Part V:

Effects of Mining and Oil and Gas Development on Water Quality

Greens Creek Mine, Tongass National Forest, Alaska, with sediment pond.
Photo by Stephen Glasser

Chapter 18

Hardrock Mining

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Introduction

Mining can significantly impact the quality of water used for domestic and municipal water supplies. These impacts can be brief or long lasting, and they differ with the type of ore, the mining method, the method of ore processing, the effectiveness of water management, and after mining ceases, the overall nature of mine closure. The impacts include transport and deposition of sediment, acid runoff, and release and transport of dissolved metals and other associated mine contaminants.

Hardrock mining is defined as the extraction of precious and industrial metals and nonfuel minerals by surface and underground mining methods (Lyon and others 1993). In the United States, extensive hardrock mining started in the 1880's, and, for the next 70 to 80 years, was a major industry in many States. Many metals and minerals produced by hardrock mining are valuable natural resources and have been important to the economy of many States. The legacy of the active period of hardrock mining includes more than 200,000 abandoned or inactive mines. As of 1992, there were more than 500 operating mines in the United States, of which, more than 200 are gold mines. As of 1997, there were approximately 60 mine sites in 26 States on the Federal Superfund National Priorities List because of serious pollution problems.

Hardrock mining is a large-scale activity that typically disturbs large areas of land. Unlike other industrial facilities, mines must be located at specific places where ore bodies are found. Many ore bodies and mines are located on public land administered by Federal land management agencies—the Forest Service in the U.S. Department of Agriculture and several agencies in the U.S. Department of the Interior. Mines on public land are frequently located in watersheds with relatively little development. Unless proper environmental controls are used during mining and ore processing, and after mine closure, serious environmental damage can result. During the first half of the 20th century, environmental controls were very limited or nonexistent and, as a result, numerous abandoned mines continue to cause serious environmental damage. Ownership of abandoned mines on public land is often difficult or impossible to establish. To date, the Forest Service does not have a complete inventory of these mines. However, some State mine-permitting agencies have compiled inventories.

Because of the high waste-to-product ratios associated with mining most ore bodies, large volumes of waste are generated. Mine waste includes all of the leftover material generated as a result of mining and ore processing activities. Most mine waste is considered to be nonmarketable, but mine waste materials often contain environmentally significant concentrations of heavy metals and precious metals.

This report describes the major potential impacts on the quality of public drinking water sources associated with the various elements of mining. It is recognized that some discussion may not accurately reflect the environmental conditions at modern hardrock mining operations that are well designed, operated, and regulated. The intent of the discussion is to describe environmental problems that may occur at historic, current, and future mine sites.

Mining Methods

Precious metals and industrial metals typically occur in disseminated ore bodies or vein deposits. The two primary methods used to mine metals and minerals include surface or open-pit mining and underground mining. Surface or open-pit mining is typically used for large shallow ore bodies, which have a low metal or mineral value per volume of rock. Underground mining is typically used when the mineralized rock is deep and occurs in veins.

Surface or open-pit mining often requires the removal and disposal of soil and rock overburden that contains no target mineral. The underlying ore body typically includes some rock that contains uneconomical concentrations of the target mineral. This waste rock is also removed and typically

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stockpiled or otherwise disposed of. The portion of the ore body to be mined is drilled, blasted, and transported to a facility where it is crushed and prepared for milling or leaching.

Underground mining requires the excavation of vertical shafts, horizontal adits, and inclined adits to access the ore body. The rock that is excavated during adit construction is commonly referred to as development rock. Once the ore body is reached, horizontal passages called drifts and crosscuts are developed on numerous levels and the ore is mined. Waste rock and ore are transported to the surface via rails or small trucks, or they are hoisted to the surface in vertical shafts.

In both surface and underground mining, extraction of ore waste materials requires heavy equipment and explosives. A commonly used explosive is a mixture of ammonium nitrate and fuel oil. As the development rock, waste rock, and ore are removed, they are typically transferred to large trucks for transportation to storage or processing facilities. Overburden and development rock usually do not contain minerals that reduce the quality of surface or ground water, and they can be used as mine backfill, but they are typically disposed of in piles near the mine site. Waste rock from the ore body can contain environmentally significant amounts of metals and should be tested for acid-generating potential. It is important to segregate waste rock that is potentially acid generating and not use it for mine backfill or impoundment dams.

Surface and underground mines typically extend below the local and regional water table or both. As a result, ground water may flow into the mine pit or underground workings. Water collecting in the mine pit or workings must be removed. In open-pit mines, this water is typically pumped out and discharged to nearby surface water. In underground mines, the water can be pumped out or drainage adits can be constructed at or below the lowest mine level to allow for free drainage of the water entering the workings. Many precious metal ore bodies occur in mountainous terrain where the host rock is commonly comprised of igneous or metamorphic rocks. In these types of rocks, ground water occurrence and flow is controlled by the distribution and orientation of fractures, joints, and faults. In these settings, ground water inflow into mine workings occurs only where the mine workings intersect water-bearing structures.

Ore Processing

Ore processing, or milling, refers to the processing of ore rock to create the size of the desired product, remove unwanted constituents, and concentrate or otherwise improve the quality of the desired product. Applicable milling processes are determined based on the physical and chemical properties of the target metal or mineral, the ore grade, and environmental considerations.

Amalgamation

This is the process where metallic mercury is added to gold ore to separate the gold from the ore rock. When liquid mercury comes in contact with gold, it bonds with the surface of the gold particles (amalgamation). The mercury-coated gold particles coalesce or collect into a gray, plastic mass. When this mass is heated, the mercury is driven off and the metallic gold remains.

Flotation

The physical and chemical properties of many minerals allow for separation and concentration by flotation. Finely crushed ore rock is added to water containing selected reagents. These reagents create a froth, which selectively floats some minerals while others sink. Common reagents include copper, zinc, chromium, cyanide, nitrate, phenolic compounds, and, for copper ore, sulfuric acid. The waste (tailings) and the wastewater are typically disposed of in large, constructed impoundments.

Leaching

Leaching refers to processes that involve spraying, pouring, or injecting an acid or cyanide solution over crushed and uncrushed ore to dissolve metals for later extraction. The type of solution used depends on the ore's physical and chemical characteristics. Leaching is used almost exclusively on low-grade ore. The main types of leaching include dump, heap, and in situ leaching. For each type, a nearby holding area (typically a pond) is used to store the pregnant solution prior to recovery of the desired metal by a chemical or electrical process. Once the desired metal is recovered, the solution is reused in the leaching process.

