A Manual for Training Reclamation Inspectors in the Fundamentals of Hydrology

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Contents

Foreword

This handbook is intended to be a desk reference to help nonhydrologists achieve a basic understanding of hydrology as it relates to surface mining and reclamation. Surface coal mining and reclamation inspectors and other staff will find it useful in implementing regulatory programs. The handbook is not meant to be a comprehensive treatment of the subject. The handbook can be used in the training of surface mining and reclamation inspectors, both Federal and State, and as a basic reference for inspectors in carrying out their assigned duties. The handbook describes clues and indicators of potential problems, suggests ways to prevent or mitigate them, and discusses various observation and sampling techniques.

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Permit Application Information

Each permit approved under a permanent program for surface coal mining and reclamation is issued based upon the review of information submitted by the applicant in the Permit Application Package. The Permit Application Package contains a comprehensive review of groundwater and surface water resources, including extensive baseline data, for the proposed mining site and adjacent areas. This information is used by the applicant to estimate the probable hydrologic consequences (PHC) of the proposed mining. If the probable hydrologic consequences are adverse, the applicant sets forth a plan to prevent or minimize disturbance to the hydrologic balance. That plan includes a proposed monitoring scheme to verify its effects.

The regulatory authority uses the applicant's PHCs and other information to make a cumulative hydrologic impact assessment (CHIA) which is used as a "yardstick" in the permit approval process to determine whether the proposed operation has been designed to prevent material damage to the hydrologic balance beyond the permit area. It may be necessary to update CHIAs as additional data are gathered or when permit applications undergo extensive revision.

Before making an initial inspection, the reclamation inspector should review the Permit Application Package; the permit, which may contain specific stipulations, and the CHIA to become familiar with:

- the general topography of the mine plan area and its relationship to the proposed method of operation and any previous mining;
- the location of surface waters within and adjacent to the permit site and potential users of surface water and groundwater resources;
- the location of identifiable mining-related hydrologic contact points such as sediment ponds, stream buffer zones, diversions, monitoring wells, and point-source discharges from the permit area;
- the geologic description of lands within and adjacent to the permit area and the expected relationship of that geology to surface and subsurface flow patterns before and after disturbance;
- the analysis of coal and overburden, especially the identification of acid- or toxic-forming materials that may be disturbed or activated during mining;
- the character and population of aquatic biota,—fish, plant, or other biological resources—that may be affected by disruptions in flow or changes in water quality caused by mining;
- the water parameters on the permit site before mining, as well as the baseline information for adjacent groundwater or surface water resources;
- the areas or locations authorized for point source discharge and any conditions upon such discharges which are delineated in the approved Permit Application Package;
- the monitoring and reporting requirements specified;
- the identity of special hydrologic features, functions, or requirements stated in or conditioned by the Permit Application Package and the permit; and
- the soil types within the Permit Application Package area and their susceptibility to erosion and transport.

For an initial inspection where mining will be underground, the inspector should consider:

- type of mining;
- possibilities of surface water and groundwater depletion; and
- long-term problems such as subsidence.

During review of the Permit Application Package, the inspector should pay close attention to any baseline data that indicate abnormal conditions or fluctuations and note any such abnormalities that might need verification under field conditions. Where modeling techniques or adjacent area studies are referenced, the inspector may need to compare actual site conditions to the hypothetical projections presented in the application.

During review of the PHC, frequent cross-checking within the Permit Application Package may be necessary. Review the proposed mining procedures, such as handling of overburden and burial of acid or toxic waste for their likely impact upon the hydrology. The CHIA, if available, can be a useful reference because it may help identify possible errors in the PHC or discrepancies in the impact area described in the Permit Application Package.

While conducting the Permit Application Package review, the inspector should make brief notes for later field reference and report writing. Such notes might include:

- typical effluent quality of the receiving streams and the identity of parameters measurable in the field;
- average seasonal rainfall and dimensions of commonly referenced events, such as 10 year, 24 hour, or probable maximum precipitation event;
- discharge parameters at key monitoring points if different from routine performance standards;
- characteristics of major affected soil types such as erodibility, particle suspension, and coloration;
- typical habitat and organisms in receiving streams;
- types of streams in and near the mining area;
- the identity of any users of those groundwaters and surface waters that might be affected by operations;
- the names, dimensions, and general quality of the coal seam(s) to be mined, including any potentially adverse characteristics such as acidity, iron, or manganese;
- general direction of identifiable subsurface flow and the names of important aquifers;
- location and depth of any monitoring wells and the identity of parameters to be measured as shown or listed in the Permit Application Package;
- types of vegetation and soil-stabilizing practices required; and
- for underground mining, the nature, extent, and projected mining impacts.

