Summary

Application of the various methods of controlling groundwater flow into mine workings requires knowledge of the source and pathways of the portion of the aquifer that is hydrologically connected to the mine. The previous discussion of methods provides an overview of the investigation. No single method will provide all the pertinent information. It will be necessary to compile information from several sources and compose a conceptual model of the groundwater flow system near the mine.

Elkhorn Mine

The discharge of 80 to 130 gallons per minute from the main adit of the lower Elkhorn Mine far exceeds that of most mines in Montana. Discharge from most adits is in the 5- to 10-gallon-per-minute range (Hargrave and others 2000). The Elkhorn Mine is also one of the largest abandoned mines in Montana with acid mine drainage problems. The mine has a reported 24,000 feet of workings. This investigation was limited to a survey of surface features, surface water, soils, vegetation, and existing information on geology and workings.

Although information is incomplete and sometimes contradictory, the mine probably intersects a number of faults and well-jointed granitic rock capable of transmitting groundwater. The volume of rock available for groundwater recharge to the mine is quite large. This is evidenced, in part, by the high sustained discharge from the adit. The workings of the Elkhorn Mine extend toward the Park Mine. Flooded shafts and prospects prevent us from knowing whether there is a direct connection between the two mines, but there could be some contribution of groundwater from the Park Mine to the Elkhorn Mine workings.

Any attempt to control or eliminate adit discharge from the lower Elkhorn Mine would have to include an investigation of the underground workings. The true extent of the workings, the effects of the faults on groundwater flow, and fracture/joint orientation and density are unknown. Extensive tree cover severely limited the use of aerial photos or field mapping to identify fractures and joints on the surface.

The unnamed tributary flowing through the disturbed area, along with several closed depressions throughout the area, probably contribute a significant portion of the groundwater recharge to the adjacent underground workings. Infiltration controls on the streambed and surface disturbances may reduce discharge from the adits. Further investigations are warranted, particularly investigations to identify the recharge area. For example, age-dating the adit discharges would provide a means to estimate flow paths and residence times. Similarly, tracer tests and detailed flow measurements of the stream may identify segments losing water.

Charter Oak Mine

A portion of the discharges at the Charter Oak Mine site may be the result of fault-related flow; faults were described in the underground workings on the unpublished maps of the area. No mention of water in the workings was made in the sparse information available for the mine. However, the amount of water contributed from these fault conduits is probably small. The seasonal response in adit discharge and the shallow workings suggest a similarly shallow groundwater flow system that may be a good candidate for source control.

References

Hydrology

Hargrave, P.A.; Metesh, J.J.; Oravetz, Steve. 2000. Using recharge control to reduce mine adit discharges: a preliminary investigation. Tech. Rep. 0071–2804–MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 10 p.

Kendall, C.; McDonnell, J.J., eds. 1998. Isotope tracers in catchment hydrology. Amsterdam: Elsevier Science B.V. 839 p.

Kimball, B.A.; Broshears, R.E.; Bencala, K.E.; McKnight, D.M. 1994. Coupling of hydrologic transport and chemical reactions in a stream affected by acid mine drainage. Environmental Science and Technology. 28: 2065–2073.

Metesh, J.J.; Jarrell, Terrie; Oravetz, Steve. 1998. Treating acid mine drainage from abandoned mines in remote areas. Tech. Rep. 9871–2821–MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 22 p.

Poreda, R.J.; Cerling, T.E.; Solomon, D.K. 1988. Tritium and helium isotopes as hydrologic tracers in a shallow unconfined aquifer. Journal of Hydrology. 103: 1–9.

Soil and Wetlands Interpretation

Brinson, M.M. 1993. A hydrogeomorphic classification for wetlands. Wetlands Research Program Tech. Rep. WRP–DE–4. Vicksburg, MS: U.S. Army Corps of Engineers Waterways Experiment Station.

Committee on Characterization of Wetlands. 1995. Wetlands: characteristics and boundaries. Washington, DC: National Research Council. National Academic Press.

Cowardin, L.M.; Carter, V.; Golet, F.C.; LaRoe, E.T. 1979. Classification of wetlands and deepwater habitats of the United States. Tech. Rep. FWS/OBS-79/31. U.S. Department of the Interior, Fish and Wildlife Service.

Drury, S.A. 1990. A guide to remote sensing; interpreting images of the earth. Oxford University Press. 199 p.

Hansen, P.L.; Pfister, R.D.; Boggs, K.; Cook, B.J.; Joy, J.; Hinckley, D.K. 1995. Classification and management of Montana's riparian and wetland sites. Misc. Publ. 54. Missoula, MT: University of Montana, School of Forestry, Montana Forest and Conservation Experiment Station. 646 p.

Hurt, G.W.; Whited, P.M.; Pringle, R.F., eds. 1998. Field indicators of hydric soils in the United States: version 4.0. Fort Worth, TX: U.S. Department of Agriculture, Natural Resources Conservation Service.

Maus, P. 1995. Guidelines for the use of digital imagery for vegetation mapping. Tech. Rep. EM–7140–25. Washington, DC: U.S. Department of Agriculture, Forest Service, Engineering Staff.

Reed, P.B., Jr. 1988. National list of plant species that occur in wetlands: 1988 national summary. Biological Rep. 88 (24). U.S. Department of the Interior, Fish and Wildlife Service.

U.S. Army Corps of Engineers. 1987. Corps of Engineers wetlands delineation manual. Tech. Rep. Y–87–1.

U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Survey Staff. 1996. National soil survey. Agric. Handb. 430–VI, Issue 4. Washington, DC: U.S. Department of Agriculture.

U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Survey Staff. 1999. Soil taxonomy. 2d ed. Agric. Handb. 436. Washington, DC: U.S. Department of Agriculture.

U.S. Department of Agriculture, Soil Survey Division Staff. 1993. Soil survey manual. Agric. Handb. 18. Washington, DC: U.S. Department of Agriculture. 437 p.

U.S. Department of the Interior, Fish and Wildlife Service; Environmental Protection Agency; Department of the Army; Soil Conservation Service. 1989. Federal manual for identifying and delineating jurisdictional wetlands: an interagency cooperative publication.

Vepraskas, M.J. 1992. Redoximorphic features for identifying aquic conditions. Tech. Bull. 301. Raleigh, NC: North Carolina State University, North Carolina Agricultural Research Service.

Aerial Photointerpretation

Colwell, R.N., ed. 1960. Manual of photographic interpretation. Washington, DC: American Society of Photogrammetry. 868 p.

Bither, K.M.; Tolman, A.L. 1993. Conjunctive use of air photo interpretation and geophysics to evaluate fractured bedrock aquifers: abstracts with programs. Geological Society of America, Northeastern Section, 28th annual meeting. 25(2). 5 p.