In dump leaching, the material is generally piled on the ground, and the leaching solution is applied to the pile by spraying, injecting, or washing. Dump leach piles can be very large, often covering hundreds of acres (hectares) and containing millions of tons of ore rock. Leaching solutions aided by precipitation dissolve the desired metals. Dump leach piles are not placed on clay or synthetic liners. The pregnant solution drains away from the bottom of the leach pile to a holding pond. Pregnant solution can be lost to the subsurface, which reduces the amount transported to the holding pond, and potentially contaminates ground water. Dump leaching is used for very low-grade ore.

Heap leaching is used for higher grade ores and is generally conducted on a smaller scale than dump leaching. The ore is usually crushed and is placed on a pad constructed of synthetic materials or clay. These low-permeability liners help maximize recovery of the leachate.

In situ leaching involves pumping a reagent (commonly a sulfuric acid solution) directly into the ore body. The reagent dissolves the desired mineral, and the pregnant solution is collected and pumped to the surface for extraction of the desired mineral.

Leaching can recover economic quantities of the desired mineral for months, years, or decades. When leaching no longer produces economical quantities of metals, the spent ore is typically rinsed to dilute or otherwise detoxify the reagent solution to meet environmental standards. If standards are met, the rinsing may be discontinued and the leached material may be allowed to drain. The spent ore is then typically left in place.

Water Management

Management of water at large mine sites is a critical element of a mining operation. At large mine sites that include a mill and a tailings impoundment, water management is difficult. It is complicated by the many management requirements, which may include the dewatering of open pits and underground mine workings or both, the transportation of surface runoff across mine sites, the use and containment of water used for ore processing, and the need to meet applicable water-quality standards for all discharges from the mine site. Historically, the management of water has not focused enough on prevention of environmental impacts. Nationwide, there have been numerous incidents where contaminated water from a mine site has been improperly discharged, impairing the quality of surface water.

Waste Management

Hardrock mining typically produces large volumes of solid waste, including overburden, development rock, waste rock, spent ore, and tailings. Overburden, development rock, and waste rock are typically stockpiled at the mine site. Some of these materials may be used as pit backfill or uncommonly for backfill of underground workings. Overburden and development rock usually pose minimal threats to the environment. Waste rock can contain significant concentrations of metals and pyrite and may present an environmental problem. Some waste rock stockpiles may be left in place for future ore processing.

Tailings are the waste solids remaining after ore processing. Tailings generally leave the mill as slurry consisting of 40 to 70 percent liquid and 30 to 60 percent fine-grained solids. Tailings can contain significant concentrations of heavy metals and other contaminants. Most tailings are disposed of in on-site impoundments. Historically, tailing impoundments were not lined and were located without consideration of potential environmental impacts. Modern tailing impoundment design often includes low-permeability clay or synthetic liners, engineered caps designed to eliminate or minimize infiltration of water into the tailings, and collection systems to capture leachate that escapes from the impoundment.

Seepage from tailing impoundments is often unavoidable and raises the probability of surface water and ground water contamination. Such seepage and acid rock drainage may require water treatment long after the active life of the facility. Failure to maintain adequate hydrostatic pressure within and behind an impoundment dam may result in failure of the impoundment structure, releasing tailings and effluent to surface and ground water.

Spent ore is a waste material that is generated at mines that utilize heap or dump leaching. The volume of spent ore can be very large and can contain environmentally significant residual amounts of leaching reagent and dissolved metals. Both spent ore and tailings need to be actively managed for years after mine closure to ensure that leachate does not escape to a nearby stream or infiltrate into underlying ground water.

Mine Closure

Closure of a mining operation occurs during temporary shutdown of operations or permanent decommissioning of the facilities. Depending on the type of mine, the size and nature of the area of disturbance, and the type of ore processing, active management of the mine site including water management may be necessary for years or even decades following closure. Until recently, reclamation was limited to grading and revegetating waste materials and pits to minimize erosion and improve the visual landscape. Permanent closure now routinely includes some or all of the following: removal and disposal of stored fuels and chemicals, structure tear down, removal of unnecessary roadways and ditches, shaft and adit plugging, waste detoxification, capping of tailings, backfilling pits, and active water management to ensure that all applicable water-quality standards are met. In numerous cases, a water treatment facility must be operated and maintained. At mine sites where acid mine drainage is a problem, water treatment may be necessary for decades.

The long-term nature of mining impacts may require that environmental monitoring (source, early warning, and compliance monitoring), contingency planning, and financial insurance be in place for decades. Geochemical conditions in the ore body, waste rock, tailings, and workings can change over time. Hence, the ability is needed to make necessary changes in water control and water treatment after mine closure.

Issues and Risks

At hardrock mines, adits and shafts, underground workings, open pits, overburden, development rock and waste rock dumps, tailings impoundments, leach pads, process ponds, and mills are known sources of heavy metals, sulfate, cyanide, and nitrate. If released in environmentally harmful concentrations, these contaminants can have significant negative effects on the quality of surface water and ground water for public drinking water sources. Dissolved and total metals concentrations can impact public water supplies and the aquatic health of stream and riparian systems.

Surface runoff is a key mechanism for release of pollutants into streams and lakes. Seepage from tailings ponds and waste rock piles, unwanted releases from process water ponds or wastewater ponds, drainage from underground workings, and discharge of pit water may contaminate water resources. Surface waters may also be impacted by contaminated ground water or contaminated by heavy metals in sediments. The mobility of contaminants is increased by exposure to rain and snowmelt.

A variety of complex geochemical and hydrogeological processes control the transport, attenuation, and ultimate distribution of heavy metals and other mine-related contaminants. Dissolved and suspended contaminants are transported to aquifers and streams via complex overland and subsurface pathways. This complexity, combined with the large scale of mining activities and the numerous mine-related sources of contaminants, make water-quality assessments and restoration and remediation of mine sites very difficult.

Environmental problems are often more difficult to deal with at abandoned mine sites that lack environmental monitoring. Several thousand abandoned and inactive mines exist on public land. The U.S. Department of Agriculture, Office of Inspector General estimates that there are more than 38,000 abandoned and inactive hardrock mines on land administered by the Forest Service.

The major types of water-quality impacts include erosion and sedimentation, acid rock drainage, cyanide leaching, and dissolution and transport of toxic metals. These impacts are discussed in the following sections.

