Introduction
This report was prepared in support of the environmental analysis for the Musgrove Exploration Drilling project, which includes core drilling up to forty-two (42) holes, in fourteen drilling locations (up to three holes per drilling location), and a total drilling depth of 42,000 feet (1000 feet per hole). The 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 Musgrove project area is located in the Musgrove Creek drainage in central Idaho, near the Blackbird Mine in Lemhi County, Idaho approximately 25 miles southwest of Salmon, Idaho. The project is located in the Blackbird Mining District.
Geology
The Blackbird quadrangle contains the western part of the cobalt-bearing Blackbird mining district. The Blackbird mining district occupies the central, widest, and most-mineralized part of the Idaho cobalt belt, a northwest-trending belt of Cu-Co mines, prospects, and geochemical anomalies. The Idaho cobalt belt is ~35 miles long and extends ~17 miles to the southeast and northwest of its centroid. Broad ridges are deeply weathered to saprolite, and hillsides are mostly covered with talus and periglacial colluvium. Bedrock outcrops are sparse, except along steep upper slopes and road cuts (Bookstrom et al., 2016). The steeply dipping Quartzite Mountain fault, a major fault that transects the quadrangle, delimits the western extent of the mining district and the western extent of the stratabound cobalt-bearing rocks of the Yellowjacket/Apple Creek Formation (Tysdal et al., 2000). The Blackbird district contains at least eight stratabound ore zones and many discordant lodes, mostly in the upper part of the banded siltite unit of the Apple Creek Formation of Yellow Lake, which generally consists of interbedded siltite and argillite (Bookstrom et al., 2016). In the Blackbird mine area, argillite beds in six stratigraphic intervals are altered to biotite containing over 75 vol% of greenish hydrothermal biotite, which is preferentially mineralized (Bookstrom et al., 2016).

At the Musgrove project area the dominant host rocks are the Yellowjacket (Apple Creek) Formation banded siltite; sequences of quartzose siltites and fine-grained sandstones that consist mostly of quartz, clay and muscovite and alternate with thick laminated argillite composed of clay, fine grained biotite and carbonaceous material. These rocks are locally metamorphosed to biotite and muscovite phyllites or, in some areas, schist. The Musgrove project area also contains Challis Formation rocks associated with the Panther Creek Graben; rhyolite to dacite ash flows, tuffs and lavas interbedded with coarse-grained volcanic sediments. The Challis Volcanics cover faulted Apple Creek Formation rocks (Makepeace, 2006).

Bedrock Geology
Cratonized oceanic-islandarc–type basement rocks of the Paleoproterozoic Selway terrane (ca. 1.86–1.7 Ga) probably underlie most of the Co-Cu deposits of the Idaho cobalt belt and the Blackbird district (Foster et al., 2006).
**Surficial Geology**

The geologic units in the Musgrove project vicinity are Proterozoic siltites and argilites of the Yellowjacket Formation (now recognized as the slightly younger Apple Creek Formation), Tertiary Challis Volcanics and Quaternary (Holocene and Pleistocene) glacial deposits. The Musgrove drill sites are located in the Proterozoic Yellowjacket (Apple Creek) Formation.

**Structural Geology**

The dominant structural features of the area are north-to-northwest striking faults and shear zones. In the Musgrove project area, bedding strikes northwest with foliation generally parallel to bedding. There are fault zones within the project area; the Trans-Challis, Musgrove and Ostrander Creek Fault Zones. These fault zones are the primary source of mineralization at the project area and most of the ore lies along the Musgrove Fault Zone (Makepeace, 2006).
Musgrove Exploration Drilling Project: Hydrogeology Report