Howe, R.H.L. 1958. Procedures of applying air photo interpretation in the location of groundwater. Photogrammetric Engineering. 24(1): 35–49.

Howe, Robert; Wilke, H.R.; Bloodgood, D.E. 1956. Application of air photo interpretation in the location of groundwater. American Water Works Association. 48(11): 1380–1390.

Lattman, L.H. 1958. Technique of mapping geologic fracture traces and lineaments on aerial photographs. Photogrammetric Engineering. 24(4): 568–576.

Mayer, J.R.; Sharp, J.M., Jr. 1998. Fracture control of regional groundwater flow in a carbonate aquifer in a semi-arid region. Geological Society of America Bulletin. 110(2): 269–283.

Ray, R.G. 1960. Aerial photographs in geologic interpretation and mapping. U.S. Geological Survey Professional Pap. 373. 230 p.

Stotelmeyer, R.B.; Johnson, F.L.; Lindsay, D.S.; Ridenour, James; Schmauch, S.W. 1983. Economic appraisal of the North Absaroka Wilderness Study Area, Park and Sweet Grass Counties, Montana. In: Mineral Resources of the North Absaroka Wilderness Study Area, Park and Sweet Grass Counties, MT. U.S. Geological Survey Bull. 1505: 115–236.

Elkhorn Mine

Butler, W.R. (n.d.). Unpublished report on the Elkhorn Mine in the Montana Bureau of Mines and Geology mineral property files. Butte, MT. 8 p.

Brinson, M.M. 1993. A hydrogeomorphic classification for wetlands. Wetlands Research Program Tech. Rep. WRP–DE–4. Vicksburg, MS: U.S. Army Corps of Engineers Waterways Experiment Station.

Committee on Characterization of Wetlands. 1995. Wetlands—characteristics and boundaries. Washington, DC: National Research Council. National Academic Press.

Dickman, R.N. 1913. Report on the Central and Park group of claims, Beaverhead County, MT. Unpublished report from *The Rookery,* Chicago, IL, in Montana Bureau of Mines and Geology files. Butte, MT. 12 p.

Evans, H.J. 1946. Report on the mining properties of Bostana Mines Company, Beaverhead County, MT. Internal report to Marvin E. Walker. Montana Bureau of Mines and Geology files, Rm. 213, Main Hall. Butte, MT. 25 p.

Geach, R.D. 1972. Mines and mineral deposits (except fuels), Beaverhead County, MT. Montana Bureau of Mines and Geology Bull. 85. Butte, MT: Montana Bureau of Mines and Geology. 194 p.

Hansen, P.L.; Pfister, R.D.; Boggs, K.; Cook, B.J.; Joy, J.; Hinckley, D.K. 1995. Classification and management of Montana's riparian and wetland sites. Misc. Publ. 54. Missoula, MT: University of Montana, School of Forestry, Montana Forest and Conservation Experiment Station. 646 p.

Loen, J.S.; Pearson, R.C. 1989. Map showing locations of mines and prospects in the Dillon 2° x 1° quadrangle, Idaho and Montana. U.S. Geological Survey Miscellaneous Investigations Series Map I–1803–C. 85 p. Scale 1:250,000.

Marvin, R.K.; Hargrave, P.A.; Lonn, J.; Abdo, G.N.; Metesh, J.J.; Bump, K. 1998. Abandoned-inactive mines in the southern Beaverhead-Deerlodge National Forest. Tech. Rep. MBMG–379. Butte, MT: Montana Bureau of Mines and Geology. 322 p.

Ruppel, E.T.; O'Neill, J.M.; Lopez, D.A. 1993. Geologic map of the Dillon 2° x 1° quadrangle, Idaho and Montana. U.S. Geological Survey Miscellaneous Investigations Series Map I–1803–H. Scale 1:250,000.

Sassman, Oren. 1941. Metal mining in historic Beaverhead. Bozeman, MT: Montana State University. 310 p. Thesis.

U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Survey Staff. 1993. Soil survey manual. Handb. 18. Washington, DC: U.S. Department of Agriculture, Natural Resources Conservation Service. 437 p.

U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Survey Staff. 1996. National Soil Survey Handb. 430–VI, Issue 4.

Vepraskas, M.J. 1992. Redoximorphic features for identifying aquic conditions. Tech. Bull. 301. Raleigh, NC: North Carolina State University, North Carolina Agricultural Research Service.

Winchell, A.N. 1914. Mining districts of the Dillon quadrangle, Montana, and adjacent areas. U.S. Geological Survey Bull. 574. 191 p.

Winters, R.; Graham, D.; Hillman, T.; Hughes, C.; Johnson, R. 1994. Mineral resource appraisal of the Beaverhead National Forest, MT. U.S. Bureau of Mines MLA 18–94. 84 p. 9 appendixes.

Charter Oak Mine

Elliot, J.E.; Loen, J.S.; Wise, K.K.; Blaskowski, M.J. 1992. Maps showing locations of mines and prospects in the Butte 2° x 1° quadrangle, western Montana: U.S. Geological Survey Miscellaneous Investigations Map I–2050–C. Scale 1:250,000.

Hargrave, P.A.; Bowler, T.P.; Lonn, J.; Madison, J.P.; Metesh, J.J.; Wintergerst, R. 1998. Abandoned-inactive mines in the Helena National Forest, Volume II: Blackfoot and Little Blackfoot River drainages. Tech. Rep. MBMG-368. Butte, MT: Montana Bureau of Mines and Geology. 181 p.

McClernan, H.G. 1975. Preliminary bibliography and index of the metallic mineral resources of Montana through 1969. Spec. Publ. 70. Butte, MT: Montana Bureau of Mines and Geology. 91 p.

McClernan, H.G. 1976. Metallic mineral deposits of Powell County, Montana. Bull. 98. Butte, MT: Montana Bureau of Mines and Geology. 69 p. Scale: 1 inch = 1 mile.

Pardee, J.T.; Schrader, F.C. 1993. Metalliferous deposits of the greater Helena mining region, Montana. Bull. 842. U.S. Geological Survey. 318 p.

Schmidt, R.G.; Loen, J.S.; Wallace, C.A.; Mehnert, H.H. 1994. Reconnaissance geologic map of the Elliston region, Powell and Lewis and Clark Counties, MT. U.S. Geological Survey Bull. 2045. 25 p. Scale: 1:62,500.

Appendix A—*Elkhorn Mine Riparian and Wetlands Characterization and Mapping*

Methods

The office procedures, field investigations, and mapping results are discussed on pages 17 and 18. Figure 1 shows the points where data were collected for the wetland and riparian characterization and mapping.