Erosion and Sedimentation

Because mining may disturb large areas and expose large quantities of earthen materials, erosion and subsequent transport of sediment to surface water can be a major concern. Major sources of erosion and sedimentation include open-pit areas, heap and dump leach piles, overburden, development and waste rock piles, tailings piles and dams, haul and access roads, ore stockpiles, vehicle and equipment maintenance areas, exploration areas, and reclamation areas. Historically, erosion and sedimentation have built up thick layers of mineral fines and sediment in floodplains and streams at many mine sites. These sediments can carry attached chemical pollutants and toxic metals, which can be stored in floodplain and bed sediments. To avoid these problems, erosion and sedimentation must be controlled from the beginning of operations through postclosure treatments.

Sediments and minerals deposited in floodplains can impact the quality of nearby surface water and underlying ground water. Oxidation of sulfide minerals may lower the pH of surface runoff, thereby mobilizing heavy metals that can infiltrate into underlying ground water and/or be transported to nearby surface water. Reduced soil pH also may kill riparian vegetation.

Drinking water impacts associated with erosion and sedimentation are discussed in chapter 2.

Mining disturbances also can increase surface runoff, which can result in increased streamflow velocities and volumes, downstream flooding, scouring of stream channels and structural damage to water diversions, drinking water intakes, bridge footings, and culverts.

Acid Rock Drainage

A major water-quality problem at hardrock mine sites is the formation of acid rock drainage and the associated mobilization of toxic metals, iron, sulfate, and total dissolved solids. The formation of acid rock drainage results from the exposure of sulfide minerals (pyrite, pyrrhotite, galena, sphalerite, and chalcopyrite) to air and water. Sulfide minerals are commonly associated with coal deposits and precious and heavy metal ore bodies. Pyrite (FeS), the most common sulfide mineral, reacts with water and oxygen to produce ferrous iron (Fe^{+2}), sulfate (SO_4), and acid (H^+). In waters where oxidizing conditions are prevalent and the pH is >3.5, ferrous iron will oxidize to ferric iron. Much of the ferric iron precipitates as iron hydroxide. Some ferric iron remains in solution and continues to chemically accelerate the oxidation of pyrite and subsequent generation of acid. As the pH continues to decrease, the oxidation of ferrous iron decreases and the precipitation of iron hydroxide decreases. This results in a greater dissolved concentration of ferric iron and, therefore, a greater rate of sulfide (pyrite) oxidation. The oxidation of sulfide minerals is also catalyzed by Thiobacillus ferrooxidans bacteria. These bacteria, which are common in the subsurface, can increase the rate of sulfide oxidation by 5 or 6 orders of magnitude. When low pH water comes in contact with metal-bearing rocks and minerals, a number of toxic metals dissolve and are transported by the water. Different metals are dissolved over different ranges of pH. The most common metals associated with sulfide minerals include lead, zinc, copper, cadmium, and arsenic.

Both water and oxygen are necessary to generate acid drainage. Water is both a reactant and a medium for the bacteria that catalyze the oxidation process. Water also transports the oxidation reaction products and the associated dissolved metals. Atmospheric oxygen is a very strong oxidizing agent and is important for bacterially catalyzed oxidation at pH values below 3.5. Surface water and shallow ground water typically have relatively high concentrations of dissolved oxygen.

Acid rock drainage can be discharged from underground mine workings, open-pit walls and floors, tailings impoundments, waste rock piles, and spent ore from leaching operations. Acid rock drainage occurs at both active and abandoned mines. Acid generation and drainage of acid water with high concentrations of dissolved metals affect both surface and ground water. Ingesting water contaminated by heavy metals can have significant health affects for humans and aquatic organisms, including water birds and fish. Metals and other mine-related contaminants in sources of drinking water can exceed water-quality standards. Expensive treatment or acquisition of another source of water may be the only alternatives.

Cyanide Leaching

For over a century, cyanide has been used as a pyrite suppressant in base metal flotation and in gold extraction. Dump leaching and heap leaching operations commonly use cyanide in the leaching solution. Continued improvements in cyanide leaching technology have allowed the economic mining of lower grade ores. As a result, increasing amounts of cyanide are being used in mining. The mining industry now uses most of the sodium cyanide used in the United States. More than 100 million pounds (45 million kilograms) were used by gold and silver leaching operations in 1990.

Cyanide can cause two major types of environmental impacts: (1) ponds and ditches (and to a lesser degree, tailings impoundments) that contain process water containing cyanide solutions can present an acute hazard to wildlife, especially aquatic birds; and (2) spills or other unwanted releases of cyanide solution from ponds, leach impoundments, spent ore piles, or tailings impoundments can enter surface water killing fish and contaminating drinking water sources. During the 1980’s and early 1990’s as the use of cyanide leaching increased worldwide, a number of serious cyanide spills and unwanted releases have occurred. Impacts on wildlife and streamwater quality have been significant. These incidents and the acute toxicity of cyanide have focused public attention on the use of cyanide in the mining industry.

When cyanide is inhaled or ingested, it interferes with an organism’s oxygen metabolism and can be lethal in a short time. Cyanide is much more toxic to aquatic organisms than to humans. The acute aquatic standard is 22 milligrams (mg) per liter and the chronic aquatic standard is 5.2 mg per liter. The maximum contaminant level for public drinking water supplies is 200 mg per liter. These values are for total cyanide even though toxicity is caused by free cyanide. Total cyanide is usually measured because it is difficult to measure free cyanide. Nitrate, a breakdown product of cyanide, is also a drinking water problem (see chapter 2).

Cyanide that is dissolved in water readily complexes with metals. At pH values below 9, weaker cyanide compounds can dissociate and hydrogen cyanide (HCN), a volatile poisonous gas, is formed as a byproduct. If cyanide-contaminated water infiltrates into unsaturated soil and the pH of the water is lowered to below 9, free cyanide can volatilize to hydrogen cyanide. Cyanide can also be attenuated to some degree by other processes, including adsorption, precipitation, oxidation to cyanate, and biodegradation.

Once the leaching of ore dumps or heaps is complete, it is necessary to rinse the spent ore until the appropriate cyanide standard is reached. In arid regions, getting enough water to rinse heaps or dumps can be a significant problem. In wet climates, excess water from heavy precipitation can increase the risk of unwanted cyanide releases from leach dumps or heaps. The chemistry of the spent ore and the associated water in leaching impoundments can change over time, creating a potential for continued release and transport of dissolved metals long after the cyanide concentration has been reduced by rinsing. Factors affecting the chemistry of a heap leaching impoundment include pH, moisture, and ore mineralogy.

