ATTACHMENT 1

Working Guide
Evaluating Groundwater Resources
For Mineral Exploration Drilling

For Internal Use

WORKING GUIDE

Evaluating Groundwater Resources For Mineral Exploration Drilling

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USDA Forest Service
Minerals and Geology Management
National Groundwater Program

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Preface

Growing recognition of the ecological and socio-economic importance of groundwater and groundwater-related resources (springs and groundwater-supported wetlands and streams) has emphasized the need for the Forest Service to ensure adequate analysis of potential effects on groundwater from mineral exploration drilling and other mineral and energy exploration and development activities. Exploration drilling aims to identify the location and quality of a mineral deposit. Thorough, robust environmental analyses will help local resource specialists in identifying potential effects and appropriate mitigations for such effects, as well as help Districts and Forests defend challenges to decisions and allegations of insufficient analysis under NEPA requirements.

The purpose of this guide, along with a companion guide for oil and gas leasing and operations, is to enable field units to conduct adequate analyses of groundwater resources and potential effects to those resources using local expertise. Local geologists and hydrologists with basic knowledge and training in hydrogeology should be able to adequately identify and characterize groundwater resources and the connections between those resources and mineral exploration activities. This guidance addresses what kind of information to use, where to get that information, how to interpret it, and how to present it in specialist reports and environmental analysis documentation. Guidelines are based on real experience with actual projects, but are not intended to be "one size fits all". We recognize the wide diversity of resources and situations across the Forest Service that will require modified approaches and judgments based on local conditions. Consequently, this guide is intended to be a working document, subject to modification and re-issuance as the Forest Service develops more experience in understanding the distribution and nature of groundwater resources and how mineral exploration activities interface with groundwater resources.

Joe Gurrieri, hydrogeologist on the MGM staff, developed this guide with input and assistance from several other experts and field units challenged with producing thorough and robust groundwater analyses. The application of this approach to groundwater analysis for mineral exploration drilling has passed the test of legal challenge in two situations. We anticipate that use of the approaches described herein in analyses of proposed mineral exploration activities will lead to fewer challenges and strengthened defense of analyses that are challenged.

Because these are "working guidelines", we ask that results of following them be shared with the Office of Geologic Resources, Hazards, and Surface Management, and any recommendations for changes, clarification, and additions to these guidelines be transmitted to us for consideration and incorporation into future versions of this guidance.

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Minerals and Geology Management – National Groundwater Program

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Introduction

Most mineral exploration drilling operations are conducted with no detrimental effects to water resources. There is potential, however, for adverse effects to subsurface and surface resources. Surface effects are more common because of the nature and extent of ground disturbance, inadequate management of drilling fluids, transportation and storage of fuels, presence of artesian waters, and inadequate reclamation. On rare occasions, effects to groundwater have occurred with either groundwater quality or quantity being compromised.

This guide is designed to assist Forest Service specialists in their assessments of water resources through the environmental analysis phase of mineral exploration permitting. This guide provides information relevant to exploratory drilling operations and the effects such operations may have on groundwater and connected surface water resources. It also provides advice on best practices designed to protect aquifers and surface water features dependent on groundwater discharge including wetlands, springs, and streams.

This document does not address wells drilled by exploration or mining companies specifically for water supply, dewatering purposes, or for groundwater monitoring, although the concerns and risks would generally be the same. The fact that exploratory drill holes are precursors to development of mineral resources (mining) does not mean potential physical and chemical effects or risks are different from other boreholes drilled with equivalent techniques. An important distinction from other types of boreholes is that a mineral exploration drill hole is simply a conduit to remove a rock sample from underground. It has no long-term use and is plugged shortly after completion.

The relevance of these considerations to a specific project will depend in part on the extent of applicable state regulations. If regulations already exist to address certain concerns, they should be followed and supplemented with measures discussed here.

Environmental Analysis

For an environmental analysis of the effects on groundwater from a mineral exploration drilling project to be adequate, a “hard look” must be undertaken and documented. Documentation must clearly disclose to the public and the decision maker how exploration drilling may affect the groundwater resources in the area under consideration. Issues for a particular proposed project will drive the level of analysis (CE, EA, or EIS). However, most drilling projects to date have been permitted under an EA with a finding of no significant impact (FONSI) to groundwater resources. When and where effects on groundwater are deemed to be significant and cannot be mitigated, a more robust analysis documented in an EIS may be necessary. Examples of possible situations where significant effects to groundwater might occur include:

- Drilling in karst areas. (Karst is a type of landscape formed by dissolution of carbonate rock, such as limestone and dolomite, and characterized by sinkholes, caves, and underground drainage.)
- Drilling in municipal watersheds or source water protection areas.
- Drilling in formations know to generate acid or dissolved constituents of concern.
- Drilling in areas where groundwater supports Threatened or Endangered Species (TES).

The assessment can be made by referring to geologic or hydrogeologic maps and reports, contacting local agencies that collect and analyze groundwater data, asking the proponent for information, collecting field data, requesting the assistance of a Forest Service groundwater specialist, and/or retaining a groundwater consultant.

Data Collection and Background Literature Review

To protect surface water, water well owners, groundwater, and groundwater-dependent ecosystems, we must analyze the potential impacts of proposed activities within a hydrologic investigation area. A Forest Service specialist (minerals administrator, geologist, hydrologist, etc.) reviews the proposed drilling exploration plan for information regarding water resources using the "Water Resources Worksheet for Exploration Drilling Projects" (Appendix A). If information is determined to be lacking, relevant information can be requested from the project proponent using the "Water Resources Questionnaire for Exploration Drilling Projects" (Appendix B) to obtain enough data to analyze effects of the proposed activities. While some of this questionnaire is voluntary information, it may greatly help to speed the permitting process and increase the operator's chances of sustaining a 36 CFR 215 appeal or 36 CFR 218 objections. Information gained through this process is used in conjunction with this Working Guide.

Thorough review and collection of relevant literature and existing data can reduce uncertainty, better focus the analysis effort, and provide a more defensible work product. For compiling geologic and hydrogeologic information the following sources of information should be consulted:

- The United States Geological Survey (USGS) – The "National Geologic Map Database" website is a particularly useful place to begin a search. A specific location can be entered and a list of federal and state geologic and hydrogeologic literature potentially relevant to that location can be generated.
- State agencies – These include state geologic surveys, departments of natural resources and environment, and State Engineer offices, which maintain water well records and databases.
- Existing Forest Service documents – Prior agency environmental reviews and other studies and data collection efforts may provide useful information or references.
- Project proponent – Mineral exploration companies generally have a significant amount of data on the geology of the area they want to explore.

Published scientific literature can provide useful information. The Forest Service library will provide literature searches and assistance with obtaining copies of specific references at no cost. Natural Resources Conservation Service (NRCS) soil surveys also may provide useful information. Additionally, some county governments or regional planning commissions may have collected data or performed studies applicable to the review.

No matter what information is used, it is important that it be properly documented so that it can be referenced if necessary in addressing comments or questions later on in the process. Copies of all references used should be collected, whether cited or not. If a reference is used but not specifically cited in the review document, it may be worth including in a list of references consulted as part of the review. To help avoid charges of incomplete or biased background research, it also may be advisable to note references that could be considered relevant to the review, but were not used for some reason (controversial, speculative, not well accepted by the scientific community, etc.), along with a short explanation of why it was not used.

Proposed Action - Describe Exploration Drilling and Abandonment Methods and Materials

A description of the type of drilling proposed (diamond core, reverse circulation, etc.), the drilling materials/fluids that will be used, and the anticipated location, number, depth and spacing of drill holes is essential for understanding the potential effects on groundwater. (See Appendix A for a description of the most common drilling methods in mineral exploration.) The proposed drill hole abandonment procedures, materials, and timing should be clearly described, as well as any state requirements. Based on information gathered on the affected hydrogeologic environment and the subsequent environmental analysis, specific abandonment methods and procedures may need to be revised to limit effects on groundwater resources.

Affected Environment: Describing the Hydrogeologic Setting

A description of the hydrogeologic setting conveys a clear understanding of the affected environment for groundwater resources. More specifically, the hydrogeologic setting is where groundwater occurs and how it moves through various rock units. The affected environment for groundwater resources is commonly described based on the geologic setting, water-bearing zones and confining units, flow systems, and ambient water quality in the analysis area. By reason of the diverse geologic settings within the NFS, there are numerous hydrogeologic settings in which groundwater resources occur. Descriptions and hydrogeologic properties of many aquifer systems can be found in the Groundwater Atlas of the United States http://pubs.usgs.gov/ha/ha730/gwa.html.