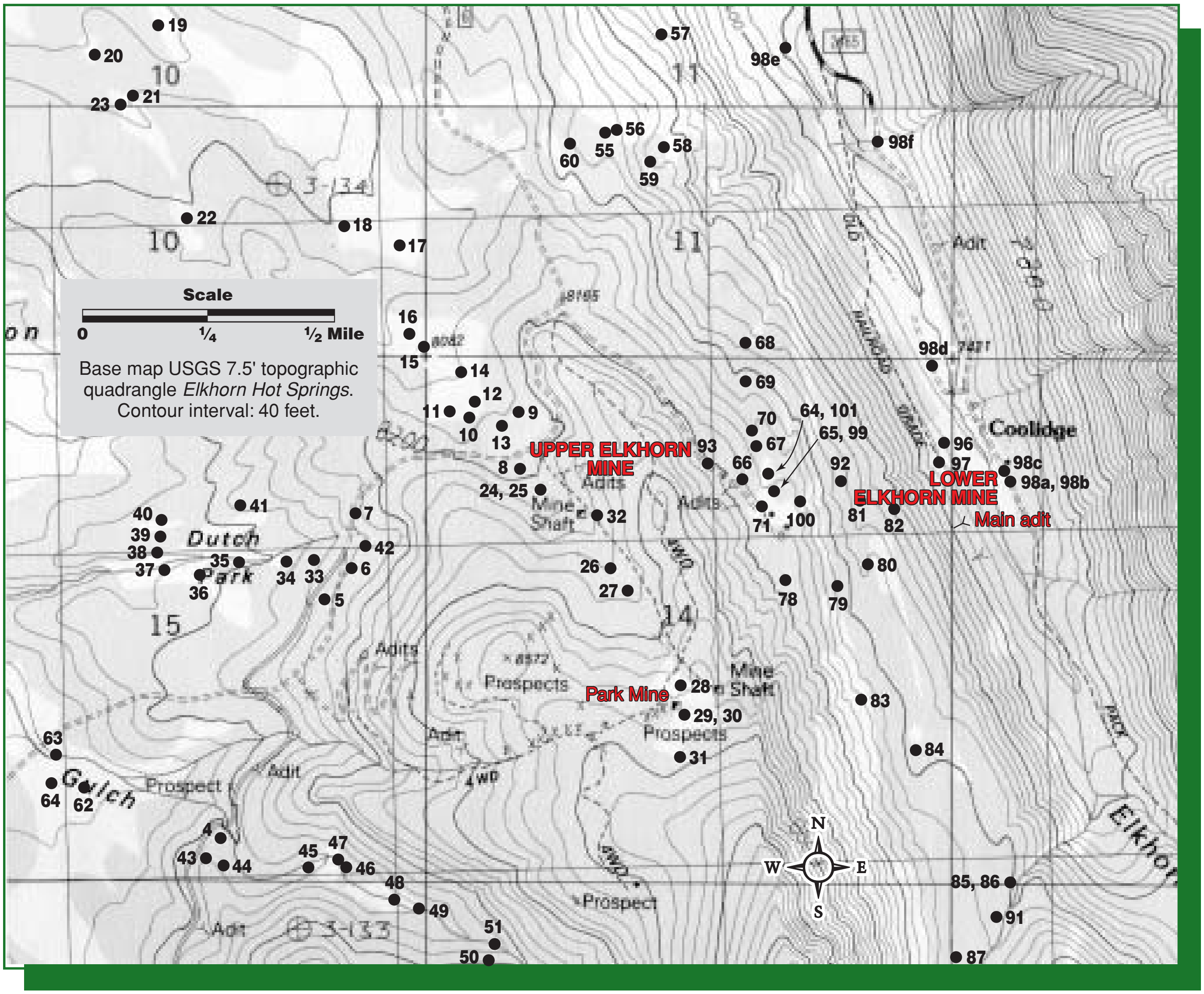

Figure 1—Stop points (data collection sites) for the wetland and riparian characterization and mapping in the Elkhorn Mine area.

Brief descriptions of the major ecological units follow.

The large grassy parks to the southwest, west, and northwest of the mine surface workings reflect a combination of clay soils and seasonally to yearlong saturation of the upper soil profile. Within the parks closest to the mine sites, the wettest areas occupy the lowest parts of the valley bottoms along small intermittent and perennial streams (figure 2). The somewhat drier sites border these areas slightly upslope (figure 3). These sites are bordered upslope by upland forests dominated by lodgepole pine growing on coarse glacial till or colluvium (map unit 3U). Farther west (lower in elevation), the parks are dominated by the very wet map unit. Characteristic soils on the wettest portions of the large parks are Histic Cryaquolls, Typic Cryaquolls, Cryohemists, and Cryofibrists (U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Survey Staff 1999). Soils are saturated above the 12-inch depth throughout the year in most years. Dominant plant associations are water sedge, wolf willow/water sedge,

Figure 2—Map unit 1H: A wet meadow ponded at the surface. Beaked sedge and water sedge dominate the plant community. Soils have an 8-inch-thick fibric organic surface layer.

Figure 3—Map unit 2H: A meadow in extremely bouldery glacial till, seasonally saturated in the upper 12 inches of soil which has a thick, dark mineral surface. The plant community is dominated by tufted hairgrass and American bistort.

and tufted hairgrass (Hansen and others 1995). Characteristic soils on the somewhat drier portions of these large parks are Cumulic Cryaquolls, Aquic Argicryolls, and Aquic Haplocryolls. Soils are saturated to the surface during snowmelt and the early part of the growing season. The depth to saturation drops to 20 to 35 inches at the end of the growing season. The dominant plant association is tufted hairgrass.

Very wet Engelmann spruce and subalpine fir areas are associated with coarse stream alluvium and glacial till (figure 4). Dominant soils are Histic Cryaquepts, Typic Cryaquepts, and Typic Cryaquolls. The depth to saturated soils is to 18 inches throughout the year in most years.

Characteristic plant associations are Engelmann spruce/Holm's Rocky Mountain sedge (an undescribed type), subalpine fir/Labrador tea-bluejoint reedgrass, and Engelmann spruce/bluejoint reedgrass. Slightly drier forested areas form transition zones between these wet forests and the dry upland forests (figure 5).

Figure 4—Map unit 1F: A wet slump deposit at the base of a steep glacial moraine. The soil has 17 inches of saturated hemic (partially decomposed) organic material at the surface. The plant community is mainly Holm's Rocky Mountain sedge, Engelmann spruce, and Jeffrey's shooting star.

Figure 5—Map unit 2F: Foreground is a moderately wet inclusion (too small to map as a separate unit) dominated by common camas, tufted hairgrass, and American bistort. The forested background is the major part of the map unit, dominated by Engelmann spruce, subalpine fir, arrowleaf groundsel, and Labrador tea.