Also of significant concern is the long-term structural stability of large heap leach impoundments. The physical characteristics of the leached ore, the physical configuration of the impoundment, and specific site conditions affect the long-term structural stability of a leach impoundment. Structurally unstable impoundments may fail, allowing contaminated leachate or sediments to reach public drinking water sources.

Transport of Dissolved Contaminants

Dissolved contaminants (primarily metals, sulfate, and nitrate) can migrate from mining operations to underlying ground water or nearby surface water that is a source for drinking water. Discharges of process water, mine water, runoff, and seepage from mine waste piles or impoundments can transport dissolved contaminants to source water.

Under specific conditions, dissolved constituents in surface water can precipitate and attach to sediments. Elevated concentrations of lead and mercury are often found in sediments while being undetected in the water column. Sediment contamination may affect human health through consumption of fish that bioaccumulate toxic pollutants. Contaminated sediment provides a long-term potential source of pollutants that, under certain geochemical conditions, can dissolve in the water column.

The likelihood of contaminants dissolving and migrating from mine waste materials or mine workings to ground water depends on the nature and management of the waste materials, the local hydrogeologic setting, and the geochemical conditions in the underlying vadose zone and aquifer. Risks to human health and the environment from contaminated ground water can be significant. In many hydrogeologic settings, ground water discharge provides a significant percentage of stream baseflow. In this manner, ground water contaminated by mining activities can also contaminate surface water.

At some locations, naturally occurring substances in an ore body can be a significant source of contaminants. The rocks that comprise ore bodies contain varying concentrations of nontarget minerals, including radioactive minerals. Other minerals may be present at concentrations that can be toxic and can be mobilized by the same geochemical and hydrological processes that control transport of mine-related contaminants. Nontarget minerals that can pose a risk to drinking water sources include aluminum, arsenic, asbestos, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, silver, selenium, thallium, and zinc. Unlike many other types of industrial operations and associated discharges, contaminant loading from hardrock mine sites can vary significantly with the season.

Findings from Studies

During the past 10 years, an increasing number of environmental studies have characterized the environmental impacts associated with active, inactive, and abandoned hardrock mines. Most of these studies have focused on water-quality impacts. In 1995, the Bureau of Land Management, the U.S. Geological Survey (USGS), and the Forest Service jointly developed a strategy to address cleanup of abandoned mines on Federal land (Nimick and von Guerard 1998). As part of this strategy, the USGS developed an abandoned mine land initiative that included numerous pilot studies in the Boulder River watershed in Montana and the Animas River watershed in Colorado. Most of the applied research efforts associated with this initiative were aimed at determining sources and magnitudes of metal loadings in nearby streams. A number of these studies documented significant metal loading from mining-related facilities and also from unmined areas underlain by sulfide ore bodies.

Using authorities under the Clean Water Act and Comprehensive Environmental Response, Compensation and Liability Act (CERLA), the U.S. Environment Protection Agency (EPA) has conducted a number of studies in Colorado and Montana. These studies have characterized the hydrologic pathways and geochemical processes that control the release and transport of toxic metals from mining facilities to underlying ground water and nearby surface water. Allen and Stanley (1998) summarize water-quality data collected in 1974–97 from streams that flow out of the New World Mining District in southwestern Montana. Water quality in two different streams has been significantly impacted by metals loading from mine workings, mine waste, and, to a lesser degree, by “natural” background loading (metals mobilized and transported to streams in the absence of any mine-related disturbance). In Daisy Creek, which flows past a mine pit that has been backfilled with mine waste, dissolved copper concentrations have ranged from 0.93 to 6.22 mg per liter at a location just downstream from the mine pit. The average concentration in 13 samples was 2.24 mg per liter. The drinking water standard is 1.0 mg per liter, and the chronic aquatic standard is 0.012 mg per liter. Dissolved iron concentrations at the same location ranged from 0.55 to 12.30 mg per liter. The average concentration in 13 samples was 3.53 mg per liter. The drinking water standard for iron is 0.30 mg per liter.

Studies conducted by EPA's Region VIII and the Colorado Division of Minerals and Geology in the Chalk Creek mining district in southern Colorado have documented extensive metal loading to Chalk Creek from the historic Mary Murphy gold mine. Zinc loading attributed to the extensive underground workings in Chrysolite Mountain and mine waste piles in the floodplain of Chalk Creek has been well documented. Zinc concentrations as high as 192,300 micrograms (µg) per liter have been measured in leachate from an old tailings pile less than one-fourth of a mile from Chalk Creek.[2] Data from 1999 indicate excessive zinc levels at three locations: (1) as high as 32,730 µg per liter in water discharging from the portal of the Golf Tunnel, which is the lowermost adit in Chrysolite Mountain; (2) 221,300 µg per liter in ground water seeping down through the upper workings in Chrysolite Mountain; and (3) 341 µg per liter in Chalk Creek below the Mary Murphy mine.[3] The drinking water standard for zinc is 5,000 µg per liter and the chronic aquatic standard is 110 µg per liter (at 100 mg-per-liter hardness). It is clear from these data that mining activities have had a significant impact to ground water and surface water in the vicinity of the Mary Murphy mine.

Reliability and Limitations of Findings

Data and information on potential environmental impacts related to hardrock mining have increased greatly in the past 10 years. Numerous investigations and published reports have documented movement of toxic metals to ground water and surface water from mines and mine-related facilities. The data from the increasing number of reports is reliable because the findings are comparable and often present the same conclusions. Many of the study results have been published in peer-reviewed literature.

One point of disagreement and uncertainty is the significance of "natural" background metal loadings versus metal loadings that result from mining activities. A number of studies have attempted to separate "natural" from man-caused loading (Nimick and von Guerard, 1998). Researchers have used water-quality data, including isotopes and tracers, to try to identify loading caused by leaching of unmined ore bodies. However, to date there has been no reliable technique developed to clearly separate natural from man-caused loading.

Research Needs

1. Research needs related to the environmental management of hardrock mine sites include two primary areas: (a) characterization of hydrologic and geochemical processes that control the release and transport of mine-related contaminants away from a mine site to ground water or nearby surface water; and (b) development of workable, passive systems for treating water with low pH and high concentrations of dissolved metals.
2. Hardrock mines often occur in complex hydrogeologic settings where a standard approach to characterization of ground water and surface water is inadequate. A mine can greatly disturb natural hydrologic systems, creating major water pollution problems. It is critical that we continue to improve characterization approaches and tools. An increased understanding of processes, which control distribution of mine-related contaminants, will be helpful for planning future mines and implementing effective environmental controls.
3. Capital, operating, and maintenance costs associated with active treatment of contaminated mine water are prohibitive at most mine sites. It is extremely important to continue research directed at developing efficient and cost-effective passive treatment technologies that can be operated year-round at high elevations. Research must continue on the use of organic substrata to facilitate the utilization of sulfide-reducing bacteria to remove dissolved metals from water. To date these technologies have been limited by the inability to deal with high-flow rates and the extreme climatic conditions at high elevations.