Whenever possible, some field inspections should be conducted during or immediately after adverse weather conditions. Inspection during periods of system stress allows better evaluation of both Permit Application Package proposals and the likely effectiveness of their application. Hydrologic protection measures should be designed to accommodate problems that arise under extreme conditions and should be judged accordingly.

Field evaluation of mining operations often requires travel in areas not easily accessible by vehicle. The necessary documentation and sampling equipment should have minimum encumbrance and weight.

Except where the inspector is extremely familiar with a permit, drainage or hydrology maps and notes accumulated during the Permit Application Package study should always be on hand during a field review. To avoid overlooking areas or items which may have problems, make a brief list of specific areas or facilities to be checked. A more detailed version might include a point-to-point itinerary and a list of items to be inspected at each location along the route.

Use facts and insight gained through review of the Permit Application Package and prior inspections to identify specific areas, items, facilities, etc. to be inspected and to choose the equipment needed to make the necessary measurements and take the necessary samples. Some nearly indispensable items are:

- a camera with extra film;
- "quick check" water quality indicators, such as a Hach Kit;
- several clean, prenumbered sample bottles;
- nitric acid;
- 0.45 micron filters;
- a device for measuring water level in wells;
- a 6- to 12-foot retractable tape measure; and
- a note pad.

These items may be managed easily in a knapsack. By using them correctly an inspector can adequately identify and document most water violations common to mining.

Hydrologic Aspects of the Permit Application Package

Nearly every step of the mining/reclamation process, and every structure designed and built to serve the permit site, may be viewed as a technique for the control of drainage and erosion. Preparing mining and reclamation plans and maps, designating the sequence of operations, designing structures, and selecting methods and processes by which the overburden and spoils are to be removed, handled, and placed are all aimed toward controlling water.

Specific inspection duties of the reclamation inspector may vary with circumstances and time of involvement. Some inspectors become involved during permit application review, and may be required to verify in the field the various statements, conditions, and site situations described in the Permit Application Package. For others, duties begin only after the Permit Application Package has been approved. Still others exercise what is primarily an oversight role; their duties involve periodic inspection of mining and reclamation operations.

Regardless of an inspector's specific duties, their scope, or when during the permitting and inspection process they begin, it is important that inspectors understand and be able to interpret the various permit documents in light of the requirements, and understand the assumptions and principles upon which the spoil handling methods, construction techniques, and reclamation practices have been selected.

Equally important in the day-to-day performance of an inspector's duties is the ability to recognize in the field any conditions that support or contradict these assumptions and any clues to inappropriate mining, construction, and reclamation practices.

Field-checking the Permit Application Package

The Permit Application Package identifies measures that are approved for use on a given site. The major questions are: (1) Are the proposed control measures appropriate for the site conditions and mining practices described in the Permit Application Package? (2) Are the site conditions, as they are presented in these documents, verifiable in the field? (3) Are they supported by the inspector's independent observations made on the site? and (4) Do the measures and practices set forth in the Permit Application Package, with any requested variances, meet requirements?

Answers to these questions can be found from evaluations such as the three given here. This is not intended to be a complete list. Any specific case may involve any or all of the listed items—plus others.

Evaluation of the Completeness and Applicability of the Mining and Reclamation Plan with Respect to Hydrology

I. Investigation pertinent to the particular permit area.
   A. Study maps of geology, hydrology, and topography along with other permit documents to see if the plan is complete and meets regulatory requirements. Pertinent items may include:
      1. general strike and dip of strata;
      2. variations in strike and dip in and near the permit area;
      3. slope of land surface;
      4. location of natural surface drainage courses;
      5. location of previous man-made alterations to the natural surface and drainage patterns as caused by roads, such as logging roads, skid trails; previous mining, as evidenced by spoil piles, deep mine adits, auger holes, subsidence; irrigation facilities, such as ditches and pipes;
      6. surface water and groundwater monitoring programs should address sampling site locations, sampling methods, sampling schedules, sample preservation and chain of possession, testing methods, and names and qualifications of testing lab personnel; and
      7. determine whether an aquifer exists and if so, verify:
         a. description of physical characteristics of matrix materials
         b. description of hydrologic characteristics of the aquifer(s). Some items of interest are:
            (1) Is the potential yield to wells of consequence?
            (2) Is it of a pressurized (artesian) or unpressurized (free water table) type?
            (3) Seasonal flow and stage characteristics
            (4) Chemistry of the water.
         c. What are the geographic limits of the aquifer? For example: Is the aquifer entirely within the permit area or does part of it extend beyond that area?