Characteristic soils of the slightly drier forests are Aquic Dystrocryepts and Typic Cryaquepts. Seasonally, the soils are saturated within the upper 12 inches of the soil profile, but the depth to saturation drops to 24 to 40 inches at the end of the growing season in most years. The dominant plant association is subalpine fir/Labrador tea-Labrador tea. Small, grassy, wet meadows included in the wet forests are the wettest sites observed in the assessment area. In these small meadows, shallow ponding of water on the surface was observed. The ponded meadows occur along low-gradient drainageways, slumps, and in seepage areas (figure 6).

In some locations, small areas of the wet forests and very wet, grassy meadows are intermixed in a fine, complex pattern that did not permit mapping the two types separately at the mapping scale used. These areas were mapped as a complex of the two types (figure 7).

The soils and plant associations that characterize these areas are similar to those of their respective components (map units 1F and 1H). The minor differences are described in appendix B.

All areas that were not mapped as water, or as any of the five riparian and wetland map units discussed above, were mapped as upland areas (map unit 3U). The unit includes forested and nonforested lands, and areas of rock outcrop and talus/scree. The soils of the upland meadows and forests are well-drained to excessively drained Typic Dystrocryepts, Andic Dystrocryepts, and Lithic Dystrocryepts. They formed mainly in colluvium (a loose deposit of rock debris that accumulates at the base of a cliff or slope) and glacial till. Water tables and saturated soils may occur below the 40-inch depth examined in this study, but this could not be ascertained from the soil profiles, vegetation, or aerial photos. The dominant plant associations are subalpine fir/grouse whortleberry-pinegrass and subalpine fir-whitebark pine/grouse whortleberry.

Figure 6—A wet meadow slump in map unit 1F. The slump headscarp is in the background. The slump deposit is saturated to the surface and has areas of surface ponding. The soil has 9 inches of fibric organic material over gleyed loam. Holm's Rocky Mountain sedge, beaked sedge, and seep-spring arnica dominate the plant community.

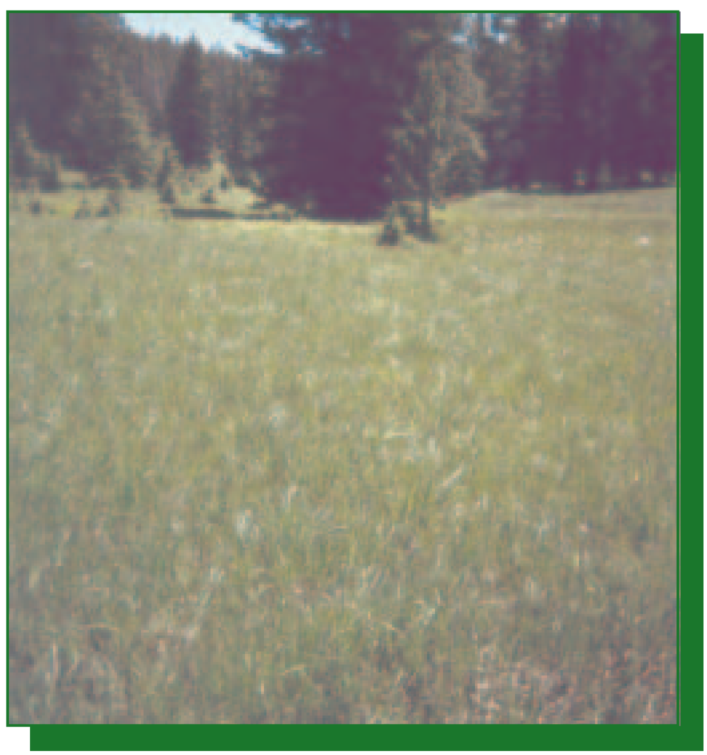

Figure 7—Map unit 1FH: A complex of small areas of wet meadows, saturated to the surface yearlong (foreground). Holm's Rocky Mountain sedge and water sedge mixed with small, wet forested areas (background) having soils saturated within the upper 6 inches yearlong, dominated by Engelmann spruce, subalpine fir, bluejoint reedgrass, and willow. Soils of both components have thick organic surface layers.

Discharge and Recharge Areas

General information about the discharge and recharge areas, including St. Louis Gulch (figure 8), is included in the *Discharge and Recharge Areas* section (pages 18 and 19). Another area with several sites of apparent groundwater recharge is around the Upper Camp of Elkhorn Mine. A 100- by 300-foot wet sedge meadow (figure 9) is at the toe of the flat, large fill immediately east of the collapsed upper adit portal.

This meadow consists of about 5 inches of saturated organic soil material over 8 inches of extremely acidic, fine sandy loam and silt loam alluvium which is saturated and gleyed. These recent deposits of alluvium buried the native wetland soil. The buried soil profile is still intact and consists of buried organic horizons over dark, gleyed silty clay loam, which overlies gleyed very cobbly sandy loam, likely from glacial till. The recent alluvium is probably associated with the mine operations. Part of the alluvium collected behind a

Figure 8—Looking upslope into collapsed hillside mine workings about ¾ mile south of the Elkhorn Mine upper adit. A small, very acidic flow (pH 4.2) emerges from the workings, then becomes groundwater 30 feet downstream. The water deposits thick iron coatings on soil and rocks in the shallow channel.

Figure 9—Buried wetland soil at the Elkhorn Mine's upper adit. The upper 13 inches of soil is saturated and covers the original saturated wetland soil. The upper 5 inches has dark brown to reddish fibric organic horizons overlying gleyed, mucky silt loam. The original soil surface (below 13 inches) is fibric to hemic organic material. The tape measure shows inches.

constructed dam at the base of the wet meadow (a complete soil profile description of this site is in the project file). Immediately above this dam is a deposit of saturated silty clay loam that appears to be bentonite or drilling mud with 30- to 35-percent clay. It varies from red to buff grey or black. This is not native material, but its purpose in the mine operation is unknown—perhaps it is drilling mud that was used for exploratory drilling. This clayey alluvium continues in the wet meadow below the dam (stop 67). The native wetland was buried by the clayey alluvium in this lower meadow. The pH of the recent organic deposits and the recent alluvium ranged from 4.3 to 5.5 at a ratio of 1:1 as soil: distilled water. Surface water adjacent to the meadow is pH 4.3.