[2] Science Applications International Corporation. 1993. Chalk Creek nonpoint source project case history. 99 p. Unpublished report prepared for U.S. Environmental Protection Agency, Region VIII, Denver, CO. On file with: Science Applications International Corporation, 999 18th Street, Denver, CO 80202–2405.

[3] Wireman, Mike. 1999. Unpublished field data from Mary Murphy mine—Chalk Creek Mine District, Chaffee County, CO. [Not paged]. On file with: Mike Wireman, U.S. Environmental Protection Agency, Region VIII, 999 18th Street, Suite 500, Denver, CO 80202–2405.

Key Points

1. Management practices are commonly used to control erosion and sedimentation at mine sites. The selection of erosion control measures is based on site-specific considerations, such as facility size, climate, geographic location, geology, hydrology, and the environmental setting of each mine site. Mining facilities are often in remote locations and may operate only seasonally or intermittently, but they need year-round pollution controls. At least six categories of management practices are available to limit erosion and the off-site transport of sediment including discharge diversions, drainage and stormwater conveyance systems, runoff dispersion, sediment control and collection, vegetation and soil stabilization, and capping sources of contamination.
2. No easy or inexpensive solutions to acid rock drainage are currently available. An appropriate approach is to isolate or otherwise segregate waste with acid-generation potential, and then treat them appropriately. Management may include minimizing contact with oxygen and water and/or neutralizing acid that is produced with natural or introduced material. Techniques used include subaqueous disposal, covers, waste blending, hydrologic controls, bacterial control, and treatment.
3. Acid-generation prediction tests are increasingly relied upon to assess the long-term potential of pit walls and floors, underground workings, and mine waste to generate acid. Mineralogy and other factors affecting the potential for acid rock drainage are highly variable from site to site, and this can result in less than accurate predictions. In general, the methods used to predict the acid-generation potential are classified as either static or kinetic. Static tests are intended only to predict the potential to produce acid rather than predict the rate of acid generation. Static tests can be conducted quickly and are inexpensive compared with kinetic tests. Kinetic tests are intended to mimic the processes found in the environment of the ore body or waste unit environment; however, they require more time and are more expensive than static tests. Reliable dynamic tests that are faster and less expensive are needed.
4. The heightened awareness of the potential environmental problems associated with cyanide leaching led Federal land managers and States to implement increasingly stringent regulations and guidelines. These regulations and guidelines address the design of facilities that use cyanide and include requiring or recommending use of liners with heap leach piles or tailings impoundments, monitoring of solutions in process waters and ponds, treatment requirements for cyanide-containing wastes, and closure and reclamation requirements. Operators are generally required to take steps either to reduce or eliminate unwanted releases of cyanide solutions or to reduce cyanide concentrations in exposed materials to below standards. Regulatory requirements and guidelines on the allowable concentration of cyanide in exposed process solutions vary. When numeric limitations are established, they generally range around 50 mg per liter.

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Chapter 19

Coal Mining

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Introduction

The mining of coal can have many of the same environmental impacts to water quality as hardrock mining. However, some aspects of coal mining are different enough to warrant a separate discussion. After a brief description of coal mining, this chapter focuses on aspects of coal mining that are significantly different from hardrock mining with regard to the potential to impact water quality.

Coal accounts for one-third of the total energy usage and more than one-half of the electricity generated in the country (U.S. Geological Survey 1996). Domestic coal production has been steadily increasing since the 1950's. In 1998, total domestic production was 1.18 billion tons.[2] Approximately 570.5 million tons were produced in States east of the Mississippi River and 547.6 million tons from States west of the Mississippi River. Coal production in the West has almost doubled since the passage of the 1991 Amendments to the Clean Air Act. Wyoming leads the Nation in coal production. West Virginia and Kentucky are second and third, respectively. About 60 percent of domestic production is from surface mines and 40 percent from underground mines.

Mining Methods

Strip mining is the most common method of producing coal from surface mines. Strip mining commonly includes the removal and storage of topsoil, the removal of any overburden material, and the subsequent excavation of the coal seam. As the operation advances across the land surface, only a relatively small area is actively mined. With this method, the overburden is removed from the advanced side of the active mine face and placed on the retreat side, where the coal has been mined out. There are two common methods of underground mining: room and pillar mining and longwall mining. In the room and pillar method, entries or adits are driven into the coal seam, and crosscuts are driven at right angles to the adits at spacings dictated by the individual mine plan. A checkerboard pattern of interconnected tunnels or rooms and pillars is created. In longwall mining, numerous crosscuts are developed around a large block of coal. Once the crosscuts are fully developed, the large block is completely excavated, and the chamber is allowed to collapse. Longwall mining results in predictable subsidence of the overlying ground surface.

Coal Preparation

Coal that is excavated from a seam or deposit requires preparation to improve the quality and make it suitable for a given use. Preparation includes the separation of the heavier waste material from the lighter coal by flotation processes that rely on the differential densities of the coal and the waste material. Reagents are sometimes used to make the coal more amenable to flotation. Coal preparation creates a relatively uniform product size, reduces the amount of ash in the coal, and may reduce the sulfur content. In addition to clean coal, the preparation process produces a coarse, dewatered waste rock material and a fine-grained slurry with significant water content.

Waste Management

Waste materials are generated from coal mining and coal preparation. Overburden material removed for surface mining is often used to backfill the excavated area. Waste materials from underground mining are disposed of in mined-out workings to the extent possible, but they often are placed in a designated waste rock disposal area on the surface.

Large volumes of waste material can be generated from coal preparation. Both the coarse waste rock and the fine-grained slurry are typically disposed of in disturbed portions of the permit area. The fine slurry waste is commonly disposed of in an impoundment where the slurry solid settles, and the water is reclaimed from pond on top of the impoundment.