Hydrology
The Musgrove project area lies within the Middle Salmon River-Panther Creek sub-basin and the Middle Panther Creek Subwatershed. According to the IDEQ sub-basin assessment report, *Middle Salmon River-Panther Creek sub-basin Assessment*, the sub-basin encompasses 1,810 square miles with 1,957.95 stream miles. The northern extent of the sub-basin is bounded by the continental divide, which also delineates the boundary between Idaho and Montana. The southern boundary of this sub-basin ends at the town of Ellis located north of the city of Challis. On the northwest corner, there is a small portion of the Frank Church River of No Return Wilderness within the sub-basin. Elevations of the area range from 2,085 feet within the Salmon River Valley, to an elevation of 10,985 feet (Lem Peak) along the Lemhi Range in the southern portion of the sub-basin (IDEQ, 2001). The Musgrove project area ranges from 5800 feet to 7200 feet in elevation.

The climate of the Salmon-Panther sub-basin varies from a near desert environment to an almost alpine environment (IDEQ, 2001). The Musgrove project area vegetation consists of open alpine grass areas to some forested areas; fir and pine trees. The majority of the annual precipitation in the Salmon-Panther sub-basin occurs in the late fall and early spring. The predominant form of precipitation occurs as snow with infrequent thunderstorms in the summer months. Snowmelt in the lower reaches begins in the early spring while snowmelt on the higher reaches occurs in early to mid-summer. The greater snow pack in the higher elevations causes greater runoff in the summer months, thus causing larger stream flow discharge in the mid to late summer. The average precipitation ranges from 10 inches in the lower elevations to 16 inches at the middle elevations and 28 inches in the high elevations (IDEQ, 2001).

Panther Creek, the largest tributary in the sub-basin, contributes an average flow rate of 258 cfs. Panther Creek would be expected to reach its highest flows near 3,000 cfs every 10 years (IDEQ, 2001). The Panther Creek watershed includes some 400 miles of perennial streams, which drain into the lower Salmon River section downstream of Shoup. Stream flow patterns are typical snowmelt runoff driven, with peaks in May or June and lows in fall and winter.

The Musgrove project lies within the Middle Panther Creek subwatershed which encompasses Panther Creek (from Musgrove Creek to Blackbird Creek), Blackbird Creek, Woodtick Creek,
Musgrove Creek, and the first order stream Copper Creek. The watershed area is 58,581 acres with approximately 44 stream miles.

**Hydrogeology**

The types of soils in the sub-basin affect many aspects of surface water, particularly the quantity and texture of sediment in the water bodies. In the Salmon-Panthersub-basin, soils tend to be shallow to moderately deep in the mountains and moderately deep to deep in valley bottoms (SCNF, 1993). The uplands and valley bottom landforms vary greatly in their soil types. The soil in the upland areas is generally poorly productive and exhibits coarse textures. Soil types on gentle and moderate mountain slopes can be rocky but are somewhat more productive. Valley bottom soil types vary. Some poorly-drained meadows exist that are flooded in spring, with deep loam and clay loam textures over coarse sand layers (EPA, 2008). The combination of these soils, steep topography, and climatic stresses give rise to significant base surface erosion, slumping, and debris avalanche hazards.

In 2003, Wave Exploration Corporation conducted a small exploration program at the Musgrove site that included a geochemical soil sample grid; that data is presented in a 2004 Technical Report (NI 43-101 Technical Report). The soil samples were generally from a poorly developed B soil horizon and the grid identified a large “geochemical anomaly (arsenic and gold) that extends northwest from drilling” that occurred in 2004.

Given the project location, it is anticipated that any groundwater encountered will be typical of fractured bedrock systems, which are usually unconfined and in which flow is exceedingly slow and heterogeneous. Such bedrock aquifers tend to flow in a direction that generally follows surface topography.

