cake. Additionally, bentonite muds are thixotropic which means that they coagulate into a highly viscous gel when not subjected to shear stresses (e.g. pumping). Thus, when “dead zones” in the flow form within the formation they tend to gel and flow no further.

Total Loss of Returns

If a LCZ is encountered where the driller observes a strong pressure loss and a complete cessation of mud flow at the surface (referred to as a “loss of returns”) then a different approach is called for. Drilling stops and mud is circulated in an effort to allow the zone to seal which is indicated by the resumption of mud flow at the surface. If the driller hasn’t gotten returns back within about three minutes, they stop circulating and prepare a 25-40 gallon slug of lost circulation material (LCM) (John Eddy, T&J Drilling Foreman, personal communication). There are many types of lost circulation material available, but high-solids bentonite grouts (Holeplug®, Quik-Grout®) would primarily be used for this project. Unlike standard bentonite drilling mud which has a solids content of 10-20%, the bentonite grouts have a solids content of 70%+, which produces a highly viscous fluid with the approximate consistency of peanut butter. The LCM is prepared separately and pumped down the hole. Usually this successfully seals the LCZ.

If the lost circulation material still doesn’t control fluid loss, then a variety of more aggressive methods can be used. The LCZ can be cemented and drilled through, or the existing drill string can be used as casing and cemented in through the LCZ. In the latter case, a smaller drill bit and pipe would be used inside the new casing to drill onward. This stepping down of pipe sizes can be done more than once if necessary.

Surface Discharge of Drilling Fluid

In some cases of substantial lost circulation, drilling mud can discharge at the ground surface downslope of the borehole. The risk of this occurring is greatest when drilling through poorly consolidated alluvium or heavily fractured bedrock near the ground surface on steep slopes. Incidents of this nature have occurred during past drilling projects at Stibnite.

At the time of publication of the second EA, there were two known instances in 2012 when drilling mud discharged downslope from a drill site. One of these was actually a surface spill when a mud mixing tank overflowed. The other occurred due to a loss of circulation either into old underground workings or blast fracturing in the Homestake area which subsequently discharged at the surface. Proper response measures were implemented, and the environmental consequences of the incidents were negligible. Details of these events can be found in the BMP monitoring logs (Rygh, 2012a, 2012b).

It has since come to the attention of the Forest Service that six other instances of mud coming to the surface below the drilling rig occurred in 2012 (Smith, 2012). In all instances a small amount of drilling fluid reached live water. All of these events occurred on private ground and were associated with attempts to drill underneath the Yellow Pine pit. Five of the events occurred in historically blast-fractured rock around the pit, while one (the Hennessey Creek hole) was due to drilling a shallow-angle, uncased hole in poorly consolidated alluvium. Once the surface discharges of mud were discovered, the drilling crews were able to implement response measures during these events (mud pumping was halted, surface flow of mud was contained, and the LCZ was promptly cemented). Details of the events and the response actions taken are described in an attachment to the aforementioned document. On-site personnel considered the effects of these events to be minor and did not feel they warranted a 24-hour notification to EPA. EPA has not responded to the report. These events were relatively uncommon, occurring in approximately 5% of the total holes drilled. The Homestake area events were not documented as part of this report because although the mud reached an old man-made sediment retention pond, it did not reach a natural stream channel and thus was not required to be reported.

These experiences in 2012 have led to MGI developing SOPs designed to minimize both the risk of surface discharge occurring and the risk of drilling fluid subsequently reaching live water. These SOPs were implemented during the 2013 drilling season. Many of the holes drilled in 2013 were in the same blast-fractured rock around the Yellow Pine pit that the 2012 holes were drilled in. Although approximately 12 of these holes produced drilling mud at the surface, in every case the new response SOPs proved highly effective in preventing any mud from reaching live water (Kyle Fend, Midas Environmental Permitting & Compliance Coordinator, personal communication, 2015).

A preliminary risk analysis has identified the following drilling areas proposed in the current project where there is some risk of drilling fluid discharging at the ground surface (Fend, 2015).

- IPA
- Northeast Extension
- East Stibnite
- North Stibnite
- Garnet
- Sugar
- South Sugar
- Box

Factors considered in this preliminary risk analysis included:

- Relation of the drill pad to historic mining activity including:
    - Blast fractured rock
    - Backfilled pit benches
    - Waste rock stockpiles
    - Anticipated depth to bedrock (how much overburden)
    - Composition of overburden material
- Angle and orientation of the drill hole
- Proximity to natural, heavily fractured, bedrock zones (ie. Meadow Creek fault)
- Natural overburden material anticipated thickness
- Proximity of drill pad and projected drill hole to surface water bodies and wetlands

These factors were evaluated in conjunction with the mechanisms by which mud can travel to the ground surface. All mud surfacing events are a result of the loss of drilling fluid to a zone of high hydraulic conductivity and its transport to, and subsequent discharge at, the ground surface. All of the above factors influence hydraulic conductivity or transport distance. Additional factors include drilling fluid loss volume, ground surface slope angle, and depth to water table. The presence of high hydraulic conductivity zones near the ground surface increases the likelihood of drilling fluid discharging at the surface not only because the transport distance decreases with decreasing depth, but because if these zones are above the water table in the vadose (unsaturated) zone, then there is little to no water present to offer resistance to the outward flow of drilling fluid if circulation is lost. Put another way, the hydraulic conductivity of permeable material (either fractured bedrock or poorly consolidated alluvium) is several orders of magnitude higher with respect to air than it is to water (or drilling fluid). This means that air can be displaced relatively quickly and lost fluid can travel farther and faster in the near-surface vadose zone than it can below the water table. As noted in the groundwater effects analysis, lost circulation into an aquifer would result in rapid transmission of a pressure front that could temporarily increase water flows at a discharge point (e.g. springs, seeps, stream baseflow), but transport of the drilling fluid itself would be quite slow and can be discounted in an analysis of surface discharge potential.

The volume of fluid in the hole at the time of lost circulation is another factor determining whether mud will discharge to the surface. The deeper the hole, the greater the hydraulic head at the bottom and the greater the volume of fluid that can be lost. Previous surface discharge events have produced estimated volumes ranging from 2-36 gallons (Kyle Fend, Midas Environmental

Permitting & Compliance Coordinator, personal communication, 2015). As a useful scale reference, the theoretical maximum volume of mud that could be lost from the largest diameter (HQ) drill hole, assuming that mud pumping is halted promptly and the entire hole drains into an LCZ, would be approximately 47 gallons per 100 feet of hole. For the smaller, more commonly used NQ core size this volume would be approximately 29 gallons per 100 feet of hole. The surface discharge of large volumes (e.g. > 100 gallons) is extremely unlikely.

The factors influencing fluid transport distance to a discharge point are also important in determining the likelihood of surface discharge. It is the three dimensional geometry of the drill hole in relation to the ground surface that is evaluated. For a vertical hole the potential transport distance would increase with hole depth more rapidly if drilled on a shallow angle hillslope rather than a steep one. Drill hole angle and direction required to hit the geologic target also influence transport distance. A hole drilled subparallel to the hillslope could have a substantial length within a relatively short transport distance of the ground surface compared to a hole that is angled into the hillslope directly away from the ground surface.

All the areas discussed above (with the exception of Box) have some degree of risk that drilling fluid could discharge at the ground surface downslope of the drill hole. In all cases however the implementation of SOPs would reduce both the risk of surface discharge occurring and the risk of drilling fluid subsequently reaching live water to negligible levels.

The following SOPs can be classified according to three main objectives:

- Minimize the risk of mud discharge at the surface.

    - Drillers would be informed of the drill areas at risk and would exercise a high degree of vigilance for signs of lost circulation at shallow depths.
    - The casing would be advanced simultaneously with the drill string through the alluvial section of all drill holes as described in Section 2.1.1

- Promptly detect any surface discharge should it occur.

    - Adjacent slopes below the drill rig and stream channels (if drilling in RCAs) in these areas would be regularly monitored during drilling by environmental technicians for any evidence of surface leakage. At least one person would be stationed on the slope below a drill rig at all times until surface casing is set.

- Prevent discharged mud from reaching live water.