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Environmental Regulation

With the passage of the Surface Mining and Control Reclamation Act (SMRCA) in 1977, the coal mining industry became the only mining sector in the United States that is subject to mine-specific environmental regulation. The SMCRA pertains only to coal and was promulgated by the U.S. Congress to provide environmental standards for reclaiming land that has been impacted by coal mining and processing operations. The Office of Surface Mining Reclamation and Enforcement (OSM) was established to administer the law and regulations established by SMCRA. The OSM can delegate the regulatory program to the State level and most States that have substantial coal resources have developed their own regulatory programs. Most States have developed a permit program that regulates exploration activities, surface mining, underground mining, and special mining activities.

Issues and Risks

Just as in precious metal mining, the mining of coal can result in the exposure of sulfide minerals to oxygen, water, and bacteria. Pyrite and less commonly marcasite (FeS_2) and greigite (Fe_3S_4) are the primary sulfide minerals found in coal. Oxidation of these minerals can result in the generation of acidic water and the subsequent mobilization and transport of heavy metals to ground water and surface water.

Mine waste and coal preparation waste can contain significant amounts of pyrite and heavy metals including cadmium, chromium, mercury, nickel, lead, and zinc. These metals and sulfur can be concentrated in waste materials by factors of 3 to 10 compared to raw coal (National Research Council Committee on Accessory Elements 1979). Therefore, just as in hardrock mining acid drainage, the associated mobilization of heavy metals in the waste materials is a potentially significant threat to surface and ground water resources. See chapter 18 for further discussion of acid drainage and heavy metal mobilization.

Findings from Studies

The scientific literature includes thousands of studies on water-quality impacts from the mining and processing of coal. Coal mining has been much more extensively studied in the United States than hardrock mining. In the Southeastern United States where coal mining has occurred for more than 100 years, there are numerous documented cases of contamination of streams from coal mining. Hyman and Watzlaf (1997) used water-quality data from 128 different samples of untreated coal mine drainage from mines in Pennsylvania, West Virginia, Ohio, Tennessee, Maryland, Montana, Kentucky, Colorado, Oklahoma, and Missouri to characterize the occurrence of various metals and other contaminants. Results from this study indicate that the mean concentrations for arsenic, beryllium, cadmium, and lead exceeded the maximum contaminant level for drinking water and the maximum concentrations of these metals plus antimony, chromium, and zinc exceeded the maximum concentration level. This study also concluded that the traditional use of manganese concentrations as an indicator parameter for treatment thresholds is not reliable and that water-quality protection is better achieved if individual metal concentrations are more thoroughly considered.

Reliability and Limitations of Findings

It is clear that coal mining can mobilize and transport toxic metals from mines and mine-related facilities to ground water and surface water.

Research Needs

1. Within the coal mining industry, a key focus of recent environmental research has been the environmental effects of surface mining and power generation. A significant amount of research has involved mining and reclamation because these activities have the greatest impact on the environment. Major environmental concerns faced by the coal industry include the impacts of surface mining on water resources and whether mined land can be returned to productive use for crops, livestock, timber, and wildlife (White and others 1997). Important areas of research include topsoil substitution, reforestation, forage and row crops production, and wetlands. All of these areas of research are aimed at providing a better understanding of how areas that have been disturbed by coal mining can be reclaimed to reduce impacts on water quality.
2. An area of research that needs to be expanded is the development of methods for characterizing the hydrologic and geochemical processes that control release and transport of mine-related contaminants away from a mine site to ground water or nearby surface water. This research need is similar to that for hardrock mining. More emphasis needs to be given to preventing or controlling the transport of contaminants to streams.

Key Points

1. Mining and processing of coal clearly have the potential to contaminate ground water and nearby surface water. The mobilization and transport of toxic metals and other contaminants has been well documented in many areas of the country, especially in the leading coal-producing States in the Southeast. In Kentucky, West Virginia, Tennessee, and Virginia, the potential to impact surface water quality is increased by steep topography and narrow valleys. In this terrain, it is very difficult to mine and process coal without impacting surface water.
2. In the Western United States, coal production has increased significantly since 1991. In general, the western coal has a low sulfur content, which reduces the potential for acid rock drainage. In addition, the geologic and topographic settings of coal deposits in Western States is generally more amenable to the implementation of environmental controls.
3. The SMCRA requires all coal operations to develop environmental information, file operation and reclamation plans, and post an adequate surety prior to the development of any coal mining operation. Management practices are commonly used to control erosion and sediment at mine sites. Traditionally, the focus of the reclamation has been to restore the land disturbed by coal mining to beneficial use. Since the passage of the Clean Water Act, coal mining operations have been subject to point-source permitting. However, as with hardrock mining, no easy or inexpensive solutions to controlling acid rock drainage are currently available. Isolating materials will help to prevent or minimize oxygen contact with the material and prevent water from contacting the material.

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Chapter 20

Oil and Gas Development

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Introduction

Oil and gas exploration generally has short-term effects on the quality of drinking water sources. Exploration consists of geologic mapping and ground geophysical methods consisting of surface gravity, magnetic, and seismic surveys of the prospective area. Gravity and magnetic data are obtained with little impact to the surface. Seismic surveys entail the stringing of numerous arrays of geophones and the drilling of relatively few shot holes for creating the seismic signals. Today, the seismic energy often is generated by thumpers mounted on large trucks, utilizing less-environmentally damaging vibroseis technology. Both methods require a system of crude roads for access; however, vibroseis does not require the logistical support or involve the site disturbance that is necessary for drilling.

The Bureau of Land Management (BLM) oversees drilling operations and specifies conditions that must be met during drilling on public land. These conditions are designed to meet the intent of specific laws, such as the Safe Water Drinking Act of 1996, as well as to mitigate negative effects on resources that may not be specifically protected under statute or regulation.

Exploratory well drilling entails both site occupancy and reconfiguration. It has relatively short-term effects. Exploratory wells can acquire drill cuttings and cores for visual analysis as they probe the formation for direct information about such rock characteristics as lithology, porosity, permeability, and identification of pore fluids.

The majority of well drilling in today's petroleum industry is accomplished with rotary drills. This type of drilling requires the circulation of a fluid to lubricate and cool the bit, prevent plugging of the hole, and maintain the necessary hydrostatic pressure to prevent collapse of the well. It also counterbalances any high-pressure oil, gas, or water encountered in any of the drilled formations. Thus, fluid circulation helps prevent a catastrophic surge of highly pressurized fluid, called a blowout. Blowouts can cause fires, loss of life and property, and potential contamination of surface drinking water sources.