At the upper end of this wet meadow is a small pond about 7 by 10 feet with several inches of standing, stagnant water (stop 65). This spot appears to have been previously excavated. The pH of the pond water is 2.9 and the pH of the exposed sediment adjacent to the pond ranges from 2.5 to 4.4 (stops 65 and 101). Sediment in the bottom of the pond is less acidic (pH ranged from 4.5 to 6.0) and more reduced (redox potential ranged from +39 to +186 millivolts) than the exposed sediment next to the pond (redox potential ranging from +249 to +341 millivolts). It appears that the surface of the pond represents the level of the water table under the wet meadow discussed above. The source of the acidity of the pond and adjacent wet meadow is unknown. The pH of the fillslope soil, as well as the soil in the large cutslope above the buried upper adit portal, is about 6.3 to 7.4 (stops 65 and 71).

To the east of the large, flat fill area in the Upper Camp is a large deposit of sandy loam to gravelly sandy clay loam waste-rock material that has very steep sideslopes (stop 100). This material apparently came from the upper workings underground system and was dumped from a rail system. The deposit is about 200 feet wide and 400 feet long. This material was excavated to 52 inches for study. Seven layers were described regarding pH, color, texture, redox potential, percent clay and gravel, temperature, and soil moisture status (stop 100). The pH of this material ranged from 2.9 for red soil to 3.5 for light yellow soil. The redox potential ranged from +433 (light yellow soil) to +543 millivolts (red soil). Colors to 52 inches are red (surface), grayish-yellow, and light yellow. The observed red soil only occurred in the first 16 inches, where it is about 70 percent of the soil volume. Water leaching through this extremely acidic deposit could become quite acidic. If such water reached the underground workings, it would contribute to the problem of acid drainage from the lower adit.

This acidic waste dump is bare of vegetation and shows signs of serious erosion in the form of numerous rills and several gullies. The eroded material was deposited on the forested slope (15-percent gradient) immediately below the waste dump (stop 92). Much of the sediment is deposited within 200 to 250 feet of the toe of the dump. The thickness of the overburden south of the tramway is about 5 to 8 inches. Some sediment was carried another 200 feet through the tramway corridor before spilling over the steep slope below. Some of the surface water probably becomes groundwater in these deposition zones as the flow rates decrease and surface water flows across the native volcanic ashcap soils of the area. The pH of the overburden and of the buried silt loam volcanic ash soil is 4.2. This contrasts with a pH of 5.2 for native silt loam volcanic ash surface soil in an adjacent area that was not affected by the acidic sediment. A 10-fold increase in the acidity of the native buried soil has occurred since its burial. Acidification and burial of this area south of the tramway has resulted in the death or severe defoliation of most lodgepole pines. North of the tramway, the overburden occurs in patches and is less than 2 inches thick. In this area, the tree canopies appear healthy. Acidification of the buried native soil by water leaching through the acidic overburden indicates that this area has the potential to supply acidified water to the groundwater.

Near the bottom of the tramway corridor is a recent, long narrow slump scar (stop 92). In the forested site nearby, there is a second slump in extremely bouldery glacial till. The slumps are probably due to a seasonally high water table as evidenced by several large Engelmann spruce trees and a few alder shrubs.

Soil pH of the lower workings below the lower adit were alkaline, ranging from a pH of 7.8 at a depth of 4 to 6 inches, to a pH of 8.5 at 12 to 24 inches (stop 93). The upper 6 inches is gravelly, sandy clay loam that overlies very gravelly sandy loam. Evidence of seasonally saturated soil (fine reddish iron masses) begins at about 12 inches. The upper 10 inches of the profile appear to be topsoil that was added to the site as part of previous reclamation.

Water Samples

The pH of surface water of the lower adit and various locations in Elkhorn Creek was measured on August 30, 2002. The results follow:

- **Stop 97**—Adit discharge water within several feet of the entrance: pH 6.1, redox +129 millivolts, 45 °F.
- **Stop 98b**—Adit discharge water about 3 feet before entering Elkhorn Creek: pH 6.1, redox +176 millivolts, 68 °F.
- **Stop 98a**—Elkhorn Creek 6 feet upstream of the point at which adit discharge water enters Elkhorn Creek: pH 7.1, redox +220 millivolts, 62 °F.
- **Stop 98c**—Elkhorn Creek 100 feet downstream from its junction with the lower adit discharge water: pH 6.8, redox +228 millivolts, 62 °F.
- **Stop 98d**—Elkhorn Creek about 300 feet upstream from the mill site: pH 6.5, redox +176 millivolts, 65 °F.
- **Stop 98e**—Elkhorn Creek near the parking lot and trailhead, downstream from the confluence with the diversion channel: pH 6.6, 58 °F.
- **Stop 95**—Elkhorn Creek where forest road 2465 crosses the creek in the northwest corner of section 2: pH 6.4, 45 °F.
- **Stop 98f**—A small tributary that crosses the trail to Coolidge about 200 yards upvalley from the parking lot and trailhead that drains the east wall of Elkhorn trough: pH 7.3, 58 °F.

These data indicate that the lower adit water (stops 97 and 98b) is 10 times more acidic than Elkhorn Creek water that is unaffected by the adit discharge water (stop 98a). The addition of the adit water lowers the pH of Elkhorn Creek from 7.1 (stop 98a) to 6.8 and 6.5 (stops 98c and 98d) downstream of the junction. The pH values of the adit discharge water are higher than those reported in a previous Montana Bureau of Mines and Geology report. The use of a relatively inexpensive field pH meter on the field samples mentioned above, may account for some—but probably not all—of this difference.

The adit discharge water is more reduced (redox +129 millivolts at stop 97) than that of Elkhorn Creek above the junction with the adit discharge (redox +220 millivolts at stop 98a). The redox potential of the adit water increased from +129 millivolts (stop 97) to +176 millivolts by the time it reached the junction with Elkhorn Creek (stop 98b). This discharge water runs across several hundred feet of wetland before reaching this junction. The wetland appears to influence the redox potential as well as water temperature, which rises from 45 °F at the adit portal to 68 °F by the time it reaches Elkhorn Creek. The adit discharge water does not appear to affect the redox potential of Elkhorn Creek 100 feet downstream from this junction (+228 millivolts at stop 98c), but within another couple hundred feet downstream, the redox drops again to +176 millivolts at stop 98d. The pH drops from 6.8 to 6.5 and the water temperature increases from 62 to 65 °F between these two points of Elkhorn Creek. Perhaps unidentified underground sources between the adit and the mill sites are responsible for these changes in water characteristics.

Appendix B—Elkhorn Mine Riparian Area and Wetland Map Unit Descriptions

The riparian and wetland areas surrounding the Elkhorn Mine site are characterized by various combinations of soils, vegetation, and seasonally high water tables. Five riparian/wetland map units were developed to delineate these moist areas. Additionally, an upland map unit was developed for areas that were not riparian or wetland areas. These six map units are described here. Bodies of surface water large enough to be mapped comprised the seventh map unit. The map unit symbols are appropriate combinations of soil wetness and vegetation types as follows:

First digit of the map symbol:

- **1** represents the wettest soil conditions.
- **2** represents slightly drier soil conditions.
- **3** represents the well- to excessively-well-drained soil conditions of uplands.