The following attributes of the local hydrogeologic setting should be described. This information will provide the basis upon which the potential effects of a project can be assessed and will also help define monitoring or mitigation measures that may be needed.

Geologic setting

Geology determines hydrogeology. The thoroughness and accuracy of the understanding of the site geology will influence the accuracy of the interpretation of the site hydrogeology and determination of risks associated with the proposed activity. Documentation of the affected environment should include a description of the various bedrock and surficial geologic units, structural geology, and associated aquifer systems within the project area based on existing literature, geologic maps, and information from the project proponent. A conceptual geologic model that includes geologic history should be used as a framework for developing an understanding of the site hydrogeology. Documentation of the affected environment should include identification and description of data gaps and discrepancies that affect the thoroughness and accuracy of the conceptual model (e.g., insufficient information on subsurface fracture occurrence and differences in professional interpretations of geologic data).

Aquifer types

There are four broad types of aquifers that can be identified: unconfined, confined, karst/pseudokarst, and multi-layered. Aquifers can consist of unconsolidated sediments, consolidated sediments, or crystalline bedrock (igneous or metamorphic). Both unconsolidated and consolidated sediments can potentially behave as either porous media or fractured material, depending on specific conditions in the area under consideration. Aquifers composed of crystalline rock generally behave as fractured material. Different drilling methodology and abandonment procedures apply to each type of aquifer.

Unconfined aquifers are also referred to as water table or phreatic aquifers. Their primary characteristic is that the groundwater body typically has free exchange of pressure and moisture with the unsaturated zone and, indirectly, the atmosphere. Where they intersect the land surface, they may form springs, seeps, wetlands, ponds, or lakes and frequently provide a significant fraction of the water in streams. Rainfall can percolate from the surface to the water table or the water table can be open to evaporation. These aquifers may or may not show distinct strata layering depending on the depositional environment. They can contain isolated zones of perched groundwater trapped by strata of low permeability (confining layers). These perched zones may be mistaken for the true water table aquifer during drilling. Although changes in water quality may occur with depth, little mixing takes place when drilling penetrates these aquifers. In general, unconfined aquifers are susceptible to contamination from surface land uses, including the spillage or disposal of waste.

There are instances where an unconfined aquifer may be isolated from the atmosphere by an overlying low permeability layer. The water in these aquifers is separated from the low permeability layer by an unsaturated zone within the permeable material that creates the aquifer. Confined aquifers (discussed below) may become unconfined aquifers if they are sufficiently drained to create an unsaturated zone below their confining unit. Non-water table, confined aquifers typically underlie other aquifers (discussed below).

Many exploration projects are conducted in fractured crystalline rock types. In those settings, near-surface groundwater is generally unconfined to semi-confined depending on the local nature of the rock. These rocks are widely characterized as low producers of groundwater. However, where they are sufficiently fractured, they may produce enough groundwater locally for various water supply needs. An important exception can be areas of karst associated with limestone terrains and pseudokarst associated with volcanic terrains.

Confined or artesian aquifers contain groundwater under pressure. When penetrated, the water level in the drill hole will rise above the top of the aquifer and may reach the ground surface. The level the water rises to is called the potentiometric surface of the aquifer. This level can even be above the groundwater level of overlying aquifers. Confined, or artesian, aquifers usually occur in deeper layered or stratified sediments in large sedimentary basins and in fractured rock aquifers with defined preferential flow paths (e.g., faults) in areas of high relief. The most significant characteristic of these aquifers is that major changes in the water level may be encountered as a result of aquifer penetration by a drill hole to the extent that significant water flow may occur at the surface. These aquifers, because of large pressure differentials, are highly susceptible to cross-aquifer contamination such as saline water invading a lower pressure, freshwater aquifer.

Semi-confined conditions are sometimes encountered within fractured rock aquifers. These aquifers are susceptible to cross-structure contamination where the geochemistry of one intercepted geologic structure is very different than the geochemistry of another intercepted geologic structure. Drilling in these aquifer systems requires detailed planning and special drilling techniques and abandonment procedures. The structure (jointing, fracturing, and faulting) may create areas that confine or restrict the flow of groundwater. When faults, other significant structures acting as aquitards (layers of low permeability), or isolated water-filled fracture networks at depth are penetrated by drilling, increased artesian pressures may occur in the hole. Generally, these pressures subside rapidly due to the low storativity (ability of the host rock to store water) of these aquifers or fracture networks. However, if these types of aquifers are encountered in an exploration drill hole, they can flow under considerable pressure for several days, weeks, or even years, producing large volumes of water. The water may contain elevated concentration of dissolved minerals, such as salts. Conversely, drilling through a major confining structure may cause a sudden loss of circulation as drill fluids flow into a lower pressure or unsaturated zone.

Karst aquifers are usually found in limestone or dolomite units with solution cavities (voids left by dissolution of part of the rock), but similar conditions can also be present in other soluble rocks, and in volcanic rocks as well (pseudokarst). These aquifers are characterized by voids (the largest being caves) that facilitate quick migration of water or drilling fluids away from the drill hole. Once in the voids, the fluids can travel long distances from the drill hole. Typical hydrogeologic methods often do not work for predicting flow directions or discharge points in these types of aquifers. Contaminated water may be channeled in unexpected directions, bypassing nearby groundwater receptors and affecting more distant ones. In some karst aquifers, water entering the aquifer in one surface watershed can travel for miles before being discharged in a completely different surface watershed.

These geologic settings can be particularly difficult to drill in and require specialized drilling equipment and procedures. When solution cavities and voids are penetrated, there can be a complete loss of drilling fluid that escapes into the voids. Underground mine workings can create the same conditions and have to be handled similarly.

Multi-layered aquifer systems consist of some combination of the above aquifers and are mostly associated with layered or stratified sedimentary rocks. These aquifers are separated by low permeability layers called aquitards. A characteristic of multi-layered aquifers is that the penetration of each layer by a drill hole usually results in a change in observed water level because each aquifer is independent from those above and below it. Groundwater can travel between layers along a drill hole as a result of differential pressures. Specific facilities and techniques are required at the drill site if these aquifers are expected to be encountered in drill holes.

Groundwater flow system

An understanding of the local and regional groundwater flow system and the depth to groundwater gives an indication of the direction that a potential groundwater contaminant might move, what groundwater receptors might be affected, and where to locate possible monitoring sites. An assessment of groundwater movement relative to topography and a description of the local and regional groundwater recharge and discharge areas for each aquifer type can be done for most areas of interest using available information such as geologic maps, existing wells or piezometers, topography, distribution of seeps and springs, and known losing or gaining reaches of streams. Water levels in wells provide the best way to infer both the horizontal and vertical flow directions, assuming there are sufficient appropriately constructed wells. Water flows from areas of high head (expressed as higher measured water levels relative to sea level) to areas of low head (lower measured water levels relative to sea level). In fractured crystalline bedrock where the bulk of mineral exploration occurs, groundwater flow can generally be inferred to flow from higher elevations to lower elevations.

Structural geologic data from geologic maps can be used to describe known or likely groundwater flow paths and patterns. For fractured rock settings, the flow system may be quite complex. Once the best possible description of the likely groundwater flow system has been developed, the uncertainty regarding the nature of that system should be disclosed.

There are a variety of ways to identify the potential effects of fractures on groundwater flow. These include observations of prevailing fracture patterns exposed in nearby rock outcrops, indirect surface expressions of fracture zones or faults (called lineaments) that might be discernible on various media (e.g., aerial photographs, topographic maps, LiDAR survey maps), unusual stream patterns that might indicate underlying fracture control, and even vegetation patterns that indicate fracture controlled variations in moisture or nutrients. Previous drilling programs in the area may provide information on subsurface fracture frequency and preferential directions of fracture permeability. However, be aware that drill holes are inherently biased towards intersecting fractures that are perpendicular or at an angle to them and usually miss those that are parallel to them.

Depth to water in the area of drilling is also an important parameter to estimate for other reasons in addition to inferring groundwater flow directions. This information helps predictions of the likelihood of drill holes to penetrate the saturated zone, how far into the saturated zone they are likely to penetrate, and how vulnerable groundwater is to surface spills. It also helps with determining ahead of time if special drilling techniques or drill hole construction (such as casing) will be required. Available hydrologic data from the literature, from the state water well database, from past drilling operations, from existing wells or piezometers, and from seeps/springs mapping should be used to explain known or anticipated depths to groundwater.