The fluid circulation system uses drilling muds. Generally, they are a water-based mixture of clays like bentonite and inert weighting constituents like barite with special additives mixed in low concentrations. Formulation of a particular drilling mud is based upon downhole conditions such as drilling depth, temperature, pressure, and the sensitivity of an oil or gas reservoir to water. Weighting constituents are added to the mud to counterbalance the formation pressure and prevent the formation fluids from entering the wellbore. The drilling mud is circulated downward through the drill stem, into the bit, and back up the annular space between the drill stem and the hole. It is then screened, filtered, and recirculated through tanks back into the hole. The Forest Service has some discretion in requiring that certain conditions be met in fluid system design and location. There is a risk of contamination to an intervening freshwater aquifer. The magnitude of risk depends, among other things, on the competence of the oil- and gas-containing rock, the proximity of the aquifer, and the thickness and competence of the units separating them.

Lined earthen pits, unlined earthen pits, or closed circulation systems are used for containment of water, waste fluids from drilling, rock cuttings, rigwash, and stormwater runoff. Containment design is influenced by such factors as soil conditions, depth to freshwater aquifers, proximity to surface water sources and drainages, types of drilling fluid, and availability of water for drilling. The design, location, closure, and reclamation of containment systems for drilling operations fall under the jurisdiction of both the Forest Service and the BLM.

Upon reaching the desired depth, the well is analyzed by electric and nuclear logs to determine whether the hole is a potential producer. If the well is determined to have no potential for production, it is plugged. Plugging operations fall under the jurisdiction of the BLM and the State or both. The responsible agency must ensure that plugging meets local criteria for protection of underground water sources. If the well is determined to have potential for production, the production casing is cemented into the wellbore and the

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drilling rig is replaced with a smaller completion rig. Casing a wellbore serves several purposes. It prevents the formation from caving into the wellbore; it provides a permanent passageway for conveying the oil and gas to the surface; it prevents exotic fluids from mixing with the producing formation; and it isolates the producing zone or other contaminating zones in the well from contact with any freshwater aquifers penetrated by the well. Casing operations fall under jurisdiction of the BLM and the State or both. They must be in compliance with specifications designed to protect underground water sources and to contain high pressures and any fluids or gases or both that might escape to the surface and pose hazards to surface resources, including drinking water sources.

Once drilled, cased, and completed, many wells have insufficient force to flow without further assistance because of material introduced by drilling or of material within the formation itself. Two of the most common techniques of well stimulation are acidizing and fracture treating. Acidizing is the pumping of acid into the well to help dissolve the impediment. When the permeability of a reservoir is so low that it is difficult for the oil and gas to flow into the well, the rock may be fractured to allow oil and gas to flow freely to the wellbore. A high-pressure fracture fluid comprised of thickened or gelled water is pumped at high rates into the well to fracture the formation.

After a well is completed for production, the drill is removed from the site and replaced by the well head. This phase of the operation has long-term effects because the facilities associated with it are in place over the operating life of the well. The Forest Service takes on long-term responsibilities for administering ongoing operations and monitoring conditions under which the operations occur.

Equipment design and layout are tailored to the particular characteristics of the site and the type of production (oil, gas, oil/gas mixtures; associated water production; oil/gas components such as hydrogen sulfide; etc.). The emphasis is on containment of fluids and gases, particularly in emergency circumstances. Although specific types of equipment are continuously being designed or upgraded to provide for environmentally safe production operations, it is often not practical, economical, or necessary to retrofit existing operations with some of the newer technology. The Forest Service must work closely with the BLM and the State or both in developing conditions of approval under which production facilities can be safely constructed and operated.

A flowing well is any well that has sufficient pressure belowground to cause the oil or gas to flow unassisted through the wellbore to the surface. Artificial lift is a technique that employs a mechanical or artificial means to pump or lift the oil to the surface. Depending upon the particular circumstances associated with the well, one of several types of artificial lift can be used. Primary recovery is the initial production of fluids using only natural sources of energy available within the reservoir. Depending upon the natural reservoir energy available, primary recovery can range from <5 percent to 75 percent of the resource. Secondary and tertiary recovery includes utilization of such methods as injection of water, steam, carbon dioxide, polymers, or micellar fluids to supplement natural reservoir energy and increase fluid recovery.

Generally, oil produced from the well is a mixture of oil, water, gas, and sand or other solid material. The sand and other solid materials are generally removed by gravity methods. Typically, the oil and water occur as an emulsion and must be treated to break the emulsion. Several methods are used for this purpose. Heaters can be used to heat the emulsion and separate it into its oil and water constituents. The addition of certain types of chemicals or the use of direct current can facilitate this process.

Once at the surface, the product is transferred by gathering lines to be treated then stored in underground or surface tanks until it is shipped to the purchaser. Storage facilities are comprised of welded or bolted steel tanks of various sizes ranging from 50 barrels to more than 10,000 barrels, depending on the scale of production. Facilities typically include provisions for transfer to trucks or pipelines. Refer to the discussion of roads and utility corridors in chapter 9.

Gas reservoirs generally do not contain oil, but produce gas with varying amounts of condensate or water. They generally produce well without the addition of supplementary energy and primary recovery methods are usually sufficient. Recovery is often >80 percent of the resource.

Issues and Risks

The Forest Service has a limited role in administering oil and gas operations. It has surface responsibilities only; whereas, the BLM, the U.S. Environmental Protection Agency (EPA), and the State have jurisdiction over subsurface operations. Additionally, the Forest Service can only make recommendations to the BLM regarding whether or not to issue a lease and what stipulations to apply if leased. The BLM has no obligation to implement Forest Service recommendations. The Forest Service must work closely with the BLM and the State in developing conditions of approval under which production facilities can be constructed and operations can be maintained.

The Resource Conservation and Recovery Act of 1976 (RCRA), codified at 42 U.S.C. sec. 6901 et seq., conditionally exempted from regulation as hazardous wastes drilling fluids, produced waters and other wastes associated with the exploration, development, or production of crude oil or natural gas. According to the EPA, exempted wastes include well completion, treatment, and stimulation fluids; workover wastes; packing fluids; and constituents removed from produced water before it is injected or otherwise disposed of. While these wastes are not considered hazardous, they may have an effect on the quality of drinking water sources if contamination occurs. Contamination is most likely to occur at the surface in the event of a spill or a breach of, or infiltration from, a containment structure.

Access roads and well pads erode and become sources of sediment during the exploration and production phases. See chapter 9 for discussion of roads and sediment.

Under the Clean Water Act, discharges to surface water by oil and gas exploration and production operations are addressed by the National Pollutant Discharge Elimination System. Onshore discharges are prohibited except from wells producing not more than 10 barrels per day and discharges of produced water that are determined to be beneficial to agriculture or wildlife (U.S. EPA 1992).