Second digit of the map symbol:

- **F** represents forested areas.
- **H** represents areas dominated by shrubs or grasses, sedges, and forbs.
- **U** represents upland areas.
- **W** denotes mappable bodies of surface water.

Map Unit 1F—Forested sites with soils typically saturated within the upper 18 inches throughout most years.

This map unit mainly occurs adjacent to ponds and on floodplains of small perennial streams. It also occurs in sloping areas where groundwater surfaces as seeps and springs and in areas of recent slumps that have not yet developed mature drainage systems. The tree canopy is closed to fairly open and consists of conifers such as Engelmann spruce, subalpine fir, and lodgepole pine. Where the canopy is open, a luxuriant, diverse understory of hydrophytes develops, including species such as bluejoint reedgrass, Holm's Rocky Mountain sedge, and Labrador tea. These are very wet sites and qualify as wetlands under most wetland classification and delineation systems (Cowardin and others 1979; U.S. Army Corps of Engineers 1987; U.S. Fish and Wildlife Service 1989; Brinson 1993; Committee on Characterization of Wetlands 1995; Hansen and others 1995). Soils are hydric, vegetation is hydrophytic, and water tables are at the surface or within a couple of inches of the surface for long enough and frequently enough to affect the surface soil layers and the vegetation types. Evidence of a fluctuating water table occurs within the upper 5 inches of soil in the form of redoximorphic features such as reddish iron masses and low chroma zones of iron depletion.

Less than 10 percent of the areas mapped as this map unit consist of drier soils having seasonally high water tables deeper in the soil profile. The vegetation on these areas reflects the drier soil conditions. Small areas of wet meadows similar to the ecological conditions of map unit 1H are also included in this map unit.

Dominant soils: Typic Cryaquolls, Histic Cryaquepts, and Typic Cryaquepts.

Minor soils: Typic Cryohemists, Histic Cryaquents.

Depth to saturated soil: 0 to 18 inches, season long in normal or wetter years.

Depth to redoximorphic features: 0 to 5 inches.

Dominant soil textures from 0 to 40 inches deep: organic peat and muck 2 to 20 inches thick, overlying mucky silt loam that overlies very cobbly to very gravelly sandy loam derived from glacial till.

Soil parent material: organic deposits and coarse alluvium over glacial till.

Dominant plant associations: Engelmann spruce/Holm's Rocky Mountain sedge (undescribed type), subalpine fir/Labrador tea-bluejoint reedgrass, and Engelmann spruce/bluejoint reedgrass.

Minor plant associations: Engelmann spruce/common horsetail.

Plant species: Highest frequency of occurrence: Engelmann spruce, Holm's Rocky Mountain sedge, Labrador tea.

Moderate frequency of occurrence: subalpine fir, brook saxifrage, arrowleaf groundsel, Jeffrey's shooting-star.

Lowest frequency of occurrence: small-winged sedge, common horsetail, alpine timothy, water sedge, tufted hairgrass, seep-spring arnica.

Species occurring on the drier site inclusions: green false hellebore, western twinflower, western meadowrue, sickletop lousewort, swamp currant.

Map Unit 2F—Forested sites with soils typically seasonally saturated within 2 to 12 inches deep in most years; depth to saturated soil drops to 24 to 40 inches during the latter part of the growing season.

This map unit occurs mainly on somewhat poorly to poorly drained terraces, on low, gently sloping glacial moraines, and on the slopes of moderately steep, colluvial stream headlands. Narrow bands of this riparian/wetland type can also be found at the edges of areas mapped as wetter types, such as map units 1F and 1H. These bands are transition zones between the lowland and upland areas and are too narrow to map at the mapping scale used for this project. The tree canopy of this map unit is mostly closed with some small openings. Tree species include Engelmann spruce, subalpine fir, and lodgepole pine. Many of these areas would qualify as wetlands under the U.S. Fish and Wildlife Service system (Cowardin 1979). Some sites might meet the U.S. Army Corps of Engineers (1987) and the Federal Interagency Committee for Wetland Delineation (U.S. Fish and Wildlife Service and others 1989) definitions of wetlands. Most of these areas would not meet the definitions because the soil is not saturated to the surface frequently enough or long enough to meet the criteria for hydric soils. In addition, the vegetation is marginally hydrophytic to nonhydrophytic, depending on local conditions. Evidence of fluctuating water tables occurs mostly at depths of 2 to 36 inches in the form of redoximorphic features such as reddish iron masses and low chroma zones of iron depletion.

Moderately dry, upland sites and wetter sites that are similar to map units 1F and 1H occupy less than 10 percent of the lands in this map unit.

Dominant soils: Aquic Dystrocryepts and Typic Cryaquolls.

Minor soils: Typic Cryaquepts.

Depth to saturated soil: seasonally high, 2 to 12 inches; seasonally low, 24 to 40 inches.

Depth to redoximorphic features: 2 to 30 inches.

Dominant soil textures from 0 to 40 inches deep: silt loam over silty clay loam or sandy clay loam.

Soil parent material: alluvium, colluvium, and glacial till.

Dominant plant associations: subalpine fir/Labrador tea-Labrador tea.

Minor plant associations: subalpine fir/bluejoint reedgrass-bluejoint reedgrass.

Plant species: Highest frequency of occurrence: Engelmann spruce, subalpine fir, Labrador tea, arrowleaf groundsel, grouse whortleberry, pinegrass, western meadowrue.

Moderate frequency of occurrence: bluejoint reedgrass, heartleaf arnica, *Lupinus* species.

Lowest frequency of occurrence: lodgepole pine, glacier lily, one-sided wintergreen, green false-hellebore, bracted lousewort, Jeffrey's shooting-star, swamp currant, broadleaf arnica, red mountain-heath, whitebark pine (the last two species occur only at the highest elevations in this map unit, generally above 8,400 feet).

Species occurring on the hydric soil inclusions are: common camas, tufted hairgrass, Holm's Rocky Mountain sedge, and small-winged sedge.

Map Unit 1H—Graminoid- and forb-dominated wet meadows with soils typically permanently saturated to the surface.