d. Current use of water from the aquifer(s) within the permit area and nearby as deduced from:
   (1) Water rights records
   (2) Well yield and water quality records and measurements etc.

B. Investigate geology, hydrology, and topography to verify information presented in the permit documents and determine whether the plan reflects site conditions.

1. Locate and map springs, seeps, wells, and water holes. Clues to these would be:
   a. Outcrops on down dips
   b. Axes of geologic synclines
   c. Sources of domestic water at existing or abandoned house sites
   d. Animal trails
   e. Local residents and property owners
   f. Records from other mining operations in the area
   g. Court records concerning water rights
   h. Pipelines, irrigation facilities, roads, etc.
   i. Patches of vegetation typical of marshy areas or indicative of groundwater tapped by deep roots
   j. Sudden changes in stream discharge that cannot be explained by surface or meteorological phenomena.
2. Determine whether descriptions of flow stage, duration, and water quality are sufficient and correct as given in the permit.
3. Look for possible interaction between elements of the subsurface hydrologic regime and structures proposed for control of surface drainage and sediments. Things to look for are:
   a. Position, location, and elevation of structures with respect to the water table, aquifers, and watershed boundary;
      (1) Does the structure promote or inhibit exchange between surface and subsurface flow regimes? Look for conditions that have the potential to allow:
         (a) Subsurface shortcuts under or around impoundments
         (b) Subsurface contributions into impoundments.
      (2) Does the structure promote or inhibit containment of impacts within the permit area? Drainage could cross watershed boundaries by:
         (a) Exceeding the design capacity of proposed control structures, or
         (b) Leaving the permit area without passing through a control structure.
   b. Subsurface flows that exit beyond control devices may be indicated by:
      (1) A dip of an aquifer within the area affected by mining, which outcrops within the watershed but below the treatment and control structures, or
      (2) A dip of an aquifer affected by mining that outcrops in adjacent areas or continues laterally to unmonitored areas beyond the control structures.

   NOTE: If either condition exists, then the layout of the monitoring well system may need to be changed.
4. Look for unreported, unmapped mine adits, auger holes, or subsidence. These may be indicated by:
   a. Direction, quantity, and quality of observed flows
   b. Absence of active flow (where the stream flows into a mine)
   c. Topographic expressions on the surface that indicate collapse of subsurface structures; i.e., sink-hole-like depressions in a geometric pattern
   d. Past active flows may be indicated by:
      (1) Erosion rills and gullies; land surface discoloration typical of overland flow
      (2) Atypical appearance of vegetation or lack of vegetation
      (3) Standing water within adit entrances or abandoned pits or along an existing highwall.

The above list is by no means complete. It is offered as a guide to aid in identifying likely omissions, discrepancies, or errors in mining and reclamation plans and permit applications.

II. Evaluation of Operation Sequence

A. As it is presented in the Permit Application Package:
   1. Does the operation sequence call for drainage and sediment control structures and water treatment facilities to be installed before mining commences?
   2. Are construction access routes to structure locations adequately described and do the described routes appear reasonable and within guidelines?
   3. Are spoil disposal areas identified by location, size, and position within the operation sequence and by their intended land use after mining?
   4. Are topsoil handling procedures addressed, with particular attention to removal, storage, and redistribution methods?

B. Does the Permit Application Package describe how criteria for "minimization of unreclaimed surface area" are to be satisfied?
   1. Is the beginning point of mining operation identified?
   2. Are zones of concurrent disturbance identified? Is the area of each zone correctly measured? Are the material characteristics and placement practices applicable to the design life of the drainage and sediment control structures?
   3. Are anticipated needs for temporary vegetative cover identified and are species, planting densities, and methods of application described?

C. Does the Permit Application Package address the maintenance and cleaning of sediment control structures?
   1. Are criteria given to identify when cleaning and maintenance are necessary?
   2. Do the maintenance schedules presented conflict with other operations?