    - No drill holes would be located within 100 feet of streams and pad locations within RCAs would require FS concurrence that no reasonable alternative location exists.
    - For drill holes proposed to be sited within a RCA in an area identified as having a risk of drilling fluid discharging at the ground surface (i.e. the aforementioned areas), an interdisciplinary team including Forest Service resource specialists and MGI geologists, drillers, and environmental technicians would conduct an on-site

review of all geologic target considerations and environmental risk and mitigation factors in order to identify the optimal hole locations that would present negligible environmental risk.

- Silt fence, straw wattles, portable sumps, pumps, and hoses would be pre-staged for emergency use. These materials and tools would be used to quickly construct temporary sumps to capture drilling fluid and return it to the drill rig.
- For locations that are deemed to be of sufficient risk to warrant the pre-staging of response materials, a Forest Service representative would verify that such measures are in place on the ground.

Out of 26 drilling areas, 8 have been identified as having some risk that drilling fluid could discharge at the ground surface. In 2012, attempts to drill through fractured rock to reach geologic targets beneath the Yellow Pine pit resulted in drilling fluid discharging at the surface and then running into live water six times. As a result MGI developed SOPs designed to mitigate both the risk of surface discharge occurring and the risk of drilling fluid subsequently reaching live water. These SOPs were implemented in 2013 when more holes were drilled underneath the pit. Drilling fluid was discharged at the surface twelve times in 2013, however in every case the detection and response SOPs proved highly effective in preventing any mud from reaching live water. Implementation of all the SOPs described above for the current project would make the probability of drilling fluid reaching live water extremely unlikely. The effects to surface water from the possible surface discharge of drilling fluid are therefore considered to be discountable.

Fluid Gain

If a confined aquifer is encountered where the hydraulic head exceeds that of the mud column in the borehole, water runs into the borehole from the formation. This is referred to as “making water” and can occur in both alluvial and bedrock aquifers. As noted above, minor inflows do not present a significant problem. The total volume, duration, and rate at which water flows into the borehole are governed by a number of hydraulic factors. For example, if the total water volume is small and the pressure differential is low, the water entry may be very short lived and not even noticeable. On the other hand, if there is a large volume and large pressure gradient this could result in artesian flow at the surface.

As with lost circulation, the measures taken to respond to inflows are commensurate with the severity of the flow. More substantial inflows are detected by a pressure spike in the mud system and an increase in mud flow at the surface often accompanied by a visible film of clear water on top of the mud due to incomplete mixing during travel up the hole. If sustained inflow is detected, the first step is to add barite (a high density mineral) to the mud to increase its density. This has the effect of increasing the hydrostatic pressure at the inflow zone until it exceeds the inflow pressure. At that point the flow reverses and the inflow zone behaves the same as an LCZ. Lost circulation material (LCM) is also added to the mud along with the barite in order to seal the resultant LCZ. This sealing of the inflow zone is usually effective enough that even if the mud weight is reduced back to what it was initially (with resultant reduction in hydrostatic head) the LCM is emplaced securely enough to retain a somewhat higher pressure formation water.

If a water entry is severe enough to result in artesian flow at the surface, then the well is promptly abandoned as described below in the Borehole Abandonment Section. During the time it takes to abandon the hole, artesian flow at the surface is routed into the mud sump. Should there be enough flow to exceed the sump capacity, emergency measures would entail routing any overflow to portable tanks, to the ground surface in a hand dug trench, or to an area away from active waterways or wetlands with the most available obstructions to flow (e.g. embedded logs, thick grass or brush). Emergency packers are also available on all drill rigs and can be used to stem artesian flow.

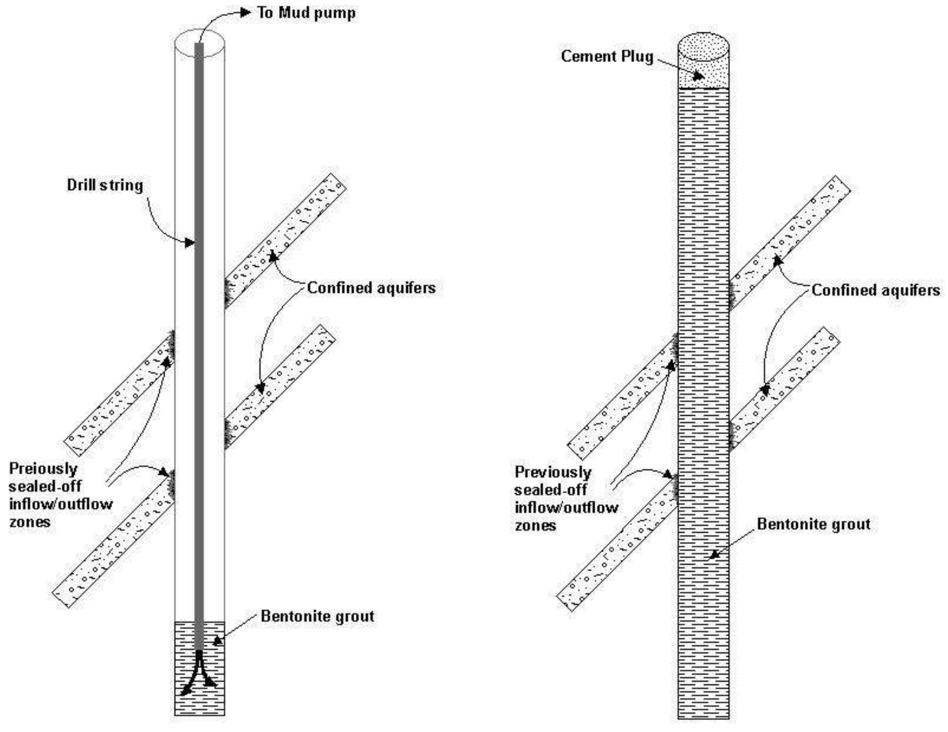
Drilling Fluid Disposal

Once drilling is completed the drilling mud is pumped into the on-site sumps for disposal. Sumps are then allowed to dry out prior to capping with the native soil that was excavated to build them. The sump area along with the rest of the drill pad is then reclaimed as described in the EA. Sumps would not be located on steep slopes, in Riparian Conservation Areas (RCAs), or in areas where groundwater levels could rise above the bottom of the sump. Drilling mud from holes in such areas would be contained in portable mud tanks during drilling and then ultimately disposed of in sumps located elsewhere.

Borehole Abandonment

Boreholes are promptly abandoned as required by the Idaho Rules Governing Exploration, Surface Mining, and Closure of Cyanidation Facilities (IDAPA 20.03.02) after reaching their total planned depth. Borehole abandonment would generally take place within hours of borehole completion to avoid the need to bring the drilling rig back to the site later. If the annular space of the casing has been sealed with cement (as is the case with boreholes expected to encounter artesian conditions), the casing is left in place. If the annular seal is bentonite, the temporary surface casing is removed before abandonment.

Borehole abandonment entails plugging the holes from bottom to top with a low-permeability bentonite-based grout (Benseal®) which seals off all water transmission. In order to ensure a continuous seal throughout the hole the grout is pumped down the hollow drill string starting at the bottom of the hole (Figure 6). As the hole is filled the drill string is withdrawn, but never pulled above the surface of the ascending column of grout, as this could produce voids. After the grout has risen to within approximately three feet of the ground surface and has set up, the remainder of the hole is plugged with cement. In the case of abandonment of a flowing artesian drill hole, neat cement grout is used to seal the entire borehole instead of bentonite grout.



a) Start sealing from bottom

b) Completed abandonment

Figure 6: Borehole abandonment

Impacts of Exploration Drilling on Groundwater Resources

Effects on groundwater flow and discharge

Effects of drilling on the hydraulic properties of an aquifer are likely to be negligible and temporary and therefore insignificant. It is useful to first recognize the scale and duration of the proposed disturbance. A simple modeling exercise with conservative assumptions may help in this regard. The volume of aquifer potentially affected by drilling compared to the total aquifer volume will provide a sense of the scale of impacts.