Groundwater quality

Use available water chemistry data from available state and federal databases, existing literature, water supply and monitoring wells, seeps and springs, surface water, historic adit discharges, etc. to assess anticipated groundwater quality. Identify wells or other boreholes in the area or region that have been completed in similar formations or to similar depths and have encountered groundwater with elevated concentrations of dissolved constituents (e.g., salts and metals) that would contaminate overlying fresh water resources if discharged to them. Note any contamination associated with known abandoned or active mines or hazmat sites within or near the project area. Determine if the local rock units are known or suspected to generate acid drainage or contain arsenic, selenium, asbestos, metals or other hazardous constituents.

Water wells and public drinking water source areas
An inventory of existing water wells in and adjacent to the project area will help in assessing the potential for effects from the drilling operation. Many states have a searchable online water well database that can be queried for the area of interest. This information can provide an estimate of the average depth to groundwater and the general permeability (yield and specific capacity) of aquifers in the area. A relatively simple method called TGUESS has been developed for estimating hydraulic conductivity from specific capacity data (Bradbury and Rothschild, 1985). A determination should be made on whether the project area is within a Source Water Protection Area for a public water supply or in an established municipal water supply watershed under FSM 2542 and 36 CFR 251.9.

Springs and wetlands
An inventory of springs and wetlands in and adjacent to the project area will help in analyzing the potential for dewatering or contamination of these features from the drilling operation. They may also serve as possible up-gradient or down-gradient monitoring locations.

Streams
An inventory of gaining and losing reaches of streams in and adjacent to the project area will help in analyzing the potential for dewatering or contamination from the drilling operation. Gaining reaches located down-gradient of the drilling operation may be good locations to establish water quality monitoring sites.

Environmental Consequences - Analyzing Effects of Exploratory Drilling
Information about the affected environment, along with an understanding of the proposed drilling methods and materials, are used for analyzing the potential effects on groundwater resources from the proposed exploration drilling project. There are five main issues to be considered when analyzing potential effects on groundwater from exploration drilling:

1) Uncontrolled artesian flow to the ground surface can cause depressurization of aquifers and run-off of contaminants and sediment into nearby surface water systems.
2) 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.
3) Significant loss of fluids from drill holes, and migration of water or drilling fluids via large faults, fractures, or solution cavities can affect a receptor, such as a stream, spring, wetland, or water supply well.
4) Spills at the surface or run-off water entering into open drill holes from the surface can contaminate groundwater.
5) Drill hole abandonment procedures for a given hydrogeologic setting must be properly designed and implemented based on local conditions to prevent effects on groundwater.

These issues may or may not be significant depending on whether a human or environmental receptor would be adversely affected, a future use of groundwater would be affected, or a state or federal law would be violated. The most common potential human receptors are wells, springs, or other water bodies that serve as water supplies. The analysis should include an evaluation of effects on municipal watersheds, domestic wells, and public water supplies, if present. Potential environmental receptors include springs, streams, cave and karst systems, wetlands, and the biota that depend on these aquatic habitats. The analysis should include an evaluation of effects on aquatic habitats by contamination or dewatering. Potential effects on groundwater-dependent aquatic resources, circumstances such as the presence of TES species, the conservation values of the habitat, and state and federal requirements for protecting aquatic systems from degradation should be analyzed.

In most cases, exploration drilling will have no effect on these receptors for various reasons (i.e., they are too far away or geologic information indicates limited subsurface hydrologic connection). Future uses of groundwater should also be protected through the use of accepted drilling and abandonment techniques. In other words, just because a receptor is not affected, degradation of groundwater resources still must be minimized to protect potential future uses.

Uncontrolled artesian flow

The potential for artesian flow from drill holes should be addressed in the analysis. Artesian flow can depressurize an aquifer causing decreases in spring flows and baseflow discharges to streams and water levels in nearby wells to drop. In addition, uncontrolled flow from a drill hole has the potential to migrate overland into existing water bodies, introducing sediment or other contaminants. The drilling proposal should specify procedures that would be employed if artesian conditions are encountered. (See Appendix B for specific best practices associated with flowing drill holes.)

Cross-aquifer flow

Multi-layered aquifers are vulnerable to degradation if water moves from one aquifer to another under the influence of differential pressure. The risk of cross-flow contamination is minimized by sealing off any inflows or outflows of water as they are encountered. The most common multi-layered aquifer situation is where unconsolidated sediments at the surface overlie bedrock. Generally, casing is driven through the unconsolidated sediments and sealed into bedrock to minimize cross contamination between aquifer systems. Exploration drill holes are often open for only a short period of time before they are abandoned, but this is not always the case. Particular attention should be paid to the proponent's proposal for management of open drill holes. When the drill holes are quickly and properly abandoned, there is little time for significant cross contamination of aquifers to occur. If a drill hole is proposed to be left open for an extended length of time, perhaps for re-entry at a later date for geophysical logging, additional measures may be necessary to prevent cross-aquifer flow. (See Appendix B for more information controlling cross aquifer flow.)

Drilling fluid loss/gain

An assessment should be made of the potential for large solution cavities or other preferential pathways to exist in the rock formations targeted for drilling so that the potential for loss or gain of drilling fluid can be anticipated. Geologic units composed of limestone, dolomite, marble, and evaporites can all have subsurface solution cavities that provide pathways along which drilling fluids can migrate. Pre-existing underground mines can pose a similar risk, especially if their location and extent are not well documented. Extrusive volcanic rocks can have large voids called lava tubes, open fractures from columnar jointing or from brecciation of lava flow bed surfaces, or highly permeable zones due to the formation of extensive networks of preserved gas bubbles (vesicles) in the lava flows. In areas where there has been a high degree of fracturing or faulting, rocks can become quite permeable. Conversely, in some highly fractured rock settings, post tectonic filling of fractures with minerals or clays results in low permeability units with low potential for loss of drilling fluids.

When analyzing how drilling affects groundwater, it is helpful to explain what the use of drilling mud does in the drill hole, how proper sealing through water-bearing strata during drilling, and how maintaining circulation of drilling fluids protect groundwater resources. Drilling muds are typically composed of water and a clay, such as bentonite, that has specific physical properties. Instead of clay, synthetic materials may be used. Drilling muds often contain other additives to impart or enhance certain performance characteristics. Among other purposes, the drilling mud is designed to form an impermeable filter cake on the walls of the hole, sealing the hole from further leakage of fluids into the formation. (See Appendix B for more information on drilling fluids.) Drilling fluids, other than water, tend to be viscous and don't generally migrate very far from the drill hole, even in highly fractured rocks. For a spring, well, or other receptor to be affected, a direct subsurface connection between the drill hole and the receptor must be present.

The scale and duration of chemical effects to groundwater are key to assessing significance of effects. 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 spaces) 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. The mobility of drilling fluids in most groundwater systems is of very limited extent because of physical, chemical, and biological factors (Campbell & Gray, 1975). These factors include the low volume of drill fluid introduced into a large volume aquifer, filtration at and near the drill hole wall, adsorption over the entire distance of flow, and dilution. In most porous media and fractured rock settings, it is unlikely that drilling fluids migrate very far from the drill hole wall (Campbell & Gray, 1975; Lapham, et al., 1997). Additionally, modern drilling fluids routinely used by the exploration industry are biodegradable, composed of mostly natural products, and certified for use in drilling drinking water wells.

Contamination from the surface

An assessment should be made as to whether the drilling proposal adequately addresses the possibility of groundwater or surface water contamination from spillage or leakage of contaminants at the surface. This includes leakage of hydraulic or other fluids from a poorly maintained drilling rig, fuel or other spills, and leakage of contaminants from sumps or other drilling fluid reservoirs or holding pits. Physical barriers to this mode of groundwater contamination include thick soils, large depth to the water table, limited vertical fracturing, use of liners in sumps and pits, and low permeability rocks. Administrative barriers include implementation of spill prevention plans, proper storage of fuels and drilling fluid additives, limits on on-site storage of fluids, frequent inspections by agency personnel, and use of National Sanitation Foundation / American National Standards Institute (NSF/ANSI) certified materials.

Disposal of drilling fluids and cuttings in on-site sumps is standard industry practice and has seldom resulted in groundwater contamination. Mitigating conditions include:

- The geochemistry of the cuttings is frequently similar to the geochemistry of the local rock units at the surface.
- The cuttings are encased in low permeability bentonite grout, limiting exposure to water or air.
- The volume of cuttings is small (less than 2 cubic yards for a 1000 foot deep hole).

Another mode of groundwater contamination is surface runoff entering the open drill hole. The drilling proposal should have specific procedures identified to prevent this from happening when the drill hole is open and un-capped.

Drill hole abandonment

Drill holes should be abandoned to restore as close as possible the controlling hydrogeologic conditions that existed prior to drilling. Restoration should be designed to prevent contamination of aquifers, interconnection between aquifers, and the physical and environmental hazards resulting from open holes. Drill hole abandonment is intended to be permanent.