D. Do Permit Application Package documents identify those stages of the proposed mining and reclamation operations when specific effects upon the water regime (both surface and subsurface) will become evident?

III. Evaluation of structure design and construction practice

A. Structure design (runoff detention and sediment catchment structures, culverts, flumes, contour trenches, diversion channels, etc.)

Here the primary concern is to develop an accurate assessment of how well the proposed structure is suited to the size and nature of the task it is expected to accomplish, and whether it will perform its task under the various conditions to which it will likely be subjected during its design life. Note that the three major components in that assessment — design life, conditions under which construction and performance will likely occur, and the nature and size of the anticipated task — interact markedly. They can, however, be evaluated independently.

Documents in the Permit Application Package that present the planned sequence of operations and describe their duration provide data upon which to judge the design life required for each structure. These documents will usually allow one to determine whether a given structure should be classed as temporary or permanent. Its class can then be related to questions of structure capacity.

Maps included in the Permit Application Package show the structures in relation to various site attributes. Documentation in the Permit Application Package addresses critical flow stages and tests of water samples. These documents may include a detailed geologic map of the area, maps and documents describing the soils, vegetation, hydrology, and area precipitation records, and a stratigraphic column. Maps delineating the horizontal and elevational limits of the total area contributing flow and the zone to be disturbed within that area are pertinent, as are maps and descriptions of pre- and post-mining topography and land use.

Demands that will be placed upon a structure depend primarily on the size and shape of the area contributing drainage to the structure, the storm patterns in the area, the effective topographic slope, vegetative cover, and the water storage capacity of soils within the contributing zone. Vegetative cover and soil water storage will be influenced by mining and this influence should be evaluated. Likewise, the size and topography of the area contributing surface drainage waters are sometimes modified during the mining process. If this will be so, then the extent and timing of those and related modifications must be investigated. The key here is to focus upon the "worst case" condition and the likelihood of its occurrence, and compare the findings with the design information presented in the Permit Application Package and the requirements of that permit.

It is important that foundations of drainage control structures be strong enough to withstand forces that might be caused by a local high water table, subsidence, or other conditions peculiar to the site. Selection of proper materials for the flow transmission components of the facility, such as spillway pipes and dewatering devices, provisions for a clay core, and a keyed foundation are important. These items are directly related to the acidity of inflow and outflow and to the flow transmission rates of those geologic strata within the construction site. Acidity of inflow and outflow over the life of a particular structure will be influenced by the mineralogy of any overburden disturbed by the mining. However, appropriate spoil handling and placement techniques may be used to isolate the acid-producing materials or to slow their reaction rate. The keys here are to ascertain whether subsurface flows are likely to have volumetric importance at the site and hence upon the appropriate design capacity of the structure or the size of flow transmission components; and whether the flow can be expected to develop undesirable chemical attributes.

Structure designs may be evaluated in two different contexts. The first encompasses the form and continuity of flow models, support data, and assumptions used to develop the design presented in the Permit Application Package. Evaluation within the second context consists of determining whether the model, data, and assumptions used in the design correctly and completely represent the attributes that actually exist in the field. In other words, how good are the models?

B. Construction Practices

During the actual construction of structures to control water flow, erosion, and sediment on surface mine operations, an inspector is concerned with the validity of the structure's design. At this stage one can actually perform observations and tests that were not possible before construction began. If both phases—office and field—of the permit approval process have been carefully executed, few errors in design will be found during construction, but it does occur.

Before a construction site is cleared and excavated, the data presented in the Permit Application Package may have been only an educated guess. Only after excavation will the actual condition be known. The key here is to determine whether the actual condition differs significantly from that presented in the approved Permit Application Package, or if some particular crucial element has been overlooked or misrepresented in the approved design.

The primary concern during construction is to be sure that the materials and practices employed in each phase of construction are capable of producing a finished product that will meet the appropriate strength and performance criteria.

It is important that the inspector know the characteristics of the materials being used, appropriate construction practices for those materials, and appropriate equipment for those practices. The inspector must be on the site during critical periods of construction. To do that, the inspector must be aware of the sequence and timing of operations.

When the Permit Application Package calls for construction of an impervious clay core for a dike or dam, or a clay wall to isolate toxic spoil, the clay will not likely perform its task if it is not of the proper type and purity, is used in scant quantity, or is in the wrong position.