**Existing Groundwater Quality and Quantity**

The closest groundwater monitoring sites to the Musgrove project are associated with the Blackbird Mine, in the Blackbird Creek drainage, approximately 5.5 miles northeast. There are 5 monitoring wells near the Blackbird Waste Treatment Plant that are used for groundwater monitoring and periodic water quality sampling. The Blackbird Mine also monitors groundwater levels. The Blackbird Mine has additional monitoring wells in the West Fork drainage near the tailings storage facility, approximately 6 miles away from the Musgrove project area. Water level measurements were taken three times in 2015 at the West Fork site and measurements indicated that water levels followed historic patterns of increased levels during snow melt and lower levels during low flow periods (Golder Associates, Inc., 2015). Water elevations at the West Fork monitoring wells ranged from an average of 5638.49 to 5701.45. A search of the Idaho Department of Water Resources well log database resulted in four monitoring well logs near the Musgrove project area, all wells owned by Blackbird Mine in T20N R18E S2. These wells were drilled in 2001 and 2012 to depths of between 35 ft and 97 ft and show lithologies of gravely silt to sandy gravel to weathered bedrock and phyllites. The only other well data near the Musgrove site are for wells drilled for the USDA Forest Service Moyeradmin site approximately 1.5 miles southeast of the Musgrove site in the Panther Creek.
Musgrove Exploration Drilling Project

Bravura Ventures has proposed to drill up to forty-two (42) core holes in an elevation band between 5800 feet to 7200 feet amsl. The Musgrove exploratory boreholes are expected to reach depths of one thousand (1000) feet and thus have the potential to penetrate bedrock aquifers, if any are present. The standard drilling procedures described below minimize the risk of contamination to or from these aquifers.

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 allows 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 immediately upon completion (see Abandonment section).

A core drilling rig uses a cylindrical, diamond-studded bit 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. 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 where it runs into a tank that allows the drill cuttings to settle out and the mud is then recirculated down the borehole.

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, including the Idaho Ground Water Rule (IDAPA 58.01.11), Idaho Rules Governing Exploration, Surface Mining Closure of Cyanidation Facilities (IDAPA 20.03.02) and Idaho Well Construction Standards Rule (IDAPA 37.03.09). The Well Construction Standards Rule is only 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. A mud sump is usually excavated for disposal of drill cuttings and drilling fluid. 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. Minor fluid leaks on the drill rig itself are contained by an impervious material (such as HDPE liner material) and collected for proper removal and disposal upon remobilizing the rig. 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 contain any perennially saturated zones that would constitute an aquifer. In the project area, such surficial formations are non-existent to very thin.

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) will always exceed the water pressure in the aquifer. Because of this pressure differential, the mud will 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”. 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 will be sealed off (see fluid loss/gain section).

Once the alluvium has been drilled through and the hole has penetrated sufficiently into solid bedrock, casing is set into the bedrock to provide a continuous seal from the surface. 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.

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 will form on the borehole walls in the same manner as when drilling through alluvial formations. Higher permeability fault and fracture zones that may be encountered in the boreholes would be the only likely zones 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. highly fractured bedrock) is encountered, the drilling fluid will flow 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 the 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 will alert the driller to an inflow/outflow condition (Tim Rygg, Midas Gold Drilling Supervisor). 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 will continue and full flow will often return as the lost circulation zone is progressively sealed by the filter cake.

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 will become stuck at points where they form bridges spanning various apertures in the flow paths. These plugs will 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 tend to 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 will 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 will stop and mud will be 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 will stop circulating and prepare a 25-40 gallon slug of lost circulation material (LCM) (pers. comm., John Eddy, T&J drilling foreman). There are many types of lost circulation material available, but the drilling contractors typically use high-solids bentonite grouts. 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 will successfully seal 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.

**Fluid Gain**

If a confined aquifer is encountered where the hydraulic head exceeds that of the mud column in the borehole, water will run 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 is 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 the 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 immediately abandoned as described in 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 measure would entail routing any overflow to discharge onto an area 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 CE. There are no Riparian Conservation Areas in the Musgrove project area so sumps would not be located in RCAs or in areas where groundwater levels could rise above the bottom of the sump. Drilling mud from holes in such areas would be 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, which is not anticipated in this project), the casing is left in place. When the annular seal is bentonite, as anticipated in this project, 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 (e.g. Benseal®) which seals off all water transmission. This is done immediately after reaching their total planned depth. 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. 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 five to ten feet of the ground surface and has set up, the surface casing is pulled, and the remainder of the hole is plugged with cement flush to the ground surface. In the case of abandonment of a flowing artesian drill hole, neat cement is used instead of bentonite grout.