The Safe Drinking Water Act specifically addresses oil and gas operations under its underground injection control program. The objective of the program is to protect good-quality ground water from contamination by injected fluids. It established a special class (class II) of injection wells for oilfield-related fluids, the regulation of which should not impede oil and gas production unless necessary to prevent contamination of underground sources of drinking water. An underground source is an aquifer that supplies drinking water for human consumption or for any public water system, or contains fewer than 10,000 milligrams per liter of total dissolved solids, does not contain minerals or hydrocarbons that are commercially producible, and is situated at a depth or location, which makes the recovery of water for drinking purposes economically or technologically practical. Class II regulatory programs are either directly administered by the States under primacy programs or by EPA where States do not administer the programs.

Injection wells are sometimes used to dispose of produced water, a byproduct of oil and gas recovery. Most produced water is strongly saline, with total dissolved solids ranging from several hundred to over 150,000 parts per million (ppm). Produced water pumped into injection wells is used to enhance production by providing the energy needed to drive the oil toward the producing well. Secondary recovery may necessitate the drilling of a few to hundreds of injection wells throughout the field, depending upon the size of the reservoir. This water is intended to provide the energy needed to drive the oil toward the producing well. Secondary recovery may necessitate the drilling of a few to hundreds of injection wells throughout the field, depending upon the size of the reservoir.

Because produced water is beneficially recycled and is an integral part of some crude oil and natural gas production processes and because injection of produced water for enhanced recovery is regulated under the Safe Drinking Water Act's Underground Injection Control Program, EPA has determined that it is not a waste for purposes of RCRA subtitle C or subtitle D.

Despite prevention measures, contamination of a drinking water aquifer can occur as a result of improper plugging of abandoned wells or casings, and through direct injection into aquifers. During exploratory and development drilling, the well has the potential to act as a conduit between formations hosting usable aquifers and formations containing hydrocarbons, heavy metals, or chlorides associated with accompanying brines. If the well penetrates an aquifer and is not cased, or the casing and grouting fail, there is a possibility for contaminants to migrate through the conduit and into the drinking water aquifer.

Stimulation of an oil reservoir utilizing the pumping of a fracture fluid under high pressure into the formation can have adverse effects. If the induced fracturing extends beyond the boundaries of the reservoir, there is a risk of contamination to a nearby freshwater aquifer. The magnitude of risk is dependent, among other things, on the competence of the reservoir rock, proximity of the aquifer, and the thickness and competence of the units separating them.

Produced water is usually a highly saline brine accompanied by trace contaminants inherent in the reservoir. Injection of produced water back into the reservoir for disposal or to enhance recovery has the potential to contaminate freshwater through grout or casing failures between the injection well and the aquifer. Injecting produced water into old injection wells with leaking casings can introduce brine into surface geologic strata where it can percolate to and contaminate surface waters. Sometimes brine water is trucked to injection wells; however, some truckers have been known to dump the brine illegally into surface water at stream crossings.

Corrosion or failure of any one of the numerous surface facilities may result in leakage and subsequent migration of hydrocarbons into shallow freshwater aquifers. Surface pipes from wells to storage tanks can corrode or break and discharge oil and brine onto the soil surface, where the discharge can run off to streams. Pipes crossing streams can rupture and discharge directly into streams. The degree of contamination depends upon, among other things, the extent and duration of leakage.

Some waste management practices associated with hydrocarbon production may have an effect on ground water. The failure of waste pits or drilling mud pits or the utilization of unlined pits for these purposes can allow percolation of contaminants through the soil and into shallow aquifers. Some natural gas contains hydrogen sulfide, carbon dioxide, or other impurities that must be removed prior to sale. Sweetening is the stripping of these impurities by various chemical processes including utilization of amine, sulfinol, iron sponge, and caustic solutions. Associated wastes may include spent amine, gycol and sulfinol, slurries of sulfur and sodium salts, iron sulfide and wood shavings, and caustic filter material, which may be commingled with produced water. These wastes may fall into a hazardous waste category but are exempted from regulation under RCRA. Any waste products associated with oil and gas production, whether exempted or not, can be a risk to drinking water sources if not managed appropriately.

The disposal of excess drilling fluid and produced water by evaporation, road spreading, and application to the land may have an effect on the quality of surface water. Runoff may allow the migration of chlorides, oily wastes, or other contaminants into streams or ground water and, thus, affect the quality of drinking water.

Findings from Studies

With respect to the disposal by landspreading of liquid and solid wastes, two primary concerns are their salt content and hydrocarbon content. Studies by Deuel (1990) and Macyk and others (1990) have shown that soil and water mixtures or both with soluble salt levels below roughly 3,000 ppm of total dissolved solids, exchangeable sodium percentage of < 16, and a sodium adsorption ratio of < 12 cause no harm to soil, vegetation, surface water, or ground water. Landspreading or wastes resulting in oil and grease concentrations of up to 1 percent by weight in the waste and soil mixture or both are not harmful and will biodegrade readily. Repetitive disking and nutrient addition can reduce concentrations in a soil mixture to these levels.

Instream monitoring by the Daniel Boone National Forest in Kentucky revealed high concentrations of brine below oil production well fields. In Texas, heavy sediment deposits in streams were traced to gas well pads and service roads.

Reliability and Limitation of Findings

Anecdotal evidence of contamination or degradation of drinking water sources from oil or gas wells exists throughout the Forest Service, particularly in areas of split mineral estates in which the Federal Government holds surface rights, but mineral rights are privately owned. Such estates are most common in the national grasslands and eastern national forests. Contamination or degradation has not been assessed on a nationwide scale, but the level of risk depends on the degree of monitoring and inspection. Databases managed by the BLM and individual States may provide more information about the extent of existing contamination or degradation and potential for such to occur in the future.

Research Need

A quantified assessment of contamination or degradation of surface and ground water by oil and gas operations that draws on BLM and State data bases is needed on a nationwide scale. It would provide a more accurate framework in which to manage oil and gas exploration and production activities.

Key Points

All facets of oil and gas exploration and production can affect the quality of drinking water. The Forest Service can control the effects associated with those activities that occur on the land surface such as site preparation, berm and pit construction, design and location of ancillary systems, road construction, and reclamation activities that probably have a greater potential to affect surface water quality. The Forest Service must work closely with the BLM, EPA, and the States to assure that drilling, production, and waste disposal activities are conducted so as to minimize adverse effects on both ground water and surface water quality for public drinking water sources.

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