When compaction is specified at 95% Proctor, the use of uncalibrated materials, or of calibrated materials that are excessively moist or dry, is unlikely to yield a finished product that meets the stated requirements. Likewise, to bed an uncoated metal pipe, a concrete culvert, or a metal culvert in pyritic materials or where acid water is likely to be encountered is unwise and, in many situations, unacceptable.

To produce a finished structure of the proper strength and performance requires that appropriate equipment be used in the proper manner. Compaction equipment should be matched by both type and weight to the materials receiving the compactive effect. Sheepsfoot rollers are for cohesive materials—the clay core of a dam—but rubber-tired rollers are for sandy, noncohesive materials such as might be used in the outer portions of the dam embankment.

Five passes with a 4-ton roller will not necessarily produce the same compaction as one pass with a 20-ton roller, and vice-versa. Layer placement and compaction does not mean to place all the layers and then compact, but to apply compactive effort *uniformly* over the *entire* surface of *each* individual layer after it is placed.

And "walking-in" culvert bedding and cover materials with dozer tracks does not accomplish the same consistent compaction as compacting thin layers with a hand-guided mechanical tamper. To allow installation of any pipe or culvert that has anti-seep collars without using a mechanical tamper to achieve proper compaction is asking for trouble.

The key points in construction are that the materials be of the proper kind, that they be correctly positioned, that the equipment be matched by size and type to the material, and that the equipment be used in an appropriate manner, to a sufficient extent, and at the proper time during each stage of construction. These points apply whether the structure is a diversion ditch, an embankment to detain runoff or trap sediment, a haul road, or a massive head-of-hollow or valley fill.

On-Site Indicators of Hydrologic Problems

The following indicate conditions with a potential to adversely affect local surface and groundwater:

- Spoil and geologic debris placed where surface drainage may exit beyond control structures. Examples are: clearing the mine site or removing overburden before installing drainage controls, and development roads or clearing operations that extend beyond contour trenches currently in place.
- Encroachment by spoil or geologic debris—whether deliberately placed, or the result of slope failure—upon Permit Application Package-designated zones of nondisturbance parallel to stream courses.
  - Mass slope movements on reclaimed surfaces indicate the slope is too steep. The development of tension cracks indicates movement has occurred and that additional movement is likely.
  - Rill development on finish-graded surfaces. Channels or gullies at the midpoint or toe of slopes and deposits of eroded materials whether on the graded surface or at the toes of slopes.
  - Deposits of eroded material at locations or in volumes that may disrupt planned drainage patterns and defeat control structures. Excess deposits may block road culverts, fill diversion ditches, overload contour trenches and sediment catchment structures, and fan out on "flat" portions of the reconstructed topography to cover newly seeded areas.
  - Evidence that waters are moving from subsurface to surface flow conditions. Some indicators are active seeps and a marshy, spongy surface, or marsh grass on finished slopes. Slumps and hummocky terrain on slopes indicate that the waters have already contributed to mass failure.
  - Evidence that improper methods or materials, or both, were used in construction of durable rock fills. Some indicators are trucks being loaded with, hauling, or dumping materials that are too small or are not durable —shales, claystones, or finely stratified material of any rock type, and the lack of increasing particle size from top to bottom in the constructed face.
  - Improper construction sequence, such as mine site clearing before construction of drainage and sediment control structures, or drilling and blasting before removal and disposition of topsoil.
  - Drainage or sediment control structures not located or not sized in accord with Permit Application Package.
  - Improper provision for, or improper handling of active drainage. Some indicators are: improper direction of flow or standing water in ditch lines, equipment for pit drainage at locations where drainage is not allowable, evidence of concentrated overland flows—rills, gullies, alluvial deposits—but no evidence of the flow source.
  - Evidence of flow into or out of underground working or auger holes, or conditions that could allow such flow at locations or times not approved in the

Permit Application Package. Indicators are: active flow, patterns upon the soil made by prior flows, and the lack of physical barriers (i.e., dams or seals) where they are called for by the approved Permit Application Package.