Impacts of Exploration Drilling on Groundwater Resources

Effects on Groundwater Quantity

Effects of drilling on the hydraulic properties of an aquifer are likely to be negligible and transitory. It is useful to recognize the scale and duration of the proposed disturbance.

A rigorous hydrologic model of flow in fractured rock would be exceedingly complex and require a host of assumptions and variables, which are unknown at this time. However, the volume of aquifer potentially affected by drilling compared to the total aquifer volume would be exceedingly small (likely substantially less than 1% of the total volume of the aquifer).

The second 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 7-13 days, immediately 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 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. However, there are no known springs or seeps upstream of the Musgrove drill sites.
**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 petroleum products and 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 (Donaldson & Chernoglazov, 1986). Reported hydraulic conductivity values for filter cake are very low from $1 \times 10^{-2}$ millidarcys to $1 \times 10^{-5}$ millidarcys (Campbell & 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 & 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 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 to give a rough estimate of 25 gallons of filtrate loss in 10 hours.

The preceding example is a very rough approximation of volumes and distances based on flow in porous media (e.g. alluvial aquifers) and may not necessarily be directly applicable to flow in fractured bedrock. As previously described, the likelihood of such lost circulation events occurring as a result of the current project is exceedingly small. 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. Acquiring sufficient data could easily require the drilling of more holes than the planned 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 to 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. The drilling additives used are non-toxic, biodegradable and approved (NSF/ANSI Standard 60 certified) 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 will only allow a small volume of filtrate to enter the formation, and filtrate production will be limited to the time the hole is open.
It should be pointed out that the use of drilling fluid mixed from themake-up water sources described above means that when 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 will act to dilute the concentrations of these metals. However, these potential beneficial effects are still 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 contaminants 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 immediately 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 $1.1 \times 10^{-8}$ cm/s (Baroid, 2012). The permeability of neat cement is $4.5 \times 10^{-7}$ cm/s (Edil et. al. 1992). Since these values are much lower than the permeability of any aquifer there will 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 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 metals) at the ground surface, this water could flow into and mix with nearby surface water. This possibility is minimized by 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 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 a 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 Drilling Fluid and Drill Cuttings Disposal**

Most of the drying of a sump takes place by evaporation but a small percentage of fluid will infiltrate the ground in the same manner that filtrate will pass 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) 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. 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 significant amount of acidity.

**Monitoring and Reporting**

Since the effective protection of groundwater resources is strongly dependent upon the proper implementation of SOPs, monitoring of these SOPs will be carried out by Forest Service personnel on a regular basis.

Forest Service regulations for locatable mineral operations require regular compliance inspections by the Forest Service administrator (36 CFR 228.7) and this project also includes provision for additional Forest Service monitoring. Because the project will have negligible to no impacts on groundwater, no extraordinary monitoring measures (e.g. monitoring wells, pulling drill string to test or collect water samples) are deemed necessary.

**Conclusions**

Most exploration drilling projects can be expected to result no impact to groundwater resources. Examples of situations where significant impacts might occur include drilling:

- in karst areas,
- in municipal watersheds or source water protection areas,
- in areas where groundwater supports TES species,
- in formations known to contain constituents of concern,

The project is not located in karst terrain, a municipal watershed, or a source-water area, nor does the project area provide habitat for groundwater-dependent species. Compared to other multi-year exploration drilling projects, the number of drill holes in the Musgrove project is not unusually large.