Many states have regulations that specify how exploration drill holes are to be abandoned. These regulations, at a minimum, should be followed (Example: Washington State Department of Natural Resources, 2012). Be aware that state regulations on exploration drill hole abandonment range from extensive to non-existent. While most states have regulations pertaining to water well abandonment, the applicability of these procedures to exploration drill holes is not always appropriate. (See Appendix B for drill hole abandonment procedures.)

When deciding on the methods of abandonment to be used, it is necessary to have some understanding of the site characteristics observed during the drilling process. Factors to be considered include:

- Site geology – Stratigraphy, rock types, structure, and geochemistry.
- Site hydrogeology – Number and types of aquifers, confining zone characteristics (lithology, thickness, etc.), fracture density, fracture filling, fracture permeability, and faulting.
- Groundwater occurrence – Depth to water (water table or potentiometric surface level), rate of water movement up or down hole, and water quality.
- Site topography – Likelihood of surface waters inundating the area around each drill hole.

Cumulative Effects

Cumulative effects include effects from connected actions or past or reasonably foreseeable future actions in the activity area. Connected actions could include drilling on adjacent private land and expansion of support facilities located on private land. Activities that could continue into the future within the activity area and which may contribute to cumulative effects on groundwater resources include additional mineral exploration and groundwater development for domestic, municipal, or industrial purposes. The groundwater resource to be considered in a cumulative analysis would generally be limited to the aquifer(s) that could be affected by the proposed action or alternatives.

Monitoring

Monitoring of exploration drilling operations generally consists of site visits and inspections by the local Forest Service mineral administrator to verify that the agreed upon drilling procedures, drill hole abandonment procedures, monitoring, and best management practices (BMPs) are being followed. Additional monitoring may be appropriate for those few projects where there are complex hydrogeologic conditions that could result in loss of circulation or migration of drill fluids over large distances or where there is very poor subsurface water quality, multiple aquifers, artesian conditions, nearby drinking water wells, or sensitive receptors. This could include a combination of surface water and groundwater sampling, monitoring well installation, or monitoring of sensitive groundwater-dependent biota or habitats. This monitoring data would be used to assess how the drilling operation affects groundwater quality and quantity compared to established baseline data and to determine any adaptive management necessary to mitigate effects.

Converting drill holes into monitoring wells

Monitoring wells are functionally different from exploration drill holes in that they are used to collect groundwater quality samples or measure groundwater levels. If monitoring wells are needed at a site, dedicated and properly constructed wells should be installed by a licensed monitoring well driller and under the advice of a hydrogeologist, using industry standard methods (USEPA, 1991). Converting exploration drill holes into monitoring wells is generally not a good idea (Rogers and Chung, 2013). The most reliable data generally comes from geo-environmental installations, monitored over some period of time to account for seasonal variances and anthropogenic effects. Many states have regulations specifying monitoring well construction standards, driller licensing, permit and reporting requirements, and abandonment procedures. Mineral exploration drill holes and drillers frequently do not meet these standards.

From a hydrogeologic perspective, monitoring wells are constructed to sample water quality and/or obtain water level information from discrete hydrostratigraphic intervals. Water quality and water level data from an open exploration drill hole hundreds to thousands of feet deep can be difficult to interpret because the hole may intersect several hydrostratigraphic intervals. Drill holes co-mingle seepage from every stratigraphic horizon penetrated by the borehole, resulting in the reporting of a composite groundwater level. Intersection of multiple water-bearing units can result in an artificial vertical hydraulic connection between these units and could result in waters of different chemistry mixing with water from the aquifer targeted for sampling. Also, exploration drill holes are generally too small in diameter for installation of casing and a screen. Without casing and a screen, it may be difficult to maintain an unobstructed hole accessible to downhole sampling apparatus.

Reporting of hydrogeological data

Hydrogeological information collected during drilling programs is an important data source for the assessment and delineation of water resources and provides some baseline data for evaluation of possible future exploration drilling or mining plans of operation. The type of data that can be collected depends on the type of drilling used. Most of the data would be collected by the drilling contractor or site geologist in a logbook or on the geologic logs of the drill holes. Important information includes:

- Aquifer type(s).
- Depth to first water zone and depths to additional water zones.

- Lithology and structural geology (fracture zones, faults, rock jointing, oxidized zones, geologic contacts, etc.).
- Salinity or specific conductance of groundwater.
- Water quality analyses, if conducted.
- Water yields.
- Standing water levels several hours after completion.
- Significant losses of circulation while drilling.

These data should be requested from the proponent as a part of the project documentation. Some of this data may be perceived as proprietary by the proponent; therefore, the types of information to be shared should be agreed to up front before the project begins.

Records of abandonment procedures

Accurate records of abandonment procedures should be kept to provide future reference and to demonstrate to other agencies and the public that the drill holes have been satisfactorily abandoned. Details to be provided should include:

- Groundwater conditions.
- Depth sealed.
- Quantity and type of sealing materials used.
- Casing details.
- Surface seal details.
- Changes made to the drill hole during abandonment.

In situations where closely spaced drilling has been undertaken in relatively uniform hydrogeologic conditions, or where groundwater was not encountered, specific abandonment documentation may not be necessary for every individual drill hole. In such situations, generalized descriptions and diagrams may suffice. Sufficient documentation should be provided to demonstrate to the appropriate agencies that adequate abandonment procedures have been followed to protect the local groundwater system.

References

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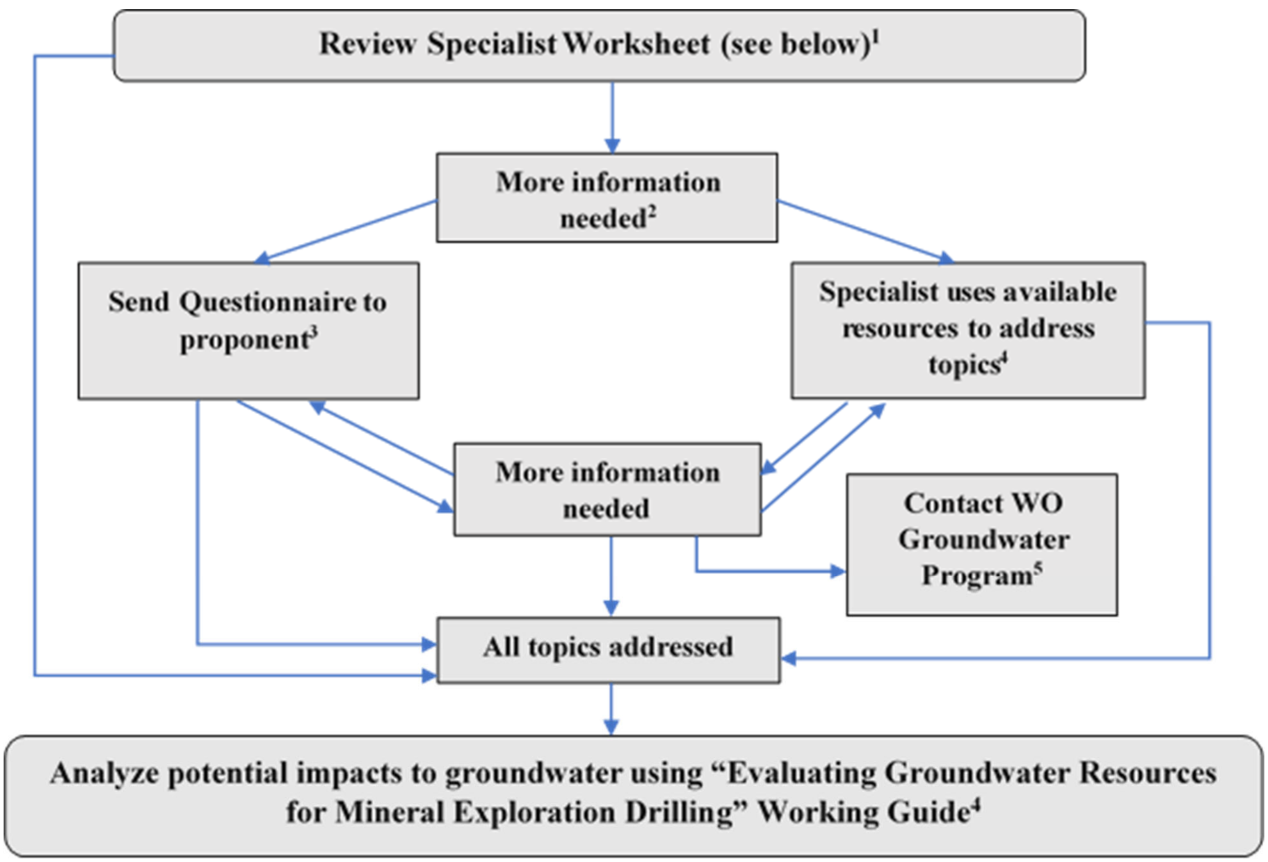
APPENDIX A – Water Resources Worksheet for Exploration Drilling Projects