As an example, consider the effects of the seven holes planned to be drilled in the Northeast Extension area. This is a reasonable example for an analysis of effects since it is one of the most likely areas where bedrock groundwater would be encountered (see bedrock aquifer section). The West End fault zone runs through this area and is estimated to be from 100-500 feet wide. Distribution of groundwater within the fault zone is not well known but for the sake of simplicity the entire fault zone will be assumed to be a discrete aquifer. Defining the boundaries of the aquifer along strike is a bit more speculative. The geologic map shows a total strike length of approximately two miles. Continuous hydraulic connectivity along the entire strike is probably unlikely, so instead the 1000 foot length of the fault zone within the Northeast Extension area boundary will be used. Taking a 1000 foot average hole depth as a vertical boundary, this would yield an aquifer volume of between 100 and 500 million cubic feet.

Assuming that all seven holes are of equal depth and drilled directly into the fault zone and that lost circulation and the resultant mud penetration and fluid loss affects (on average) a three foot radius around the wellbore for the entire depth, then the total volume of the aquifer impacted by drilling is 198,000 cubic feet or between 0.04% and 0.20% of the aquifer volume (Appendix B1). The use of this example is not intended to be a rigorous hydrologic model by any means; it is only a rough conceptual exercise to simply provide a sense of scale and illustrate the relative volumes that are being considered in this effects analysis.

The other highly relevant factor to consider when it comes to analyzing effects is the duration that the boreholes are open. The average hole is open for a period of 5-9 days, after which it is abandoned following the procedures described in the Borehole Abandonment section. After abandonment the borehole and associated plugged LCZs can essentially be considered as a relatively small impermeable column (with various short dendritic branches) of clay within the aquifer. The long term effects of these columns of clay are negligible; groundwater would continue to flow around them. There would be an insignificant reduction in bulk permeability, groundwater flow patterns, and total water storage capacity of the aquifer.

During drilling it is possible that there could be very minor pressure increases or decreases in the aquifer as a result of encountering lost circulation or water entry zones. If there were springs or seeps nearby, this could result in very brief (on the order of hours at most) fluctuations in flow if there happened to be a direct hydraulic connection between the borehole and the discharge point. Such fluctuations in discharge, if detectable, would likely not be outside the large range of seasonal variability that has been noted for many springs and seeps in the area (URS, 2000) and would have negligible effects on these features.

Effects on water quality

Drilling core holes without proper SOPs has the potential to alter the chemical composition of surface water and groundwater through the mixing of waters from different sources. The drilling SOPs described above serve to minimize or eliminate the mixing of groundwater, surface water, and drilling fluid filtrate (the liquid that passes through bentonite filter cake). For the small quantities of water that are likely to mix as a result of drilling, the net effect to the receiving aquifer can be viewed as neutral or possibly even slightly beneficial with regard to its potential consumption by various organisms. The emphasis of this effects analysis will be on substances which have the potential to degrade water quality, the mechanisms by which this could occur, and why the SOPs serve to limit such effects to the degree that they become negligible, temporary, and thus insignificant. The substances to be considered are 1) arsenic and antimony, 2) petroleum products, and 3) drilling fluid additives.

The following possible water-mixing situations will be addressed:

- Drilling fluid filtrate mixing with groundwater
- Groundwater mixing with other groundwater
- Surface water mixing with groundwater and vice-versa

In addition to the above water mixing scenarios, the related issue of drilling fluid and drill cuttings disposal will be discussed.

Effects of drilling fluid filtrate mixing with groundwater

The volume of drilling fluid filtrate lost from the borehole that could enter groundwater is minimized by the drilling SOPs which result in the formation of filter cake and the sealing of lost circulation zones.

It may be useful to further examine the effectiveness of the bentonite filter cake at limiting the extent of filtrate migration into an aquifer. The process of filter cake formation has been studied and modeled by a number of authors. The filtration rate of drilling fluid into permeable formations is controlled primarily by the permeability and thickness of the filter cake (Jaio & Sharma 1994; Wu et. al. 2005). As the filter cake builds up, it rapidly becomes less permeable (Fig 7). Reported hydraulic conductivity values for filter cake are very low (Campbell and Gray 1975; Jaio & Sharma 1994; Kelessidis et. al. 2006), and are comparable to that of unfractured granite. Wu et. al. (2005) indicate that this low permeability is reached in a matter of seconds. A wide range of filter cake thicknesses from 1 mm to 1 cm have been reported. The primary constraining factor on filter cake build-up is the flow rate of the mud which acts to erode the filter cake from the borehole wall. For the core holes on this project, a very thin filtercake is expected (probably 1 mm or less) due to the relatively high annular velocity of the mud (over 8 feet per second).

Once the filter cake forms, fluid which passes through it (the filtrate) from either the borehole surface or sealed off LCZs can migrate into an aquifer. As noted above, filter cake thickness and permeability are the main controlling factors that determine how much filtrate is produced and how far it moves away from the borehole. Campbell and Gray (1975) cite a case of filtrate moving two feet in 138 hours. Wu et. al. (2005) model a filtrate travel distance of roughly 0.4 m in 2 days for several different permeabilities. Distances such as these are likely to represent high values for what would be possible in the alluvium, since surface casing is normally set in less than a day, after which time no further fluid can move into the formation. To get a sense of filtrate volumes, the example of a 100 foot deep borehole in alluvium can be used with the values from Figure 7 to give a rough estimate of 25 gallons of filtrate loss in 10 hours.

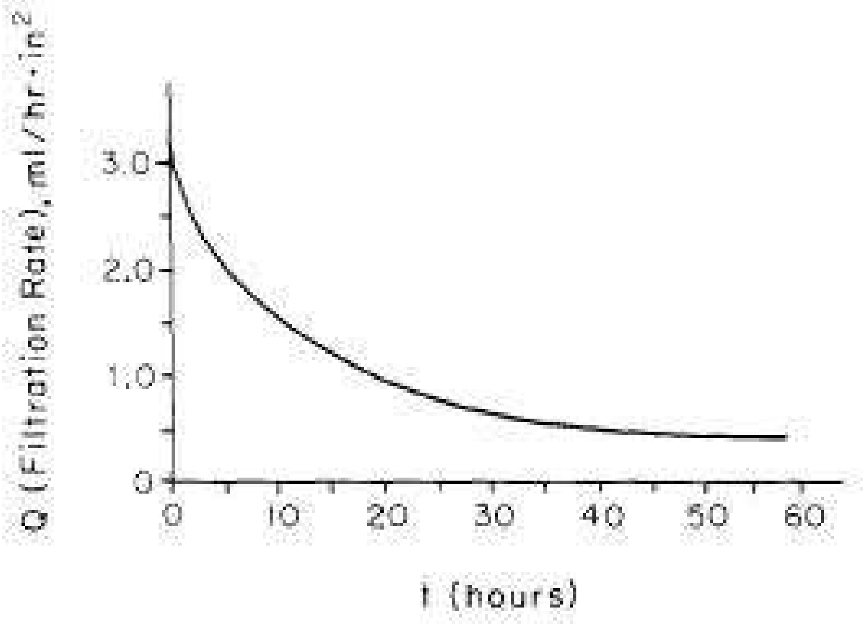


Figure 7: Filtrate infiltration vs. time (Donaldson & Chernoglazov 1986).

The preceeding examples are very rough approximations of volumes and distances based on flow in porous media (e.g. alluvial aquifers). They may not necessarily be directly applicable to flow in fractured bedrock. The few instances from past drilling programs where drilling mud has discharged at the surface from shallow fracture zones (see Total Loss of Returns section) present an exception to the limited fluid migration distances estimated above. These events occurred in the vadose zone of poorly consolidated alluvium or heavily fractured bedrock near the ground surface on steep slopes. There would be negligible effects to groundwater if similar events occurred during this project since the drilling fluid would travel through unsaturated (vadose zone) materials above the water table and there would be little to no interaction with groundwater. Potential effects to surface water from the surface discharge of drilling fluid are addressed in the Surface Hydrology Technical Report.

More accurate estimations of bedrock hydraulic properties could be derived from more intensive characterization studies and modeling, however the data required for such an exercise are not available. Aquiring sufficient data could easily require the drilling of more holes than the present exploration program and might well provide only a very minor gain in predictive accuracy and confidence level. Such a level of analysis is not justified for this project.

The filtrate chemical composition is perhaps more relevant than volume and distance estimates in assessing potential aquifer impacts. The filtrate would be composed of the water used to mix the drilling mud (make-up water), small amounts of very fine bentonite particles, and small amounts of drilling additives. In order to comply with direction in the Idaho Ground Water Quality Rule (IDAPA 58.01.11) to maintain or improve existing ground water quality, the make-up water would contain arsenic and antimony concentrations equal to or lower than the concentrations expected in groundwater that could be encountered in a borehole. Therefore the effects to groundwater quality would be insignificant.