The company's records of water sampling and testing may show unusual similarities or differences in test results—results that would not be expected because of the time, the concurrent conditions of the contributing drainage surfaces, or concurrent test results from other locations. Some examples are:

- An unlikely relationship between flow stage, water chemistry, suspended solids, and precipitation may, in the absence of unusual climatic or mining events, indicate errors in discharge measurement, sample collection, or analysis. On most watersheds, these parameters follow a fairly consistent annual cycle. Normally floods and high water stages are associated with increases in suspended solids and, because of dilution, decreases in dissolved constituents. Runoff from frozen ground surfaces, flushouts of acid following a drought, or a change in the mix or sources of waters being sampled can produce an extreme change in water quality without there having been an error in sampling or analysis. Normally suspended solids and turbidity increase and decrease together. Measurable alkalinity cannot exist in water with a pH less than 4.6 and if such is reported, one value must be wrong.
- Water quality values outside the limits permitted by the approved Permit Application Package.
- A series of samples with nearly identical chemical characteristics. This could occur because the samples were (1) collected at the same place and same time but assigned different dates, or (2) improperly analyzed in the lab; however, they could be perfectly in order. The inspector may need to take independent samples more frequently until convinced that the operator is demonstrating compliance with the permit.
- Indications of improper or inadequate sampling methodologies, such as soiled sample containers, containers made of products other than glass or plastic, absence of preservatives when such are required, or use of a pH probe in laboratory samples in a manner that may add electrolyte to the sample.
- Discovery of a cache of accumulated samples may indicate that samples were not being promptly submitted for analysis.

Detecting violations or potential problems is an essential function of field inspection and requires continual skill refinement. Because mining areas and operations are so diverse, the inspector will need to consider site-specific conditions and concerns on which to focus field review. Some of the following observation techniques may prove helpful in detecting problems regarding the surface water and groundwater aspects of the permit.

The inspector should look for evidence of water movement at locations where no movement—flow, seepage, etc.—is to be expected:

- On outslope faces of dams or sediment control structures, look for:
  - Active flow—surface or seepage
  - Rills or erosion patterns whose upper ends begin at an elevation at or below the elevation of impounded water
  - Toxic streaks—slick zones or zones barren of vegetation
  - Dispersion streaks—deposits of ultra fine-grained sediment
  - Marsh or wetland plants such as sedges, horsetail, rushes, cattails
  - Mass slope movement—hummocky terrain
  - Water flow in the channel immediately below a structure when there is no flow through the spillway
- In principal or secondary spillways, as specified on the plans, look for:
  - Outflow at other than spillway locations
  - Seepage around pipe or culvert spillways
  - Progressive removal of culvert backfill materials at the outlet end
  - Deterioration of riprap-paved structures in the form of
    - Displacement of individual stones
    - Disaggregation of the stones themselves
    - Erosion of channel bottoms and sides—usually first noticed at locations at or near the downstream extremity
  - Conditions indicative of spillway entrance malfunction, for example:
    - Trash accumulations or brush racks clogged with debris
    - Erosion patterns indicating flows at other than spillway locations
    - Insufficient freeboard
  - Evidence of structure settlement or consolidation, such as:
    - Inconsistent flowline gradient
    - Vertical or lateral shift in portions of spillway — nonalignment of flow structure
  - Flow path (route) located in or upon fill material that might:
    - Be conducive to excessive erosion
    - Allow extensive infiltration where it may not be desirable or environmentally sound
    - Promote slope saturation and mass failure
- On ditches and surface flow control and routing structures be alert for:
  - Debris deposits in the channel resulting from:
    - Cut bank failure and slippage
    - Improper or incomplete road maintenance
    - Sediment and alluvium deposits in culvert inlet basins and culverts resulting from:
      - Angle between ditch and culvert flow lines being less than 90 degrees
      - Ditch gradient being too slight
      - Culvert gradient being less than ditch gradient
    - Collapse, consolidation, or compaction under traffic of fills associated with culverts
  - Surface flow escape from ditches through or across berms or structure embankments
    - Erosion down the roadway wheel tracks—particularly in the track nearest the roadside ditches
    - Erosion across road—rills, gulleys

- Rills or deposition beyond berm crests
- Recently patched or reshaped sections of berms
- Subsurface flow escape from ditches and berms
  - Mass slope failure or hummocky terrain and seepage downslope from berms or on the outer slopes of road fills
  - Unexplained local patterns in vegetation
  - Lack of vegetation
  - Patterned deposition of dispersed soils below berms, at culvert outlets, or on road fill slopes
  - Outflow around rather than through culverts.