This map unit is a major component of the large meadows that occur to the southwest, west, and northwest of the Elkhorn Mine site. It occurs in the wettest portions of these grassy parks. It also occurs on low floodplains of small perennial streams and in alluvial basins adjacent to or near ponds. These soils formed in relatively fine-textured alluvium and colluvium. This fine soil material is found in slowly to very slowly permeable layers that tend to perch water tables (hold at unusually high levels). A weak artesian system was observed at one location. These areas lack tree canopies. However, a few widely scattered, stunted Engelmann spruce, lodgepole pine, and subalpine fir trees can be found growing on small, raised hummocks. At some sites there is a shrub canopy of wolf willow. Other sites lack this willow component and are dominated chiefly by sedges, grasses, and forbs that have an affinity for very wet soils. Essentially all of these areas would qualify as wetlands using any of the commonly used wetland classification or delineation systems. Soils are hydric and the vegetation is hydrophytic. Wetland hydrology is prevalent throughout the map unit with soil saturated to the surface or surface water ponding, at least seasonally. Most areas within the map unit are saturated to the surface yearlong. The soils often have a 5- to 12-inch-thick layer of peat and muck at the surface. Some soils have peat and muck deeper than 40 inches and are classified as organic soils (Histosols). This accumulation of organic plant matter is caused by conditions of prolonged and frequent saturation to the soil surface. These organic materials serve as sponges, storing many times their own weight of water.

Small areas of wet forest are included in this unit. These areas have ecological conditions similar to those discussed in map unit 1F. Also included in the large parks are areas similar to map unit 2H. These occur on portions of map unit 1H that are slightly higher than the very poorly drained main part of the unit. These grassy inclusions are seasonally saturated to the surface, but the depth to saturation drops 6 to 12 inches during the latter part of the growing season.

Dominant soils: Histic Cryaquolls, Typic Cryaquolls, Cryohemists, Cryofibrists.

Minor soils: Aquic Haplocryolls, Typic Cryaquents.

Depth to saturated soil: normally saturated to the surface yearlong, some local ponding.

Depth to redoximorphic features: 0 inches.

Dominant soil textures from 0 to 40 inches deep: peat and muck over mucky silt loam to silty clay loam over sandy loam or sandy clay loam.

Soil parent material: organic deposits over alluvium or colluvium.

Dominant plant associations: water sedge, Holm's Rocky Mountain sedge, and wolf willow/water sedge.

Minor plant associations: tufted hairgrass, beaked sedge, Drummond willow/beaked sedge.

Plant species: Highest frequency of occurrence: water sedge, tufted hairgrass, and beaked sedge.

Moderate frequency of occurrence: Holm's Rocky Mountain sedge, wolf willow, elephanthead.

Lowest frequency of occurrence: bluejoint reedgrass, small-winged sedge, Oregon saxifrage, seep-spring arnica, sweet-marsh butterweed, showy fleabane, Drummond willow.

Species growing on slightly raised hummocks include Engelmann spruce, subalpine fir, and lodgepole pine. The spruce and fir trees also occur as inclusions of wet, forested sites in the map unit. The slightly drier grassy meadow inclusions are dominantly tufted hairgrass communities having reduced sedge components. Inclusions comprise less than 10 percent of this map unit.

Map Unit 2H—Graminoid- and forb-dominated plant communities growing on soils seasonally saturated to the surface; depth to saturated soil drops to 20 to 35 inches during the latter part of the growing season.

This map unit occupies major portions of the large meadows that occur to the southwest, west, and northwest of the Elkhorn Mine site. It encompasses the somewhat poorly drained to poorly drained soils of these meadows. These soils typically occur upslope from areas of the parks mapped as the wetter map unit 1H and downslope from the dry upland forested areas mapped as 3U. It is rare to find this map unit in settings other than these large, grassy parks. The soils formed in relatively fine-textured alluvium and colluvium. This fine soil material is found in slowly to very slowly permeable layers that can perch water tables. Glacial till probably underlies some areas of this alluvium. Low moraines formed basins into which the alluvium was deposited. The soils have humus mixed with the mineral soil material in the upper foot or so of the profile, reflecting abundant fine root production of graminoids and forbs along with adequate soil moisture. In most years, the depth to saturated soil is about 0 to 8 inches during the wettest periods of the year, dropping to 20 to 35 inches during the dry periods of July, August, and September. Evidence of fluctuating water tables exists in the upper 3 inches of the soil profile as redoximorphic features such as reddish iron masses and low chroma iron depletions. Except for small areas of forested land included in this unit, it has graminoid- and forb-dominated plant communities. The plant species characteristic of this map unit have a moderate affinity for saturated soils; they are fairly tolerant of soils that are seasonally saturated to the surface. Many of these species would not tolerate soils permanently saturated to the surface. Most areas within this map unit would meet the definition of wetlands in most commonly used classification and delineation systems. Soils are hydric, vegetation is hydrophytic, and the soil is saturated to the surface frequently enough and long enough to meet wetland hydrology criteria.

Forested areas with somewhat poorly drained soils are included in this mapping unit. These areas also have seasonally high water tables, but the depth to saturated soils is greater than for the grassy portions of the unit. Small areas that are wetter than the characteristic grass/forb sites occur in slight depressions and on floodplains of small streams that traverse the map unit. These sites are ecologically similar to those of map unit 1H.

Dominant soils: Aquic Argicryolls and Cumulic Cryaquolls.

Minor soils: Typic Cryaquolls and Aquic Haplocryolls.

Depth to saturated soil: seasonally high depths of 0 to 3 inches, dropping to seasonally low depths of 20 to 35 inches.

Depth to redoximorphic features: 0 to 3 inches.

Dominant soil textures from 0 to 40 inches deep: silt loam to bouldery silt loam overlying sandy clay loam or bouldery sandy clay loam.

Soil parent material: alluvium and colluvium over glacial till.

Dominant plant associations: tufted hairgrass.

Minor plant associations: beaked sedge and subalpine fir/bluejoint reedgrass-bluejoint reedgrass occurring as inclusions.

Plant species: highest frequency of occurrence: tufted hairgrass, American bistort, small-winged sedge, alpine timothy.

Moderate frequency of occurrence: lodgepole pine in areas of inclusions.

Lowest frequency of occurrence: common camas, little larkspur, arrowleaf groundsel, showy fleabane.

Map Unit 1FH—Lands including wet forested areas and wet shrub/graminoid/forb areas.

This map unit occurs mainly on floodplains along moderately wide drainageways (typically 100 to 300 feet wide) and in local areas of low glacial moraines dotted with kettle depressions. The wet, forested areas within this unit resemble those in map unit 1F, but minor differences in vegetation were observed. Similarly, the wet shrub/graminoid/forb areas resemble those in map unit 1H, with minor variations in vegetation. The two types are intermixed in complex patterns at a scale too small to delineate separately at the mapping scale used. The soils are similar to those of map units 1F and 1H. The soils of the wet forested areas have organic surface horizons up to 6 inches thick overlying silty alluvium. The substratum is loamy sand. The soils of the wet shrub/graminoid/forb areas have organic surfaces up to 17 inches thick that overlie silty and clayey alluvium. The temporal patterns and duration of soil saturation are also similar to 1F and 1H. In the wet forested sites, evidence of a fluctuating water table occurs within the upper 4 inches of soil in the form of redoximorphic features such as reddish iron masses and low chroma zones of iron depletion. Soils of the wet nonforested areas are saturated to the surface yearlong in most years. Both components qualify as wetlands in commonly used wetland classification and delineation systems.