Midas has proposed three sources of make-up water: 1) a mining water supply well in Meadow Creek, 2) surface water from Hennessey Creek, and 3) surface water from West End Creek. The first two sources have very low average concentrations of arsenic (2.3 µg/l - 3.1 µg/l) and antimony (0.4 µg/l - 2.5 µg/l) (Appendices B2 & B3). This is much lower than expected bedrock groundwater concentrations in almost all instances (see bedrock aquifer discussion). The water quality at the West End Creek water source is presently unknown. Water from this source would only be used in the Northeast Extension drilling area. The pumping location is located between two current surface water quality monitoring stations (above and below) on West End Creek. Arsenic and antimony concentrations at the upper West End Creek station are 9.2 µg/l and 2.2 µg/l respectively. Concentrations at the lower West End Creek station are 76.0 µg/l and 10.0 µg/l (Appendix B3). The pumping station location would be added to the on-going baseline surface water quality study. Prior to use as make-up water, arsenic and antimony concentration values obtained from this new station would be compared to groundwater values from the baseline groundwater monitoring well MWH-B20, located within the Northeast Extension drilling area. If at any time during the regular sampling period surface water values exceed those of groundwater, make-up water would have to be obtained from one of the other sources.

The drilling additives used are non-toxic, biodegradable and certified (NSF/ANSI Standard 60) for use in domestic water supply wells. Even though all products are in regular usage for water well drilling, the question has been raised as to whether differences in the chemical composition of the drilling fluid and the groundwater could result in significant detrimental effects to an aquifer if substantial mixing occurred.

There is no question that chemical reactions will take place when two chemically different waters such as mud filtrate and groundwater are mixed. Some of the properties that may differ between the drilling fluid and groundwater are: pH, dissolved oxygen, cation exchange capacity, biochemical oxygen demand, total organic carbon, suspended solids, dissolved ions, and bacteria.

The literature on the topic of water quality changes resulting from filtrate/groundwater mixing is very sparse. Campbell and Grey (1975) discuss a multitude of physical, chemical, and biological processes involved in the mixing of drilling fluids and conclude that "…the mobility of drilling fluids in the ground-water system is clearly of very limited extent because of a variety of physical, chemical, and biological factors." However, as with many hydrogeological studies, their conclusions are based on the behavior of fluids in porous media, and may not necessarily be directly applicable to flow in fractured rock aquifers. Nevertheless, many of the attenuation processes they cite are still valid in this context.

As with the physical effects of drilling on flow described above, the scale and duration of chemical effects is key to assessing their significance. The only fluid that will migrate into the formation beyond the bentonite filter cake (whether it is coating the borehole or the surfaces of fractures or pore space in an LCZ) is the filtrate. The low permeability of the filter cake only allows a small volume of filtrate to enter the formation, and filtrate production is limited to the time the hole is open.

It should be pointed out that the use of drilling fluid mixed from the make-up water sources described above means that if drilling fluid filtrate enters an aquifer that has naturally elevated arsenic and antimony levels (as the more significant bedrock aquifers are likely to be) it acts to dilute the concentrations of these metals. However, these potential beneficial effects are still very localized and negligible with respect to the aquifer water quality as a whole.

Effects of groundwater mixing with other groundwater

The primary mechanism by which groundwater can mix with other groundwater of differing chemical composition is by aquifer cross-flow. If flow from an aquifer containing elevated levels of arsenic and/or antimony enters an aquifer having lower concentrations of those elements then degradation of water quality in the receiving aquifer would result.
The risk of groundwater mixing due to cross-flow during the active drilling phase is minimized by sealing off any inflows or outflows of water as they are encountered. The potential for cross-flow between shallow alluvial aquifers and bedrock aquifers is further reduced by casing and cementing all holes through any near-surface alluvial formations into bedrock. One possible cause of cross-flow between shallow aquifers in the cased section of a borehole is leaky annular seals. The SOPs for casing installation described above would prevent this.

In order for cross-flow to occur, a zone of inflow and a zone of outflow (a net pressure differential between zones) would have to be encountered in the same hole. Such zones are sealed off as they are drilled through so there would never be an inflow and outflow zone open simultaneously. It should be noted however that typically the sealing of inflow/outflow zones is not 100% effective and there can still be minor residual inflow/outflow leakage occurring. Thus there is a very limited time during drilling when a minor amount of cross-flow between a previously sealed inflow/outflow zone and a newly encountered inflow/outflow zone could occur. Once the second (or any subsequent) zone is sealed, the volume of any cross-flow would diminish even further.

Any arsenic or antimony in the residual inflow would be diluted by the drilling fluid prior to becoming part of any residual outflow from the borehole through an imperfectly sealed LCZ. As with other impacts analyzed here, even the limited potential for residual cross-flow described above is relatively short-lived since the holes are promptly abandoned after reaching their total planned depth. Like the drilling fluid losses described above, the overall effects to the receiving aquifer would be negligible and temporary.

After abandonment there is little risk of cross-flow occurring through either the annular grout seal or the borehole seal. Both bentonite and cement are highly effective sealants (Papp 1996). The permeability of Benseal® bentonite grout is 1.1 x 10^{-8} cm/s (Baroid, 2012). The permeability of neat cement is 4.5 x 10^{-7} cm/s (Edil et. al. 1992). Since these values are much lower than the permeability of any aquifer there would be no vertical flow paths through the annular space or the borehole itself that could interconnect aquifers.

Some of the relative advantages and disadvantages of each material in various applications are discussed in Stichman (1990). He points out that shrinkage of cement can result in cracking that may permit water flow. Edil et. al. (1992) conducted a comparative study of the sealing properties of several types of grout. They found Benseal® (a bentonite slurry grout used in this project) to be most effective. Despite some minor seepage at the seal-casing interface they considered neat cement and cement-bentonite grouts to provide a good seal.

Effects of surface water mixing with groundwater

There are two mixing situations that will be considered; when the surface water is the contributing source and the groundwater is the receiving water and vice-versa.

Flow of surface water down the borehole would not occur during active drilling because all the drill holes have surface casing that typically rises a couple feet above the surrounding pad surface which is graded to drain water. Flow of surface water into an aquifer via the annular space would be prevented by proper sealing of the casing with the approved materials described above. In addition, the various material handling measures noted in the drilling procedures section would prevent spills of hazardous materials stored on the drill site that could then infiltrate into shallow alluvial aquifers.

If a significant water entry results in an artesian flow of poor quality groundwater (e.g. elevated arsenic & antimony) at the ground surface, this water could flow into and mix with nearby surface water. This possibility can be discounted due to implementation of the SOPs described for dealing with artesian flow in the Fluid Gain section, the location of mud sumps outside of RCAs, and the prompt abandonment of flowing artesian drill holes.

Another route by which groundwater could affect surface water is when it eventually becomes surface water by discharging from a seep or spring. The low probability of groundwater quality being affected by drilling fluid or aquifer cross-flow described above becomes even lower by the time it reaches a discharge point (assuming a hydraulic connection between the borehole and the discharge point exists). Although Campbell and Gray (1975) acknowledge a host of possible reactions and processes that could occur over the transport path, they single out the attenuating processes of filtration, adsorption, and dilution in their conclusion that "…the mobility of drilling fluids in the ground-water system is clearly of very limited extent…"

Effects of Surface Discharge of Drilling Fluid

If drilling fluid were to discharge at the ground surface and be delivered to live water there could be temporary increases in stream turbidity. The SOPs listed on pages 17-18 were developed in response to such events in 2012 and were proven to be highly effective in preventing any mud from reaching live water during the 2013 drilling season. Implementation of these SOPs in the current project would make the probability of drilling fluid reaching live water extremely unlikely. The effects to surface water from the possible surface discharge of drilling fluid are therefore considered to be discountable.

Effects of drilling fluid and drill cuttings disposal

Most of the drying of a sump takes place by evaporation, but a small percentage of fluid would infiltrate the ground in the same manner that filtrate passes through filter cake in a borehole. For the same reasons as previously discussed, this filtrate is not expected to move very far beyond the immediate vicinity of the sump.