(To be completed by USFS specialist or administrator)

To protect surface water, water well owners, groundwater, and groundwater-dependent ecosystems (GDEs), we must analyze the potential impacts of proposed activities within a hydrologic investigation area. A Forest Service specialist (minerals administrator, geologist, hydrologist, etc.) reviews the proposed drilling exploration POO for information regarding water resources. If there isn't enough information in the POO to support an impact analysis, the specialist uses the references provided in this worksheet and/or requests relevant information from the proponent (see Proponent Questionnaire) in order to obtain enough data to analyze effects of the proposed activities. Additional questions can be added to the form if needed. Information gained through this process is used in conjunction with the "Evaluating Groundwater Resources for Mineral Exploration Drilling Working Guide" (Working Guide). The process for review is as follows:



Footnotes: 1) Determine whether POO satisfactorily addresses topics described below. 2) As the specialist assigned to this project, consider using available resources to complete this worksheet *before* requesting information from proponent. You may address all topics or reduce the list of unknowns. However, it may be necessary to send the Questionnaire to proponent first due to workload limitations or other circumstances. 3) Before sending Proponent Questionnaire, check *only* the topics that are relevant. Some of this information may be in the POO. Specialists are encouraged to add additional questions as appropriate to a project. 4) Use "helpful sources" listed for each topic and the Available Resources section of this document to address topics. 5) The WO Groundwater Program is available to assist by providing expertise, advice, and additional resources.

Specialist Worksheet

Topic 1: Do proposed activities comply with applicable Forest Plan Standards & Guidelines?

Why is this topic important? Many Forest Plans contains Standards and Guidelines applicable to exploration drilling POOs. For example, riparian zone buffers, wetland protection, and waste/hazardous material disposal constraints could affect proposed sump/drill cutting disposal.

Helpful sources: Forest Plan.

Topic 2: What geologic units will be encountered during drilling? Are there any known aquifers in the area? Is there a general understanding of the groundwater flow system?

Why is this topic important? This information can help us frame the hydrogeologic setting and analyze the potential for: 1) uncontrolled artesian flow, 2) cross-aquifer flow/contamination, 3) drilling fluid loss to formation, 4) groundwater contamination from the surface, and 5) the effectiveness of borehole abandonment procedures. See pages 3-10 of Working Guide for more details.

Helpful sources: POO, well records (see Available Resource #s 3 and 4 below), geologic maps, published hydrogeologic studies, USFS geology GIS layers

Topic 3**:** Are there any abandoned or active mine features in the area? Will drilling intercept underground workings? Are there any known natural or anthropogenic sources of water quality contamination in the project area?

Why is this topic important? These features can provide conduits to groundwater flow and/or increase the risk of groundwater and surface water contamination.

Helpful sources: Forest Service records, Regional CERCLA representative, USGS mineral resource databases (e.g. MRDS, USMIN), topographic maps, state agency databases

Topic 4**:** Are there any water wells or public drinking water source areas near (within ~1 mile of) the project area?

Why is this topic important? Existing wells can provide insight into the hydrogeologic setting of the project. Water level, yield, and spatial density of wells are all important data. Well owners may be concerned about drawdown or contamination of their well. Also, there may be a source water protection area near the project. See page 6 of Working Guide for more details.

Helpful sources: State agency databases (see below), Forest Service records (there may be USFS wells in the area)

Topic 5**:** Are there any groundwater-dependent ecosystems (GDEs) in or near (within ~1 mile of) the project area?

Why is this topic important? GDEs (e.g. streams, springs, wetlands, and karst) can be dewatered and/or contaminated by exploration drilling activities. Potential impacts must be considered for the entire area included in proposed activities. See page 7 of the Working Guide for more details.

Helpful sources: See Available Resource #5 below. National Hydrography Dataset; National Wetland Inventory; USFS GIS layers displaying wetlands, streams, and riparian management areas can also be useful.

Topic 6: Are there any aquatic Threatened or Endangered Species (TES) or other sensitive species in or near the project area?

Why is this topic important? Certain TES and sensitive species may be impacted by exploration activities. As an agency, we must ensure these species are protected in accordance with the law. Potential impacts and possible mitigations must be considered for all areas/regions included in proposed activities.

Helpful sources: Ask local fisheries biologist and/or botanist for advice. Review existing USFS records.

Topic 7**:** What materials will be used or generated during drilling that may impact water well owners, surface water, groundwater, and GDEs?

Why is this topic important? Contamination from exploration drilling is uncommon but possible. Contaminant transport may be over the ground surface or through the subsurface. Potential contaminants include drilling fluids, sediment/drill cuttings, gasoline, oil, and acid rock drainage. Understanding these risks becomes especially important if the project area contains Threatened or Endangered Species (TES) or sensitive ecosystems. See pages 8-10 of the Working Guide for more details.

Helpful sources: All chemicals used during drilling should be reported in the POO. The only information that may not be present is the potential for drilling products (cuttings and core) to generate acid or other hazardous materials (e.g. metals). This information may be gathered from geologic maps, existing USFS records, USGS reports, or the proponent. It is also possible that the potential for acid rock drainage is an unknown risk, which can likely be mitigated through common design features listed on page 9 of the Working Guide.

Topic 8**:** What best management practices (BMPs) and design features are proposed to protect water well owners, surface water, groundwater, and GDEs?

Why is this topic important? While exploration drilling generally presents a relatively low risk to water resources, caution must be taken to avoid contamination and depletion of water wells, streams, springs, wetlands, and other GDEs. Risk is typically reduced through BMPs and project-specific design features, mitigations, and contingency plans.

Helpful sources: The POO should include design features to reduce risk. Appendix B of the Working Guide presents methods and procedures commonly used during exploration drilling. The USDA National Best Management Practices for Water Quality Management on National Forest System Lands (2012), Min-2 Minerals Exploration, page 65, also provides useful information.

Topic 9: Are proposed reclamation activities satisfactory and appropriate? How will boreholes be abandoned?

Why is this topic important? If planned and executed properly, reclamation activities can reduce the chance of negative environmental impacts after conclusion of exploration activities. Proper abandonment of boreholes generally precludes long-term impacts to the environment. Boreholes must be abandoned according to State regulations. Some states have weak or non-existent abandonment regulations for mineral exploration boreholes. In these cases, consider specifying standard abandonment procedures described in the Working Guide. See page 10 and Appendix B in Working Guide for more details.

Helpful sources: POO, State regulations (see Available Resource #3), Forest Plan.

Available Resources (see page 2 of the Working Guide for more tips):

1) Plan of Operation (POO) should include valuable information regarding the proposed action (number, length, and depth of boreholes; drilling fluids; design features; reclamation plan; etc.). Be sure to check POO for information before requesting it from proponent.
2) Existing Forest Service documents – Prior agency reviews, data collection efforts, etc.
3) State agencies - State geologic surveys, departments of natural resources, State Engineer offices (which maintain water well records and databases).
   - State well log database with well depths, depth to water, and location by legal description.
   - State borehole and well plugging regulations.
   - Contaminated sites inventories
4) Water levels and water quality data at specific wells in the National Water Information System (NWIS) can be searched and downloaded at http://waterdata.usgs.gov/nv/nwis/inventory?introduction.
5) Color aerial photographs, topographic maps, the National Wetland Inventory https://www.fws.gov/wetlands/data/mapper.html, and the National Hydrography Dataset https://www.usgs.gov/core-science-systems/ngp/national-hydrography can be helpful in identifying wetlands, springs, perennial streams, and riparian habitat. The Springs Stewardship Institute Springs Online database holds a record of inventoried springs in the US (http://springsdata.org/).
6) U.S. Geological Survey publications, such as Hydrologic Atlases, Water Supply Papers, and Scientific Investigations Reports can be searched and downloaded at http://pubs.er.usgs.gov/.
7) National geologic map database: http://ngmdb.usgs.gov/ngm-bin/ngm_compsearch.pl
8) Geologic maps of the US: http://ngmdb.usgs.gov/maps/mapview/
9) National Best Management Practices for Water Quality Management on National Forest System Lands (2012) FS-990a: https://www.fs.fed.us/naturalresources/watershed/pubs/FS_National_Core_BMPs_April2012.pdf

APPENDIX B – Water Resources Questionnaire for Exploration Drilling Projects

To be completed by project proponent

Background: It is incumbent on the Forest Service to take a 'hard look' at the potential environmental impacts of a mineral exploration project on water resources. Consequently, the Forest Service analyzes water resources including surface water, groundwater, groundwater-dependent ecosystems, and water wells within a hydrologic investigation area for proposed drilling projects. The analysis will determine expected impacts on subsurface and surface water resources. While some of this questionnaire is voluntary information, it may greatly help to speed the permitting process and increase the operator's chances of sustaining a 36 CFR 215 appeal or 36 CFR 218 objections. Checked boxes indicate an answer is requested. Please answer all questions where pertinent information is available. If you need more space, answer questions on an additional document and attach to this form.