Less than 5 percent of this map unit has inclusions of areas with soils that have slightly greater depths to seasonal soil saturation; these small areas are similar to those mapped as map units 2F and 2H elsewhere.

Dominant soils: Typic Cryaquolls and Typic Cryaquepts.

Minor soils: Histic Cryaquepts.

Depth to saturated soil: 4 to 20 inches seasonlong in normal or wetter years.

Depth to redoximorphic features: 0 to 4 inches.

Dominant soil textures from 0 to 40 inches deep: organic peat and muck 3 to 6 inches thick, overlying silt loam, which overlies loamy sand.

Soil parent material: organic deposits and coarse to moderately fine-textured alluvium.

Dominant plant associations: subalpine fir/bluejoint reedgrass-bluejoint reedgrass.

Minor plant associations: Engelmann spruce/Holm's Rocky Mountain sedge (undescribed type), subalpine fir/Holm's Rocky Mountain sedge (undescribed type).

Plant species, highest frequency of occurrence: Engelmann spruce, Holm's Rocky Mountain sedge, bluejoint reedgrass.

Moderate frequency of occurrence: subalpine fir.

Lowest frequency of occurrence: Labrador tea, willow.

Map Unit 3U—Forested and nonforested upland areas having no evidence of soil saturation within 40 inches of the soil surface.

This map unit occupies all areas of the riparian/wetland assessment area that were not mapped as units 1F, 2F, 1H, 2H, 1FH, or W. It includes areas with soil cover and nonsoil, miscellaneous areas of rock outcrop, and talus/scree. Both in the field and on color aerial photos, these areas show no evidence of riparian/wetland vegetation or soil conditions. The exceptions are areas that are too small to delineate at the mapping scale used. The soils of these upland forests and meadows are well drained to excessively drained Typic Dystrocryepts, Andic Dystrocryepts, and Lithic Dystrocryepts that formed mainly in colluvium and glacial till. The vegetation mostly consists of forests of lodgepole pine, Douglas-fir, subalpine fir, and whitebark pine. The understory consists of plant species indicative of upland soil conditions and includes grouse whortleberry, heartleaf arnica, pinegrass, and elk sedge. The dominant plant associations are subalpine fir/grouse whortleberry-pinegrass and subalpine fir-whitebark pine/grouse whortleberry.

Information about soil depths below 40 inches is not available. Water tables and saturated soils may occur below this depth, but they could not be ascertained from the soil profiles, vegetation, or aerial photos.

Map Unit W—Bodies of water large enough to delineate at the mapping scale used, including lakes and glacial ponds.

—References cited for the appendixes are included in the References *section.*

About the Authors

Phyllis Hargrave has a bachelor's degree in geology from St. Lawrence University and a master's degree from the Montana College of Mineral Science and Technology. She worked as a geologist in the mineral exploration industry for 15 years before joining the Montana Bureau of Mines and Geology in 1994. She works primarily for the Bureau's abandoned and inactive mines program.

John J. Metesh is an associate research hydrogeologist and associate professor for the Montana Bureau of Mines and Geology at the Montana Tech of the University of Montana. He received a bachelor's degree in geology from Montana State University and a master's degree in geological engineering (hydrogeology) from the Montana College of Mineral Science and Technology. He is certified as a professional geologist by the State of Wisconsin.

Ken McBride graduated from the University of Wisconsin with a degree in botany. Graduate studies in soil science led to a position conducting soil surveys in southern Colorado for the Natural Resources Conservation Service (then known as the Soil Conservation Service). Three years later he transferred to the Rio Grande National Forest, where he continued soil mapping. In 1988 he became a soil surveyor for the Bitterroot National Forest in Montana. He has been the forest's soil scientist since 1990.

Steve Oravetz graduated from the University of Washington in civil engineering and is a licensed professional civil engineer. He began his career on the Wenatchee National Forest in 1980. While there, he worked on timber sale roads and was involved with many recreation facility projects. He became chief engineer for the Northeastern Research Station in 1993. Steve became engineering program leader at MTDC in the spring of 1996. In 2001 he became the facilities management group leader for the Northern Region.

Library Card

Hargrave, Phyllis; Metesh, John J.; McBride, Ken; Oravetz, Steve. 2003. Investigative methods for controlling groundwater flow to underground mine workings. Tech. Rep. 0371–2801–MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 42 p.

Controlling groundwater recharge to mine workings requires identifying, characterizing, and controlling surface water and groundwater that may infiltrate mine workings. This document's premise is that good-quality surface water and groundwater can be diverted from the workings to prevent the water from interacting with pyrite and other metal-bearing minerals that cause acid mine drainage. Infiltration controls may include grouting from outside the workings, streambed or soil treatment to reduce infiltration capacity, storm water and runoff management, and recontouring or regrading the natural recharge areas. Although this paper describes methods for collecting data for controlling groundwater recharge to the mine workings, many of the data collection methods could be applied when investigating other treatments, such as adit plugging, grouting or capture, and treatment and disposal of acid mine drainage. This is the fourth report on acid mine drainage produced through a partnership between the Montana Bureau of Mines and Geology and the Missoula Technology and Development Center. The other reports are:

- Adit Discharge Monitoring Summary for the Elkhorn and Charter Oak Mines, MT (0071–2858–MTDC)
- Using Recharge Control to Reduce Mine Adit Discharges: A Preliminary Investigation (0071–2804–MTDC)
- Treating Acid Mine Drainage From Abandoned Mines in Remote Areas (9871–2821–MTDC)

Keywords: acid mine drainage, ground water, groundwater, mined land, recharge control, remediation, water quality

---

Additional single copies of this document may be ordered from:
USDA Forest Service, MTDC
5785 Hwy. 10 West
Missoula, MT 59808–9361
Phone: 406–329–3978
Fax: 406–329–3719
E-mail: *wo_mtdc_pubs@fs.fed.us*

For further technical information, contact Charlie Showers at MTDC.
Phone: 406–329–3945
Fax: 406–329–3719
E-mail: *cshowers@fs.fed.us*

Electronic copies of MTDC's documents are available on the Internet at:
http://www.fs.fed.us/eng/t-d.php?link=pubs