Concerns have been expressed regarding the potential for high-sulfide drill cuttings (which may be encountered in ore zones or areas of Recognized Environmental Conditions) contained in the mud to generate acid rock drainage and/or leach metals which might then migrate with the filtrate into shallow groundwater. This possibility is unlikely primarily because the very low permeability of bentonite clay makes it an ideal material for isolating potential contaminants from the environment, and it has many environmental engineering applications in this capacity. Besides its low permeability, it has a high cation exchange capacity and tends to adsorb (and thus immobilize) metal ions (Zarha, et. al. 2009).

The bulk sulfide content of the drill cuttings would be quite low. Core logs from holes within the West End fault zone indicate several zones containing sulfides. As an example, using the data from core hole MGI-12-312, the sulfide content would equal 0.8% (approximately 0.3 cubic feet) of the total cuttings volume of 35 cubic feet (Appendix B4). For sulfides to create acid rock drainage requires that they be oxidized to liberate hydrogen ions to solution. Commonly this takes place naturally in areas where seasonal fluctuations of the water table produce alternating wet and dry conditions. The sulfides enclosed within the bentonite would have extremely limited exposure to air and water, thus would not be expected to generate any substantial amount of acidity. The negligible risk of acid generation is further reduced by the presence of acid-neutralizing carbonate minerals in the drill cuttings from many of the holes.

Monitoring

Since the effective protection of groundwater resources is strongly dependent upon the proper implementation of SOPs, monitoring of these SOPs would be carried out by Forest Service personnel on a regular basis. The monitoring plan includes the following items:

- Regular review of relevant drilling data gathered by Midas Gold (e.g. drilling fluid losses, water entries, borehole abandonment records, etc.).
- Periodic site inspection by a certified minerals administrator for compliance with BMPs & SOPs and effectiveness of implementation.

It should be noted that even though a baseline groundwater monitoring program is in place at Stibnite, it is only designed to monitor large scale trends in groundwater quality. Preliminary review of this monitoring data suggests there are no major dissimilarities to the general findings of the URS site characterization report completed in 1998. The expected effects to groundwater from the current project are very minor, localized, and unlikely to be detectable at the spatial sampling scale of the baseline monitoring program.

Direct monitoring of groundwater at the near-borehole scale to validate predictions of drilling SOP effectiveness and to be able to unequivocally attribute water quality or quantity changes to drilling activities would require a density of monitoring wells far exceeding the number of proposed drill holes. Such a study would not be commensurate with the low degree of risk of detrimental effects to groundwater which is anticipated.

Cumulative Effects

Forest Service Handbook (FSH) 1909.15, Chapter 10, Section 15.2 states "*Spatial and temporal boundaries are the two critical elements to consider when deciding which actions to include in a cumulative effects analysis. Spatial and temporal boundaries set the limits for selecting those actions that are most likely to contribute to a cumulative effect. The effects of those actions must overlap in space and time for there to be potential cumulative effects.*" Since the potential area affected by drilling is limited to the proposed drilling areas, the cumulative effect area would be the 26 drilling areas and the aquifers or portions thereof that may exist directly beneath these areas.

Past activities that could have had impacts on groundwater resources include previous mining projects in the Stibnite mining district and more recently, previous exploratory drilling projects conducted by Midas Gold. Previous work done by Midas involved the construction of roughly 177 drill pads and the drilling of associated core holes. Details of these activities are included in Appendix B of the EA. None of the past pads are located within the 26 drilling areas proposed in the current project, therefore they would not contribute to cumulative effects. As noted in section 3.14.2.4 of the Golden Meadows Exploration Project EA (March 2015), the only two drilling areas where groundwater may have been affected by previous mining activities are the Northeast Extension and Garnet areas. Despite the fact that the existing condition of the groundwater resources may have been influenced by previous mining in these areas, the insignificant effects on groundwater produced by the current proposed project would not lead to any additional cumulative effects.

Insignificant effects to groundwater flow or quality are expected as a result of this proposed project, therefore when considered in combination with other past, ongoing, or reasonably foreseeable actions, the cumulative effects of this action are insignificant.

Conclusions

The following conclusions can be made regarding the existing condition of groundwater resources:

- Among all the drilling areas, only the Box area is underlain by a shallow alluvial aquifer. Groundwater in this aquifer may exceed state groundwater quality standards for arsenic and antimony.
- Groundwater is expected to be of very limited occurrence within bedrock outside of fault and fracture zones.
- Fracture-controlled aquifers are likely to be present within bedrock fault and fracture zones. Their areal extent and interconnectedness are unknown.
- Groundwater within strongly mineralized portions of such fracture-controlled aquifers contains naturally occurring levels of arsenic and antimony that likely exceed state groundwater quality standards.

The drilling SOPs employed by the proponent would utilize the best available technology to minimize detrimental impacts to groundwater. They meet, and in many cases far exceed, all State of Idaho regulations pertaining to exploration drilling. The SOPs include:

- The use of bentonite-based drilling fluid.
- The use of non-toxic, biodegradable drilling fluid additives that are certified for use in domestic water supply wells.
- The installation of surface casing.
- The prompt sealing of borehole inflow/outflow zones.
- The prompt abandonment of boreholes after their completion.

The effects on groundwater resources from implementation of the proposed project are expected to be negligible, temporary, and insignificant. This conclusion was arrived at through the analysis process documented above. This assessment of the overall significance of the effects of the proposed project on groundwater resources is based upon 1) the existing condition of groundwater resources, 2) the degree of risk of water quality degradation posed by the proposed action, and 3) the severity of consequences should mixing of chemically different waters occur. The aquifers within the project area that could be impacted by drilling are for the most part confined to bedrock fault zones, are of limited extent, and are likely to have elevated concentrations of metals. The benign nature of the drilling fluids and the limited potential for interaction between aquifers having differing water quality poses little risk of aquifer degradation. If minor transient aquifer cross-flow does result in the mixing of small volumes of water, the consequences are slight since 1) groundwater quality would not be degraded and 2) effects to surface discharge sources (springs and seeps) would be negligible and temporary.

Bibliography

Bookstrom, A.A., B.R. Johnson, T.M. Cookro, K. Lund., K.C. Watts, H.D. King, M.D.

Kleinfkopf, J.A. Pitkin, J.D. Sanchez, and J.D. Causey. 1998. Potential Mineral Resources, Payette National Forest, Idaho: Description and Probabilistic Estimation. Open-File Report 98-219a, U.S. Department of The Interior, U.S. Geological Survey. 270 pages.

Campbell M.D., and G.R. Gray. 1975. Mobility of Well-Drilling Additives in the Ground-Water System. In Conference Proceedings, Environmental aspects of Chemical Use in Well-Drilling Operatons. Office of Toxic Substances, Environmental Protection Agency: 261-284.

Cookro, T.M., M.L. Silberman, and B.R. Berger. 1987. Gold-Tungsten-Bearing Hydrothermal Deposits in the Yellow Pine Mining District, Idaho. In Schafer, R.W., et. al., 1988, Bulk Mineable Precious Metal Deposits of the Western United States, Symposium Proceedings: 577-624.

Cooper, J.R. 1951. Geology of the Tungsten, Antimony, and Gold Deposits near Stibnite, Idaho. Geological Survey Bulletin 969-F, U.S. Government Printing Office.

Dewandel, B., P. Lachassagne, R. Wyns, J.C. Marechal, N.S. Krishnamurthy. 2006. A Generalized 3-D Geological and Hydrogeological Conceptual Model of Granite Aquifers Controlled by Single or Multiphase Weathering. Journal of Hydrology (2006) 330, 260– 284.

Donaldson, E.C., and V. Chernoglazov. 1987. Characterization of Drilling Mud Fluid Invasion. Journal of Petroleum Science and Engineering (1987) 1, 3-13.

Edil, T.B., M.M.K. Chang, L.T. Lan, and T.V. Riewe. 1992. Sealing Characteristics of Selected Grouts for Water Wells. Ground Water, Vol. 30, No. 3, 351-361.

Fend, K. 2015. Midas Gold Memo re: Ground Condition Overview and Updated Fuel Usage. 9 p.

Gustafson, G. and J. Krasny. 1994. Crystalline Rock Aquifers: Their Occurrence, Use, and Importance. Applied Hydrogeology, 2/94, 64-75.