Project name:
Name/company of preparer:
Date:

☐ Describe the number, location, depth, diameter, and azimuth/inclination of boreholes. Will borehole casing be used? If so, in which holes and to what depth?

☐ What geologic units do you expect to encounter while drilling?

☐ Do you expect to intercept the water table while drilling? If so, at what depth and based on what information?

☐ Are there any active or abandoned mine features in the area? Any hazardous material in the area?

☐ Are there any previously drilled boreholes, water or monitoring wells, piezometers, or oil/gas wells in the area? If so, is there a consistent depth to groundwater or any indication of artesian groundwater conditions?

☐ Any known surface water features that may be fed by groundwater (e.g. springs, seeps, wetlands, streams, etc.)? Will boreholes extend beneath or near surface water features or groundwater-dependent ecosystems?

☐ List all additives and chemicals used during proposed activities (e.g. drilling additives/fluids, diesel, oils, etc.). Provide SDS sheets and NFS/ANSI certifications for potable water if not included in POO.

☐ Describe best management practices (BMPs) and design elements that will be utilized in order to protect groundwater and surface water (e.g. drill water/cuttings management, management of borehole water inflows and lost circulation, artesian flow control, etc.).

☐ Describe proposed reclamation plans/procedures (e.g. drill hole abandonment materials and procedures, drill cutting disposal, etc.)

☐ Where will make-up water be obtained and how will it be transported or conveyed to the drill site? Will the source be potable water, and is there any water quality data available?

☐ Please review and answer the additional questions attached to this document.

APPENDIX C – Mineral Exploration Drilling Methods

Intent

To understand the potential effects of hard rock exploratory drilling, it is helpful to know something about its purpose and how it is performed. The primary purpose of drilling a borehole for exploratory purposes is to collect samples of the rock for evaluating the potential for economic mineral extraction. Boreholes may also be drilled for geophysical logging, well construction for groundwater evaluation and monitoring, or for collection of other types of data relevant to hard rock minerals exploration or development. Unlike oil and gas wells, hard rock exploratory boreholes are not intended for fluid production, injection, or hydraulic fracturing.

This section presents two of the most common methods and procedures that are used in the mineral exploration drilling industry to drill boreholes. These are diamond drilling and dual-wall reverse circulation drilling (Driscoll, 1986). States do not have regulations that specify drilling methods other then perhaps how materials used and generated during the process with a potential to affect the environment are to be handled, and how groundwater and other resources are to be protected. These regulations, at a minimum, should be followed.

Diamond Drilling

Diamond drilling is the most common style of exploration drilling for massive sulfide and porphyry style deposits, as well as during certain phases of exploration on other types of deposits. This method produces a series of solid core samples over the length of the hole that are extracted for examination on the surface during the drilling process. Diamond drilling does not induce down-hole cavities and voids in the drill hole wall that are generated by other drilling methods. Diamond core drilling uses a hollow diamond bit, which rotates at the end of drill rod or drill string. The opening at the end of the diamond bit allows a solid column of rock to move up into a 5- or 10-foot-long core barrel inside the drill rod. Drilling is advanced down the hole in 5- or 10-foot drilling run intervals, depending upon the length of the core barrel. Two diamond core sample recovery methods are used: conventional and wire-line. With the conventional drilling system, the entire drill string with the core barrel is removed each time to recover the core. This system is best used for shallow drill holes and in very competent rock. The wire-line system leaves the drill string in the hole, and only recovers the core barrel after each drilling run. The entire drill string is removed only after the targeted depth is reached. Standard core sizes for conventional and wire-line drilling are shown in table 1.

Table 1. Common core sizes and diameters.

Conventional drilling			Wire-line drilling		
Size	Hole diameter (mm)	Core diameter (mm)	Size	Hole diameter (mm)	Core diameter (mm)
AX	48	30	AQ	48	27
BX	60	42	BQ	60	37
NX	76	55	NQ	76	48
			HQ	96	64

Diamond drilling utilizes either water or a variety of drilling fluid types, including drill mud, that seal the drill hole with a “mud-cake” on the drill hole wall, lubricate and cool the drill bit, and carry the drill cuttings to the surface and into a mud pit where they settle out. During drilling, these fluids are pumped down the inside of the hollow drill string to the drill bit and flow back out of the hole along the outside of the drill string. Current practice is to use one or more of several types of synthetic polymer mud products to increase the viscosity of water enough to achieve the desired effects. These additives should be non-toxic and biodegradable and meet National Sanitary Foundation (NSF) specifications for municipal drinking water systems.

Where the drill string is removed each time to recover the core, the weight of the mud in the hole is designed to prevent the hole from collapsing until the drill string is replaced. This also ensures no water intrusion, no fractured rock falling into the drill hole, or any other adverse circumstance that could compromise the drill hole.

Drilling fluids are recirculated and reconditioned at the surface before being pumped down the drill string again. This method results in minimal fluid losses at land surface and very little water use. Fluid losses (loss of a volume of drilling mud to the formation) during drilling are common in most geologic environments. Typically, after a loss of some fluid, a small volume of new mud is added to keep the drill hole full. This is especially true in highly fractured igneous and metamorphic rocks because some of the breccia (rubble) may cave into the hole during drilling and require removal. This apparent “mud loss” is actually just an enlargement of the hole, which must be refilled by additional drilling mud. This does not necessarily mean that there is a significant loss to fractures.

Upon completion of the drill hole, sealant grout can be pumped into the entire drill hole for proper abandonment before the rig is moved from the site. Industry practice is to pump the grout slurry down through the drill string and out through the drill bit, filling the hole as the string is being removed, thereby displacing the existing drilling fluid upwards into the mud-pit at land surface.

Dual-Wall Reverse Circulation Drilling

Dual-wall reverse circulation (RC) drilling is a popular drilling method for mineral exploration because it is less expensive and yields quicker results than diamond drilling; however, the results are generally not as reliable as diamond drilling. RC is used to retrieve continuous chip samples from the ground where a solid core is not needed. The dual-wall method uses flush-jointed double-wall pipe in which the compressed air moves by reverse circulation. Unlike conventional drill circulation using drilling fluid which runs down the outside of the drill pipe down the annulus, the compressed air flow is contained between the two walls of the dual-wall pipe and only contacts the walls of the borehole near the bit. The most common drill pipe diameter for the dual-wall is 4 1/2-inch OD size. Although RC drilling is air-powered, water is also used to reduce dust, keep the drill bit cool, assist in pushing cuttings back up the drill string, and also when "collaring" a new hole. Clay, surfactants, or polymers are sometimes mixed with the water and pumped into the rod string down the hole. This increases fluid viscosity and helps to bring the sample to the surface. Air, water, and rock chips are then sucked back up the inner rod by the air pressure differential. At the top, the rock and water are separated by a cyclone. The rock is deposited in a sample collection container and the water is reused for drilling fluid.

An advantage of this drilling method is that the drill hole is relatively undisturbed and uncontaminated with drill fluids and the porosity and permeability of the formation remains close to its original hydrogeologic condition. RC drilling methods permit continuous sampling of cuttings as circulation is maintained at all times during drilling. If desired, water-quality samples and aquifer yield estimates can be obtained at any depth. Other advantages of the dual-wall reverse-circulation drilling method include: (1) the capability of drilling without the significant introduction of drilling fluid(s) to the subsurface; (2) maintenance of hole stability for sampling purposes and monitor-well installation and construction in poorly-indurated to unconsolidated materials; (3) no lost circulation problems even through fractures, voids and joints; and (4) no surface casing, as the outer pipe supports the borehole while circulation is maintained internally.

References

Driscoll, F.G., 1986, Groundwater and wells (Second edition): Johnson Division, St. Paul, Minnesota, 1089 pp.