**Direct and Indirect Effects**

This report considered five main issues with respect to potential impacts to groundwater related resources:

- Uncontrolled artesian flow to the ground surface causing depressurization of aquifers and run-off of contaminants and sediment into nearby surface water systems.
- Aquifers containing high-quality water may be connected by drill holes to aquifers with inferior-quality water. Cross aquifer flow may be induced by natural pressure differences or pressure differentials induced by drill fluid pumping.
- Significant loss of fluids from drill holes, and migration of water or drilling fluids via large faults, fractures, or solution cavities to a receptor (stream, spring, wetland, or water well).
- Groundwater contamination from spills at the surface or from run-off water entering into open drill holes from the surface.
- Properly implementing appropriate drill hole abandonment procedures for a given hydrogeologic setting.
Each of the above risks was determined to be minimal due to the inherent nature of the local subsurface environment and the nature, scale, and timing of the project. Standard industry best practices for core drilling, including contingencies for unanticipated conditions, further reduce the likelihood that any of the above impacts would occur in such a manner as to be detectable in the short or long term. Therefore, like most drilling operations, direct or indirect effects of the Musgrove Exploration Drilling project on groundwater or the subsurface environment are expected to be negligible and temporary. 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 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 would be minimal since groundwater quality will not be degraded.

**Cumulative Effects**
There are no connected actions occurring on adjacent private lands that are not administered by the Forest Service.

While there are underground workings in the project vicinity associated with the Blackbird Mine, it is highly unlikely that any hydraulic connection exists between the planned borings and these openings/voids. Therefore, no impacts on the planned drilling are expected due to the presence of the Blackbird Mine, nor are impacts anticipated on the workings from the drilling because the workings are approximately 5.5 miles away and extend from the surface in the direction opposite the proposed drilling.

The present project should have no effect on groundwater hydraulics or water quality since the potential area of effect is within about 2 feet of the drill holes. The cumulative effects area will be the 14 drill sites and the subsurface that core holes can be directed into vertically and horizontally. Therefore, like most drilling operations, it is anticipated that the Musgrove Exploration Drilling project will result in no detectable cumulative effects to groundwater or the subsurface environment.

**Regulatory Compliance**
The Salmon Forest Plan contains no specific standard(s) for subsurface resources, in general, or groundwater, in particular. Forest Plan standards that indirectly address these resources and with which the project complies include:

- **Monitor operations to ensure that mitigative measures are effective and in compliance with State water quality standards (IV-51).** State standards for ground water quality include narrative standards and numerical standards for primary and secondary constituents in relation to natural background levels (IDAPA 58.01.02.11.200), require activities with the potential to degrade aquifers to be managed in a manner which maintains or improves existing ground water quality through the use of best management practices and best practical methods to the maximum extent practical (IDAPA 58.01.02.11.301), enumerate
measures for the prevention of ground water quality degradation, and provide for investigation, evaluation, and enforcement action by the Idaho Department of Environmental Protection (IDAPA 58.01.02.11.400). State health standards for wells that may apply to the project include requirements to prevent aquifer cross-contamination (IDAPA 37.03.09.035), to use drilling additives in accordance with manufacturer specifications (IDAPA 37.03.09.030), and to use impermeable materials to seal borings (IDAPA 37.03.09.010). As described in the previous sections, the project meets or exceeds these State standards.

- **Improve and maintain water quality to meet State water quality standards (IV-43).** As described in the previous sections, both surface and ground water quality are expected to be maintained.
- **Ongoing operations will be monitored to assure compliance with operating plan requirements...Operations which could adversely affect water quality will have a high monitoring priority (IV-52).** Because the project is not anticipated to have major impacts on other resources, there are no mitigation measures, but the project design and operating plan include BMPs (best available technologies and industry standards) and contingency provisions. The project design also includes multiple Forest Service and operator monitoring protocols that will document how the project complies with the operating plan, BMPs, etc.

**References**


Idaho Department of Environmental Quality. 2001. Middle Salmon River-Panther Creek Subbasin Assessment and TMDL. Technical Report.

Idaho Department of Environmental Quality. 2008. Middle Fork Salmon River Subbasin