Jiao, D. and M.M. Sharma. 1994. Mechanism of Cake Buildup in Crossflow Filtration of Colloidal Suspensions. Journal of Colloid and Interface Science (1994) 162, 454-462.

Kelessidis, V.C., D. Tsamantaki, N. Pasadakis, E. Repouskou, and E. Hamilaki. 2006. Permeability, porosity and surface characteristics of Filter Cakes from Water-Bentonite Suspensions. Paper to be presented at the 6th International Conference on Advances in Fluid Mechanics, 8-10 May, 2006, Skiathos, Greece.

Naylor, P. 2012. Review of Known Hydrogeologic Conditions at the Midas Gold – Golden Meadows Project Area. Technical Memorandum, MWH Global.

Papp, J.E. 1996. Sodium Bentonite as a Borehole Sealant. In Sealing of Boreholes and Underground Excavations in Rock. Edited by K. Fuenkajorn and J.J.K. Daemen. Chapman & Hall: 280-297.

Rygh, J.T. 2012a. Golden Meadows Drilling Project Site Inspection Log 07/12/2012. Unpublished Report, USDA Forest Service, Payette National Forest. 2 p.

Rygh, J.T. 2012b. Golden Meadows Drilling Project Site Inspection Log 07/18/2012. Unpublished Report, USDA Forest Service, Payette National Forest. 2 p.

Smith, N. 2012. MWH Letter to EPA re: Golden Meadows Exploration Project MSGP 2012 Annual Report. 11 p.

State of Idaho. 2012. Rules Governing Exploration, Surface Mining, and Closure of Cyanidation Facilities. IDAPA 20.03.02.

State of Idaho. 2012. Well Construction Standards Rules. IDAPA 37.03.09.

State of Idaho. 2012. Ground Water Quality Rule. IDAPA 58.01.11.

Stichman, R.W. 1990. Methods of Borehole Stabilization to Avoid Groundwater Contamination. Paper presented to Toronto, Ontario HAZTECH/CANADA Conference, May 16, 1990.

URS Corporation. 2000. Stibnite Area Site Characterization Report.

Wu, J., C. Torres-Verdin, K. Sepehrnoori, and M.A. Proett. 2005. The Influence of Water-Base Mud Properties and Petrophysical Parameters on Mudcake Growth, Filtrate Invasion, and Formation Pressure. Petrophysics, (February 2005), Vol. 46, No. 1, p. 14-32.

Zahra, N., S.T. Sheikh, A. Mahmood, and K. Javed. 2009. Removal of Arsenic From Wastewater Using Bentonite. Bangladesh J. Sci. Ind. Res. 44(1): 81-86

Appendix A1

EFSFSR Alluvial Wells With Pump Tests

IDWR Permit #	Name	Discharge
813356	SMC1	100*
825129	SMC2	15
741592	LA-1	1
741593	LA-2	10
741594	LA-3	5
751591	UG-2	2
862557	MGCW11	30
863525	MGCW12	15
864244	MWH-A09	4
AVG		10.25

* This value considered to be an outlier and not included in avg.
Note: other dry holes not included.

Appendix A2

Stibnite Bedrock Wells

Well ID	Total Depth	Water Entry/Screened Interval	Static Level
MW-1	171	108-118	104
MW-2	192	115-125	110
MW-3	153	115-135	112
MW-4	150	136-146	140
MW96-1	42	unk	26
MW96-2	203	unk	181
MW96-3	83	unk	58
MW96-4	171	unk	96
MW96-5	53	unk	30
MW96-6	83	unk	71
MW96-7	293	unk	112
MW96-8	325	unk	295
MW96-9	93	unk	60
MW96-10	25	unk	6
MWH-02	60	48-58	20
MWH-05	223	208-218	159
MWH-07	295	284-294	56
MWH-09	100	85-100	16
MWH-10	90	30-90	unk
MWH-15	300	155-185	50
MWH-19	300	dry	dry
MWH-20	385	multiple	138
HEC1	55	unk	31

Appendix A3

Bedrock Well Discharges

Location	Well ID	Screened Interval	Flow (gpm)
Stibnite	HEC1	none	0.3
Stibnite	MWH B07	284-294	0.3
Stibnite	MWH B09	85-110	0.8
Stibnite	MWH B15	155-185	0.5
AVG			**0.4**
Big Creek	BC1	25-65	4.0
Big Creek	BC2	300-320	0.5
Johnson Creek	JC1	none	12.0
Johnson Creek	JC2	143-170	10.0
Yellow Pine	YP1	13-70	6.4
Yellow Pine	YP2	150-310	5.5
Yellow Pine	YP3	15-83	3.3
AVG			**6.0**

Appendix A4

Bedrock Groundwater Chemistry

SPRINGS

#	As	Sb	As	Sb
SPMC5			443.0	115.0
			2600.0	67.6
			621.0	23.7
SPMC4	16.2	33.6		
	57.8	93.4		
SPMC7	120.0	79.9		
	48.8	83.3		
SPMC10	117.0	11.7		
	80.6	7.0		
	34.3	15.6		
SPEF-3	156.0	18.0		
	165.0	18.7		
	174.0	38.9		
SPGC-1	250.0	33.7		
	200.0	27.2		
	187.0	28.5		
SPHP-1	39.8	33.2		
	60.1	2.9		
	13.0	4.0		
SPGH-1	34.7	22.4		
	50.7	43.2		
SPGH-2	51.8	56.8		
	51.5	64.2		
SPGH-3	142.0	57.5		
	133.0	55.0		
SPGH-4	79.8	152.0		
	63.6	160.0		
AVG	**96.9**	**47.5**		

NOTE: SPMC-5 was left out of the average as it was an extreme outlier and may have been strongly influenced by the old Meadow Crk. Mine

BEDROCK WELLS

MW96-3	126.0	39.2
	154.0	37.9
	118.0	35.9
MW96-4	107.0	25.9
	146.0	28.1
	127.0	32.2
AVG	**129.7**	**33.2**

Appendix B1

West End Borehole Volume as a Percentage of a Hypothetical Aquifer Volume

WE Fault Zone width: 100-500' (taken from MidasGeology.docx)
WE Fault Zone assumed length: 1000'
Assumed average borehole depth: 1000'
Number of boreholes: 7
Assumed average radius of mud/filtrate influence around borehole: 3' (note: assumed for entire borehole depth; probably a significant overestimate)

Volume range of hypothetical aquifer = 100'(1000')(1000') to 500'(1000')(1000')
= 100,000,000 ft^3 to 500,000,000 ft^3

Borehole volume = $h\pi r^2$
= $1000'\pi(3')^2$
= 28,274 ft^3

Total borehole affected volume = 7(28,274 ft^3) = 197,920 ft^3

Percentage range of affected aquifer = 197,920 ft^3 / 100,000,000 ft^3 = **0.20%**
to 197,920 ft^3 / 500,000,000 ft^3 = **0.04%**

Appendix B2

Project	Sample	Units	Component	Dilution Factor	Reporting Limit	Detection Limit	Result
Midas Gold	Gestrid Well	mg/L	Cyanide, Total	1	0.0047	0.0009	ND
Midas Gold	Gestrid Well-02	mg/L	Cyanide, Total	1	0.0047	0.0009	ND
Midas Gold	Gestrid Well	ug/L	Arsenic (III)	1	0.02	0.003	0.149
Midas Gold	Gestrid Well-02	ug/L	Arsenic (III)	1	0.02	0.003	0.259
Midas Gold	Gestrid Well	ug/L	Antimony, Total	1.0	0.05	0.02	2.41
Midas Gold	Gestrid Well	ug/L	Arsenic, Total	1.0	0.50	0.07	3.80
Midas Gold	Gestrid Well	ug/L	Antimony, Dissolved	1.0	0.05	0.02	2.44
Midas Gold	Gestrid Well	ug/L	Arsenic, Dissolved	1.0	0.50	0.07	3.09
Midas Gold	Gestrid Well-02	ug/L	Antimony, Total	1.0	0.05	0.02	2.32
Midas Gold	Gestrid Well-02	ug/L	Arsenic, Total	1.0	0.50	0.07	3.64
Midas Gold	Gestrid Well-02	ug/L	Antimony, Dissolved	1.0	0.05	0.02	2.51
Midas Gold	Gestrid Well-02	ug/L	Arsenic, Dissolved	1.0	0.50	0.07	3.22