APPENDIX D – Groundwater Protection and Best Practices for Mineral Exploration Drilling

Intent

This section presents some of the methods and procedures that are commonly used in the mineral exploration drilling industry to protect water quality and limit overall environmental effects. Many states also have regulations that specify how drill holes are to be abandoned (also called "plugged"). These regulations, at a minimum, should be followed. The need for additional BMPs will depend on the extent of those regulations and the specific concerns at the proposed exploration site(s). Best practices are employed to protect groundwater and groundwater-dependent resources during the mineral exploration process by maintaining and preserving the natural barriers to surface and groundwater movement between aquifers, to seal aquifers or strata penetrated during the exploration process, and to take measures to seal any conduits to and between aquifers. This appendix was developed from British Columbia Ministry of the Environment (2011), Djuric (2012), State of Nevada Administrative Code, URS and USDA Forest Service (2013), Washington State Department of Natural Resources (2012), and Western Australia Department of Minerals and Energy (2002).

Identification of Aquifer Types at the Drill Site

The aquifer type and therefore potential for aquifer degradation can be reasonably assessed at the drill site by combining knowledge of the geologic conditions of the site with the following hydrogeologic information:

- Depth to the top and bottom of each aquifer intersected by the drill hole, as evident from increases and reductions in drilling water return flows and the types of encountered formation materials.
- Depth to which the water level rises in the drill hole. The water level may rise above the surface in artesian aquifers.

Once an aquifer type is determined, a drill hole abandonment procedure is chosen to minimize potential for aquifer degradation.

Spill Prevention

Spills at the drill site have the potential to contaminate shallow groundwater. Each drill rig should be subject to preventative maintenance to minimize potential for mechanical breakdown and potential loss of hydraulic and other rig fluids. Each drill rig should have a spill kit to address any type of spill from the rig itself. Additionally, there should be appropriate preventative measures in place to address any potential negative environmental effects on and beyond the edge of the drill pad. For example, liners could be used in drill sumps and materials placed onsite to respond to any release of potentially contaminated fluids from the rig or drill hole that may not be captured by the sump or overtops the sump.

Casing

If drilling penetrates unconsolidated or poorly consolidated materials, casing is typically placed through this section before the borehole is extended into intact bedrock. Casing provides a means for efficiently entering the borehole, keeps unconsolidated material and any contained groundwater from entering the borehole, and keeps drilling fluids from entering the unconsolidated material and shallow groundwater. Although less common, casing may be placed in the bedrock portion of the borehole to seal off groundwater zones or to control unstable borehole conditions. Casing may or may not be cemented in place depending on the purposes of the borehole and the encountered conditions. If casing is to be left in place after borehole abandonment, the opening between the casing and the borehole wall (the annular space) should be filled with some type of sealing material first to avoid creating flow paths through this space.

Drilling Fluids

Method requirements and subsurface characteristics can dictate the need to use a drilling fluid, and some drilling methods require specific types of fluid. A drilling fluid is used in the drilling operation to remove cuttings from the hole, to clean and cool the bit, to reduce friction between the drill string and the sides of the hole, and to seal the borehole." The hydrostatic head of the drilling fluid maintains pressure on the borehole wall and prevents its collapse. Drilling muds build a filter cake or rind on the borehole wall that exerts a positive hydrostatic pressure against the borehole wall, preventing inflow of groundwater into the borehole. It also helps maintain borehole stability, which helps to prevent invasion of the fluid into the borehole wall and reduce cross contamination between aquifers.

Drilling fluids generally circulate to the surface where they are typically directed to a sump or basin to settle out the cuttings. The drilling mud is recycled and pumped back down-hole. It is common to dig a sump within the drill pad area. The sumps are often lined with a permeable matting material to settle the returned drill cuttings. Decanted drilling fluid, which is primarily water, would then be allowed to infiltrate into the subsurface beneath and adjacent to the sump. If the water is to be reused, the sump or basin is constructed to hold water. Rock flour and cuttings are allowed to settle out and the fluid is recirculated to the drill bit. Reuse of the water, or drilling fluid, allows the driller to reduce the total amount of water, bentonite, and additives necessary to complete a successful hole.

Only potable water or water from a clean surface water source should be introduced into the drill hole while drilling to reduce the potential for inadvertent introduction of potential contaminants into groundwater. All polymers and additives used in drilling should be certified by NSF/ANSI approval standards, or equivalent standards, for use in potable water supply wells. The product should be clearly labeled as meeting these standards.

Common drilling fluids include water; water with additives of clay (usually bentonite), clay mixtures (bentonite amended with certain additives), or polymers (chemical foams); and compressed air. Additives modify fluid characteristics (such as density or viscosity) in order to address a change in borehole or geologic conditions during drilling. Compressed air introduced into the drill stem also can be used to enhance circulation of the drilling fluid and helps move cuttings to the surface, but must be filtered adequately to avoid introducing significant quantities of hydrocarbons.

Drilling Fluid Loss

If a zone of very high permeability and low relative pressure (e.g., a coarse gravel lens, solution void, or 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 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% or more of the drilling fluid will alert the driller to an inflow or outflow condition. 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 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 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 farther.

If a lost circulation zone 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 mud flow at the surface does not resume, the driller will stop circulating and prepare a slug of lost circulation material. There are many types of lost circulation material available, but high-solids bentonite grouts are commonly used. Unlike standard bentonite drilling mud which has a solids content of 10-20%, the high-solids bentonite grouts have a solids content of over 70%, which produces a highly viscous fluid with the approximate consistency of peanut butter. The lost circulation material is prepared separately and pumped down the hole. Usually this will successfully seal the lost circulation zone.

If the lost circulation material still doesn’t control fluid loss, then a variety of more aggressive methods can be used. The lost circulation zone can be cemented and drilled through, or the existing drill string can be used as casing and cemented in through the lost circulation zone, or additional casing may be installed. 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.

Artesian Conditions

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 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 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 a lost circulation zone. Lost circulation material is also added to the mud along with the barite in order to seal the zone. 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 lost circulation material is emplaced securely enough to retain the 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 below in the Drill Hole 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 digging another sump or routing any overflow to discharge onto an area with the most available obstructions to flow (e.g., embedded logs, thick grass, or brush).

It is imperative that boreholes with surface artesian flow be properly abandoned and the boreholes are checked later to confirm proper abandonment. A borehole that continues to flow or resumes flowing due to improper abandonment can be a source of sediment and contaminated water discharge to surface water. Also, if the upper borehole was drilled through unconsolidated sediment and was not adequately cased, the flowing water can erode the borehole into a considerably larger hole that will be much more difficult and expensive to plug.

Sealing of Mineral Exploration Drill Holes

Care should be taken during the drilling operations to seal off aquifers or strata penetrated that could impair water quality, interconnect aquifers, or result in cascading water. All sealing must be permanent and prevent movement of surface and or groundwater along, around, or through the drill hole and can often involve the emplacement of permanent casing. The sealing technique utilized should prevent the movement of artesian waters within the annular space around any well casing and prevent the contamination or wasting of groundwater.

Before abandonment, drill holes should be checked to ensure that there are no obstructions that may interfere with effective plugging operations. Where possible, all obstructions should be removed from the drill hole prior to abandonment.

If artesian flow is encountered and cannot be readily controlled through the drilling process, the driller is responsible for stopping the flow and plugging the drill hole. The driller should notify the local Forest Service office any time artesian flow is encountered. The driller should continue to keep the local Forest Service office informed as flow is controlled and the hole is plugged. If this flow is inadvertently discharged to the environment, a sample can be obtained and analyzed to determine if it was contaminated and if special mitigation or remediation measures are required. Due to the potential for encountering groundwater with elevated salinity or other dissolved constituents, no water or drilling fluids produced under flowing artesian conditions should be disposed at the site without being properly characterized and determined to be safe for on-site disposal.

The mineral exploration hole should be plugged so that the natural barriers to groundwater movement are preserved. It will be necessary to ensure that the material used to plug the hole does not migrate down or move up the drill hole under pressure during or after installation. The plugging material should therefore be of adequate specific gravity to overcome aquifer pressure and may require the installation of bridge plugs or packers as a further precaution.

An emergency abandonment plan should be developed to deal with unforeseen events. The plan should include instructions and contact information for getting equipment and supplies to the drill site in a timely manner and provide reasonable plans for controlling and stopping flow.

Obstructions

Before abandonment, drill holes should be checked to ensure that there are no obstructions that may interfere with effective plugging operations. Where possible, all obstructions should be removed from the drill hole prior to abandonment.