Control of Water and Water Quality

Effects of Surface Mining

Water Flow

Whether water runs off or infiltrates during a rainstorm depends on slope, vegetative cover, soil conditions, and soil compaction. Infiltration will be increased by mining activities that produce cast spoil that is full of voids. This may also result in greater permeability and significant increases in water-holding capacity. But overburden moved by either scraper or truck will tend to be compacted and will likely have more runoff than the undisturbed site.

Surface mining may increase groundwater storage capacity. Any increase in capacity will depend on both the method of spoil placement and the character of the spoil itself. It is possible that "recharge zones" may be created by selecting those portions of the spoil that have the best infiltration characteristics and placing them where surface water can be diverted into them.

Increased infiltration usually means higher and longer baseflow of streams when the water eventually reappears in springs or seeps. Increased streamflow during dry weather and prolonged flow in streams that normally flow only intermittently are generally considered desirable. Studies have shown an increase in dry weather streamflow following surface mining. Other studies have shown that storm peak flows may be several times higher from mined watersheds than from unmined areas during and immediately after mining, but that after reclamation is complete, peak flows in mined areas can be significantly lower. The amount and velocity of runoff during storms will be a major factor in the amount of erosion and hence the amount of sedimentation.

Water Quality

Acid mine drainage (AMD), the detachment and transport of solid particles by flowing water, and the subsequent settling of those particles (sedimentation) are the major water quality problems caused by surface mining.

Sediment. Many experiments have quantified the sediment resulting from erosion on both active and abandoned surface mines. Current technology for control of erosion and sediment has evolved from experimental data as well as from field trials of a variety of sediment control features.

Preventing erosion and subsequent sedimentation is important to prevent:

- Sediment deposition in stream channels
- Continual exposure of toxic- or acid-forming spoil by erosion of unstable slopes
- Loss of soil needed to support a vigorous vegetative cover.

Acid Mine Drainage. When coal is mined, previously protected strata are exposed to oxygen, and in the case of surface mines, to direct weathering as well. When water and oxygen come into contact with iron disulfides (pyrite and marcasite), these minerals will oxidize and release sulfuric acid and ferrous sulfate. These oxidation products, together with an assortment of trace elements soluble in acid, are commonly called acid mine drainage (AMD). In most cases AMD will eventually find its way into streams and groundwater. The ferrous sulfate can oxidize further to produce an insoluble precipitate of ferric hydroxide and additional sulfuric acid. Iron disulfide that is under water or buried in impermeable materials will be effectively protected from oxygen, so no significant oxidation will take place. The only pyritic material in natural systems that can be oxidized at an environmentally significant rate is that which is exposed to atmospheric oxygen. The amount and rate of acid formation and the quality of water discharged are functions of the amount and type of pyrite in the overburden and coal, the duration of exposure to oxygen, the characteristics of the overburden, and the amount of water available.

If the overburden also contains alkaline material such as limestone, acid may be partially or entirely neutralized before it is discharged. However, discharges may be high in sulfate.

The pattern of acid discharge tends to be erratic. Streams may be damaged by continuous acid discharges that occur when streamflows are at low and moderate levels. However, the extremely high discharges when mines are dewatered can also be damaging. Likewise, "flushouts" of acids by the first storm following a drought can be devastating.

Acid Prevention. All techniques for preventing acid formation are based on the control of oxygen. There are two mechanisms by which oxygen can be transported to pyrite: convective transport and molecular diffusion.

The major energy source for convection transport is likely to be the heat generated by the oxidizing pyrite. As hot gases surrounding the pyrite rise, they are replaced by cool air containing oxygen. Changes in atmospheric pressure also induce exchanges between spoil gases and the atmosphere. Wind currents against steep slopes can drive oxygen deeper into the spoil mass. As pyrite is oxidized, oxygen is removed from the spoil atmosphere, thus creating a partial vacuum and drawing in still more outside air.

Molecular diffusion occurs whenever there is a gradient of oxygen concentration between two points, in this case, the spoil surface and some point within the spoil. Molecular diffusion is applicable to any fluid system, either gaseous or liquid. Oxygen will move from the air near the surface of the spoil, where the concentration is higher, into the gases or liquid-filled pores within the spoil, where the concentration is lower. The rate of oxygen transfer is much higher in gases than in liquids. For example, the diffusion of oxygen through air is approximately 10,000 times as fast as in water. Therefore, even a thin layer of water (several millimeters) serves as a good oxygen barrier.