Appendix B3

2012 Surface Water Sampling Data for Hennessey Crk. & West End Creek

(Arsenic & Antimony Only)

Hennessey	Month	Sb total ug/L	Sb dissolved ug/L	As total ug/L	As Dissolved ug/L
	apr	0.550	0.490	2.100	1.700
	may	0.560	0.060	1.200	2.100
	jun	0.340	0.280	1.100	0.800
	july	0.520	0.430	1.900	1.700
	aug	0.500	0.570	2.900	2.800
	sept	0.510	0.500	3.700	3.300
	oct	0.760	0.470	3.100	2.900
	nov	0.720	0.560	3.000	2.500
	dec	0.630	0.660	3.100	3.100
Annual Avg		**0.5**	**0.4**	**2.5**	**2.3**
Upper West End					
	may	2.100	0.060	8.300	8.200
	jun	1.920	1.910	8.100	7.900
	july	2.300	1.960	10.200	8.200
	aug	2.150	2.090	9.000	8.400
	sept	2.300	2.220	10.100	9.700
	oct	2.210	2.170	9.500	9.300
	nov	2.250	2.290	9.500	9.000
Annual Avg		**2.2**	**1.8**	**9.2**	**8.7**
Lower West End					
	may	11.500	0.350	85.700	82.400
	jun	9.550	9.490	69.200	68.500
	july	9.110	8.920	70.800	67.300
	aug	9.270	9.310	68.500	65.800
	sept	10.100	10.100	83.400	77.800
	oct	9.690	9.610	74.800	74.100
	nov	10.000	9.990	74.900	74.800
	dec	10.600	11.000	81.000	83.900
Annual Avg		**10.0**	**8.6**	**76.0**	**74.3**

Appendix B4

Borehole MWH-B20 Sulfide Content Calculation

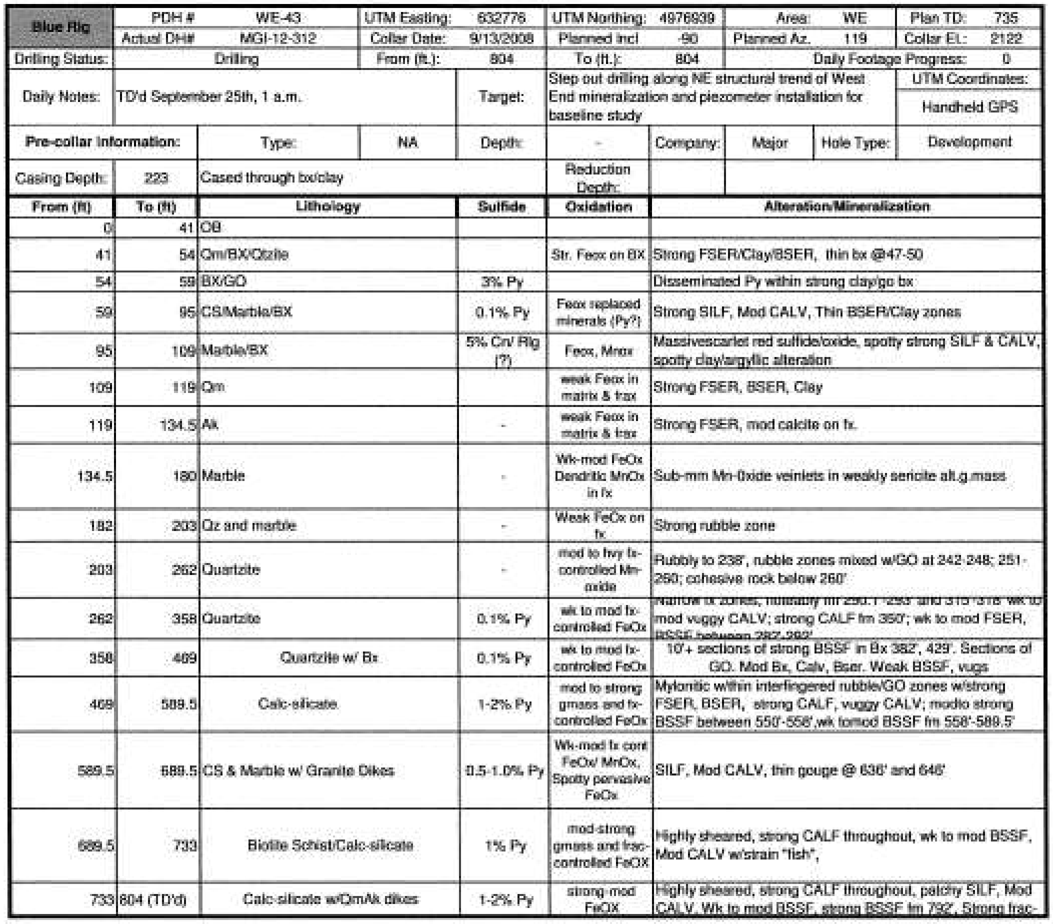
Hole diameter = HQ outside diam. = 96mm = 0.315 ft. $r_{OD} = 0.157$ ft.
Core diameter = HQ inside diam. = 63.5 mm = 0.208 ft. $r_{ID} = 0.104$ ft.
Hole depth = 804 ft.

Cuttings volume = Hole diam. – Core diam. = $h\pi\,(r_{OD})^2 - h\pi\,(r_{ID})^2$
$= 804'\pi(0.157)^2 - 804'\pi(0.104)^2$
$= 62.3\ \text{ft}^3 - 27.3\ \text{ft}^3$
$= \mathbf{35\ ft^3}$

Sulfide Content

Interval containing sulfide			Sulfide	Equivalent feet of 100 % sulfide
From (ft.)	To (ft.)	Distance	Percentage	
54	59	5	3	0.15
59	95	36	0.1	0.036
95	109	14	5	0.7
262	358	96	0.1	0.096
358	469	111	0.1	0.111
469	589	120	2	2.4
589	689	100	1	1
689	733	44	1	0.44
733	804	71	2	1.42
Total eq. ft. sulfide				**6.353**

Sulfide % of total cuttings = (6.353’ / 804’)100 = **0.8%**
Total sulfide volume = .008(35 ft^3) = **0.3 ft^3**



Blue Rig	PDH #	WE-43	UTM Easting:	632776	UTM Northing:	4976939	Area: WE	Plan TD:	735
	Actual DH#	MGI-12-312	Collar Date:	9/13/2008	Planned Incl	-90	Planned Az. 119	Collar EL:	2122
Drilling Status:	Drilling		From (ft.):	804	To (ft.):	804	Daily Footage Progress:		0
Daily Notes:	TD'd September 25th, 1 a.m.		Target:	Step out drilling along NE structural trend of West End mineralization and piezometer installation for baseline study				UTM Coordinates: Handheld GPS	
Pre-collar Information:	Type:	NA	Depth:	-	Company:	Major	Hole Type:	Development	
Casing Depth:	223	Cased through bx/clay		Reduction Depth:					