Abandonment Materials

Grout is used to prevent intermingling of groundwater from different aquifers intersected by mineral exploration drill holes and flow from the drill holes. Drill holes can be plugged by completely infilling with grout or by setting intermediate grout plugs (or packers) at predetermined positions along the length of the hole. Grout generally consists of a fluid mixture of cement and water (neat cement). However, the slurry may also contain sand, gravel, bentonite or hydrated lime. A clay slurry made with high-grade bentonite can also be used, provided that it is not emplaced at or near the ground surface where drying and shrinkage of the grout will occur, or where water movement could wash away the clay particles. Synthetic materials, especially polymers, are also used as grouting materials, but their extremely low solids content and substantial shrinkage when dried make them less suitable for abandoning drill holes than the other grout types. Low viscosity (high fluidity) grouts are used to plug fine-grained, low permeability unconsolidated rocks, whereas high-viscosity grouts are used for coarse-grained, highly permeable unconsolidated rocks, cavernous rocks, and fractured rocks.

Jamming unopened bags of cement, bentonite chips, lumber, cardboard, paper or other debris (other non NSF/ANSI-certified materials) into the borehole or a washed out annulus between the borehole wall and surface casing should be avoided. Use of these materials is generally ineffective and will likely complicate further corrective action. The organic material can decompose and degrade water quality.

Commonly used grout sealants include:

- *Bentonite-based grouts* of very low-permeability that remain flexible indefinitely. Bentonite (essentially montmorillonite) is used as a grouting material because of its relative ease of placement and because of several advantages over cement grout. It has a faster setting time and it adheres to both soil and casing. However, bentonite should not be used within 2 meters of the ground surface because it will dry out and shrink. Furthermore, the presence of saline water (greater than 2,500 mg/L TDS) causes bentonite grout to flocculate, reducing its viscosity. Also, organic acids can destroy the impervious character of bentonite grout. Bentonite grout has low shear strength and density. It should therefore not be used in high pressure aquifers or in boreholes that have encountered voids unless those voids are first filled with some other more physically stable material.
- *Chipped bentonite seals* composed of 3/8-inch granules of a natural swelling bentonite clay. This sealing material is poured into the upper portion of the borehole (generally above the water table) and often overlying an intermediate plug. These seals hydrate to form a thick impermeable sludge with the consistency of modeling clay. When mixed with water, bentonite hydrates very rapidly, making it difficult to place the granular form. Pellets dumped down drill holes may begin to stick together within less than a meter of the surface and may bridge above the intended depth setting. A better practice is to use a bentonite slurry and pump it down the drill hole, filling from the bottom via a grout or tremie pipe filling from the bottom up.
- *Cement/bentonite grout mixtures* that carry the low permeability and swelling properties of bentonite and the hardening rigid qualities of cement. Regular cement or rapid-hardening variations are generally the preferred grout for plugging mineral drill holes. All cementing should be carried out using only mix densities approved by the manufacturer for the conditions of use. The cement grout mixtures should be just fluid enough to flow through grout pipes. Water used in mixing cement grout should be free of oil and other organic material such as plants, leaves, and fragments of wood. The salinity of the water should be less than 2,000 mg/L total dissolved solids (TDS). In addition, a high sulfate content is particularly undesirable. Bentonite clay can be added to the cement to hold the cement particles in suspension, reduce shrinkage, and improve fluidity of the slurry. However, the amount of bentonite added should not exceed 6%; otherwise, shrinkage of the cement will occur.
- *Straight cement grout* is always used at the top of the drill hole in areas with low soil moisture.

Drilling Fluid and Cuttings Disposal

Drill cuttings should not be used for sealing or filling mineral exploration drill holes. 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. Sumps would not be located 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.

Generally the cuttings from exploration drill holes are minimal in volume and do not pose a contamination hazard. In cases where a contamination hazard from the cuttings has been identified or the cuttings will be large in volume, a detailed plan should be developed indicating how the cuttings will be managed. If the cuttings are placed in on-site sumps, the plan should include what analysis is to be done to ensure that the cuttings don't contain any potential contaminates, including potential acid-generating minerals. If it is determined that the cuttings could be contaminated, specify how groundwater will be protected (e.g., sump liners) and how to dispose of the contaminated cuttings. Contaminated fluids or cuttings may be subject to environmental laws and regulations and require special storage and disposal. It is advisable to involve Forest Service environmental services personnel in those cases.

Drill Hole Abandonment Procedures Based on Aquifer Type

The procedure to abandon an exploration drill hole is based on the type of aquifers present at the site. Sealing procedures should prevent mixing of waters from one aquifer to another, as well as entry of any surface water that could contaminate the aquifers. It should also remove any physical hazard caused by abandoned open or unstable drill holes to people, stock and native animals as well as to foundations of structures placed over the drill sites.

Unconfined, Single-confined, or Semi-confined Aquifers, or No Identifiable Aquifer

In order to ensure that grout will provide an effective seal, it should be emplaced in one continuous operation before the initial set of the grout occurs. Grout should be introduced at the bottom of the annular space to ensure that no gaps are left in the grouted interval due to bridging in the drill hole, and to prevent segregation and contamination of the slurry. This is particularly crucial when grouting below the water level to prevent excessive dilution of the grout. Small diameter pipe (grout or tremie pipes) can be used to emplace the required quantity of grout in the drill hole. The grout slurry can be gravity fed into drill holes less than 20 meters deep. Pumping is the only practical means of introducing grout in drill holes greater than 20 meters in depth. Pumping enables large volumes of grout to be introduced rapidly and forced into the space to be sealed with little chance of leaving voids in the grout. If the hole is filled with water or drilling mud, the grout pipe can be lowered to the desired grouting depth through the fluid. When the grout is introduced, the water or mud will be forced upward on the grout because the grout is the heavier (denser) fluid.

A cement cap placed at the surface prevents entry of any surface water that could contaminate the aquifer and eliminates any physical hazard caused by abandoned open or unstable drill holes.

Multi-layered aquifer systems

Sealing can be done either by completely filling the hole with grout from bottom to top, or by placing grout across each aquifer-confining unit boundary so that each aquifer layer is separated from the aquifer above and below it. The sealing material must have a specific gravity and viscosity that can overcome aquifer pressures. Cement-based grout is generally preferred because bentonite and polymer may be too thin to prevent the movement of water from one aquifer to another. The material should be placed using a tremie pipe from the bottom upward by methods that avoid segregation or dilution of material and unnecessary contamination of the aquifer. The base of the tremie pipe should be run to the same depth that the base of the seal is required. The base of the seal should extend a minimum of two meters below the confining unit. The seal should extend not less than five meters above the top of the confining layer and should be a minimum of 20 meters in length. To ensure that sealing material does not migrate along the drill hole during or after installation, the installation of bridge plugs or packers at the base and or top of each seal may be necessary. The top of the drill hole should be completed in the same manner as unconfined or single confined aquifers or the case where there is no identifiable aquifer.

Flowing drill holes

Holes that are to be drilled into areas where artesian aquifers are known to exist should be pre-collared with surface casing set to an adequate depth and cemented in place to enable the control of water pressure blowouts. Groundwater discharge from flowing drill holes has to be controlled before sealing can take place. Flow can be controlled by introducing high specific gravity fluids (e.g., barite-weighted drilling mud) to stop the flow, or by pumping the drill hole itself or nearby bores to create drawdown in the drill hole to be abandoned.

Cement grout should be used exclusively in drill holes that flow and/or where the groundwater head of a confined aquifer is above the top of the aquifer zone. The low shear strength of bentonite grouts makes them unsuitable for high hydraulic gradient sealing locations where strength is important. Bentonite slurry grouts should not be applied in confined aquifer boundaries without additional mechanical support such as packers or adjacent cement seals. Bentonite when used alone will not provide sufficient resistance to higher artesian pressures and will eventually fail.

The cement grout should be placed by tremie pipe from the bottom upward by methods that avoid segregation or dilution of material and unnecessary contamination of the aquifer. The length of grout plugs and placement of packers set in flowing drill holes should be sufficient to completely stop discharge of groundwater. If groundwater flow cannot readily be controlled, the State or Federal agency with regulatory authority should be notified immediately.

A secondary issue with artesian flow from a drill hole is the sediment load carried with the flow toward any receiving waters should the flow overtop the sump. This would be addressed by placing sediment control materials to capture the flow and filter any sediment prior to the fluid entering receiving waters and should be incorporated into the emergency abandonment plan.

Circumstances where decommissioning procedures may be delayed or waived

There are legitimate circumstances where a hole may be left open for a limited period of time. These circumstances include:

- Where a hole is to be logged.

- Where a hole is to be enlarged in diameter or depth.
- Where a hole is to be converted into a monitoring well.
- Where further sampling and testing is to be carried out.

However, where there is a freshwater aquifer present, precautions must be taken to avoid possible contamination. These precautions would include prevention of runoff into the hole and placement of temporary plugs or seals between aquifers of different water quality or pressure head. The freshwater aquifers could also be cased as long as the annular space is properly sealed. Because of the risk to stock and people from an open hole or hole where fill has settled, the location should be marked and fenced.

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