From (ft)	**To (ft)**	**Lithology**	**Sulfide**	**Oxidation**	**Alteration/Mineralization**
0	41	OB			
41	54	Qm/BX/Qtzite		Str. Feox on BX	Strong FSER/Clay/BSER, thin bx @47-50
54	59	BX/GO	3% Py		Disseminated Py within strong clay/go bx
59	95	CS/Marble/BX	0.1% Py	Feox replaced minerals (Py?)	Strong SILF, Mod CALV, Thin BSER/Clay zones
95	109	Marble/BX	5% Cn/ Rlg (?)	Feox, Mnox	Massivescarlet red sulfide/oxide, spotty strong SILF & CALV, spotty clay/argyllic alteration
109	119	Qm		weak Feox in matrix & frax	Strong FSER, BSER, Clay
119	134.5	Ak	-	weak Feox in matrix & frax	Strong FSER, mod calcite on fx.
134.5	180	Marble	-	Wk-mod FeOx Dendritic MnOx in fx	Sub-mm Mn-0xide veinlets in weakly sericite alt.g.mass
182	203	Qz and marble	-	Weak FeOx on fx	Strong rubble zone
203	262	Quartzite	-	mod to hvy fx-controlled Mn-oxide	Rubbly to 238', rubble zones mixed w/GO at 242-248; 251-260; cohesive rock below 260'
262	358	Quartzite	0.1% Py	wk to mod fx-controlled FeOx	Narrow fx zones, rubbably fm 290.1'-293' and 315'-318' wk to mod vuggy CALV; strong CALF fm 350'; wk to mod FSER, BSSF between 287-292'
358	469	Quartzite w/ Bx	0.1% Py	wk to mod fx-controlled FeOx	10'+ sections of strong BSSF in Bx 382', 429'. Sections of GO. Mod Bx, Calv, Bser. Weak BSSF, vugs
469	589.5	Calc-silicate	1-2% Py	mod to strong gmass and fx-controlled FeOx	Mylonitic w/thin interfingered rubble/GO zones w/strong FSER, BSER, strong CALF, vuggy CALV; modto strong BSSF between 550'-558',wk tomod BSSF fm 558'-589.5'
589.5	689.5	CS & Marble w/ Granite Dikes	0.5-1.0% Py	Wk-mod fx cont FeOx/ MnOx, Spotty pervasive FeOx	SILF, Mod CALV, thin gouge @ 636' and 646'
689.5	733	Biotite Schist/Calc-silicate	1% Py	mod-strong gmass and frac-controlled FeOX	Highly sheared, strong CALF throughout, wk to mod BSSF, Mod CALV w/strain "fish",
733	804 (TD'd)	Calc-silicate w/QmAk dikes	1-2% Py	strong-mod FeOX	Highly sheared, strong CALF throughout, patchy SILF, Mod CALV. Wk to mod BSSF, strong BSSF fm 792'. Strong frac-

MWH-B20 Borehole Well Log

Appendix C

Glossary of Terms

Acid rock drainage: An acidic solution derived from the oxidation of sulfide minerals.

Adsorption: When a dissolved ion, molecule, or colloid becomes attached to the surface of a pre-existing solid substrate.

Alluvium: Sediments deposited by or in conjunction with running water in rivers, streams, or sheetwash and in alluvial fans.

Annular space: The opening between an inner and outer cylindrical body, often used to describe the space between the well casing or drill pipe and the surface of the borehole.

Aperture: The distance between the two surfaces of a fracture.

Aquifer cross-flow: Vertical groundwater flow from one hydrostratigraphic unit to another.

Aquifer: A consolidated or unconsolidated geologic unit (material, stratum, or formation) or set of connected units that yields water of suitable quality to wells or springs in economically usable amounts.

Arsenopyrite: Iron arsenic sulfide ($FeAsS$).

Artesian water: Any water that is confined in an aquifer under pressure so that the water will rise in the well casing or drilled hole above the elevation where it was first encountered. This term includes water of flowing and non-flowing wells.

Attenuation: The gradual loss in intensity of any kind of flux through a medium.

Barite: A mineral consisting of barium sulfate ($BaSO_4$).

Baseflow: Water that seeps into a stream through a permeable rock or sediment unit that outcrops in the bottom or banks of the stream.

Basement: The igneous and metamorphic rocks that exist below the oldest sedimentary cover.

Bedrock: Consolidated rock at various depths beneath the Earth's surface.

Bentonite: An absorbent aluminum phyllosilicate, essentially impure clay consisting mostly of montmorillonite.

Biochemical oxygen demand: A measure of the quantity of dissolved oxygen necessary for the decomposition of organic matter in water by organisms (chiefly bacteria).

Brecciation: The formation of areas of fragmented rock within a fault zone. Often the fragments are subsequently cemented together by mineralizing fluids.

Calc-silicate: A metamorphic rock consisting mainly of calcium-bearing silicates such as diopside and wollastonite, and formed by metamorphism of impure limestone or dolomite.

Casing: A pipe installed in a borehole to maintain the opening and, along with cementing, to confine the groundwaters to their zones of origin and to prevent the entrance of surface contaminants.

Cation exchange capacity: The capacity of a material to exchange cations with a surrounding solution.

Colluvium: Unconsolidated sediments that have been deposited at the base of hillslopes by either rainwash, sheetwash, slow continuous downslope creep, or a variable combination of these processes.

Confined aquifer: An aquifer that is immediately overlain by a low-permeability unit (confining layer). A confined aquifer does not have a water table.

Dendritic: Having multi-branching tree-like form.

Dissolved oxygen: A relative measure of the amount of oxygen that is dissolved or carried in a given medium.

Evapotranspiration: All methods of water moving from a liquid to water vapor in nature. The combination of evaporation and transpiration.

Fault: A fracture which has experienced translation or movement of the fracture walls parallel to the plane of the fracture.

Filter cake: Layer of bentonite and cuttings deposited on the surface of a borehole.

Filtrate: The liquid that passes through bentonite filter cake.

Flowing artesian borehole: A borehole in which groundwater rises above the top of the surface casing and flows at the ground surface.

Formation: A body of rock strata that consists of a certain lithology or combination of lithologies; a lithologically mapable unit.

Fracture: A subplanar discontinuity in a rock or soil formed by mechanical stresses. A fracture is visible to the naked eye and is open (i.e., not filled with minerals).

Granodiorite: An intrusive igneous rock similar to granite, but containing more plagioclase than orthoclase-type feldspar.

Grout: Bentonite- or cement-based material used to create a water-tight seal in voids.

HDPE liner: High-density polyethylene sheeting material.

Highwall: The unexcavated face of exposed overburden and/or ore in an open pit mine.

Hydraulic: Dealing with the mechanical properties of liquids.

Hydrostatic head: The pressure at a given point in a liquid measured in terms of the vertical height of a column of the liquid needed to produce the same pressure.

Lithostatic unloading: the release (usually by erosion or the melting of ice) of pressure or stress imposed on a layer of soil or rock by the weight of overlying material.

Lost circulation: A condition which occurs when drilling fluid flows into one or more geological formations instead of returning up the annular space.

Make-up water: Water used to mix drilling fluid.

Metasediments: Partially metamorphosed sedimentary rocks.

Monzonite: An igneous intrusive rock composed of approximately equal amounts of plagioclase and alkali feldspar, with less than 5% quartz by weight.

Mud sump: Excavated pit where drilling cuttings are allowed to settle out of the mud.

Neat cement: A mixture of water and cement in the ratio of not more than six (6) gallons of water to ninety-four (94) pounds of Portland cement.

Packer: An inflatable tool on a drill string that is used to seal off certain lengths of a borehole.

Permeability: The ease with which a porous medium can transmit water or other fluids.

pH: A measure of the acidity of a solution, based upon the negative logarithm of the hydrogen ion concentration.

Porous media: A material containing void spaces within a matrix.

Pumping test: A technique to evaluate the hydraulic properties of an aquifer by observing how water levels change with time when water is pumped from the aquifer.

Recharge: The process by which water enters the groundwater system or, more precisely, enters the phreatic zone.

Regolith: A general term used in reference to unconsolidated rock, alluvium or soil material on top of the bedrock. Regolith may be formed in place or transported in from adjacent lands.

Shear stress: Shear stress is the stress component parallel to a given surface, that results from forces applied parallel to the surface.

Silt fence: A temporary sediment control device consisting of a piece of synthetic filter fabric stretched between a series of wooden or metal fence stakes.

Stibnite: A sulfide mineral with the formula Sb_2S_3.

Straw wattles: A temporary sediment control device made of straw, coconut fiber or similar material formed into a tubular roll.

Sulfide: A class of minerals containing sulfide (S^{2-}) as the major anion.

Tailings: The materials left over after the process of separating the valuable fraction from the uneconomic fraction of an ore.

Thixotropic: Having a viscosity that decreases when a shear stress is applied.

Total organic carbon: The amount of carbon bound in an organic compound.

Unconfined aquifer: The upper surface of the aquifer is the water table. Unconfined aquifers are directly overlain by an unsaturated zone or a surface water body.

Underflow: The flow of ground water in the alluvial materials beneath and immediately adjacent to a stream and flowing in the same general direction as the stream.

Water table: A surface at or near the top of the phreatic zone (zone of saturation) where the fluid pressure is equal to atmospheric pressure. In the field, the water table is defined by the level of water in wells that barely penetrate the phreatic (saturated) zone.