Artificial barriers such as plastic or bituminous films or concrete would probably be effective, but they have high original and maintenance costs and could be justified only in special situations.

Surface sealants such as lime, gypsum, sodium silicate, and latex have been tried, but they too are costly, require repeated application, and are only marginally effective. The two most effective barrier materials are soil, including nonacid spoil, and water. The thickness of soil or nonacid spoil required as a barrier is a function of the soil's physical characteristics, compaction, moisture content, and vegetative cover. Deeper layers of a sandy, porous material would be required than of a tightly packed clay that is essentially impermeable. Soil thickness should be designed for the worst situation—when the soil is dry and oxygen can move more readily through cracks and pore spaces. When water instead of gas occupies the pores it blocks the flow of oxygen. A "safety factor" should be included to account for soil losses by erosion. Vegetation serves as a barrier against wind. As the vegetation dies, it becomes an oxygen user during the decomposing process and increases the effectiveness of the barrier; and the organic matter that is formed increases the moisture-holding capacity of the soil. If organic matter is buried with pyrite and immersed in water, reducing conditions should prevail under which sulfate may be reduced back to iron sulfide and eventually to pyrite or marcasite. Water is an extremely effective oxygen barrier when the pyritic material is permanently covered. However, controversy continues as to whether less AMD would be produced if pyrite were kept above the water table or if it were allowed to alternate between flooded and nonflooded cycles.

Acid Control. Additional measures to control AMD are water control and in-place neutralization. Water not only serves as the transport medium that carries the acid pollutants from the pyrite reaction sites and mine, but it also erodes soil and nonacid spoils to expose additional pyrite to oxidation. Facilities such as diversion ditches that prevent water from entering the mining area or carry it quickly through the area can significantly reduce the amount of water available to transport the acid products. These facilities, which are discussed under "Control of Water and Water Quality", are needed both during and after mining. Terraces, mulches, vegetation, etc. used to reduce the erosive forces of water are effective in preventing further exposure of pyrite.

Alkaline overburden material and agricultural limestone can be blended with acidic material to neutralize the acid in place and assist in establishing vegetation. In some cases, alkaline overburden can be graded so that acid seeps drain through it, neutralizing the acid.

Even neutral or slightly acid soils, spoils, and aquifer materials have considerable potential for removing the acid and trace element components of AMD through ion exchange processes, wherein the acids and dissolved metals from the water are exchanged with the exchangeable bases (calcium, magnesium, sodium, and potassium) from the soils, spoils, and aquifers.

Treatment of Acid Mine Drainage. A number of methods can be used to treat AMD. Where the formation of AMD cannot be prevented, treatment is necessary before the water can be discharged from the permit area. One method of treating AMD is neutralization, which provides the following benefits:

- Neutralization removes the acidity by adding alkalinity.
- It increases pH to somewhere near a neutral level.
- It removes most heavy metals by causing them to precipitate out of solution. The solubility of heavy metals is dependent on pH up to a point: usually the higher the pH, the lower the solubility.
- Soluble ferrous iron, often associated with AMD, oxidizes to ferric iron faster at higher pH values, then quickly precipitates from solution.
- Sulfate can be removed if sufficient calcium ion is added to cause the solubility product constant of calcium sulfate to be exceeded.

Some shortcomings of the neutralization process are:

- Hardness may be increased
- Sulfate may exceed 2,000 milligrams per liter
- The iron concentration usually is not reduced below 3 to 7 milligrams per liter
- A waste sludge is produced that must be disposed of
- Total concentration of dissolved solids is increased.

A typical neutralization system would include adding an alkaline reagent, mixing, aerating, and removing the precipitate. Alkaline reagents that may be used are lime, limestone, anhydrous ammonia, soda ash, and sodium hydroxide (Fig. 1).

Hydrated or slaked lime is the most commonly used treatment. Hydrated lime reacts with AMD as follows:

$$Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4 + 2\,H_2O \rightarrow CaSO_4 \bullet 2H_2O \quad (1)$$
(Hydrated Lime) + (Sulfuric Acid) → (Calcium Sulfate) + (Water) → (Gypsum)

$$Ca(OH)_2 + FeSO_4 \rightarrow Fe(OH)_2 + CaSO_4 \quad (2)$$
(Hydrated Lime) + (Ferrous Sulfate) → (Ferrous Hydroxide) + (Calcium Sulfate)

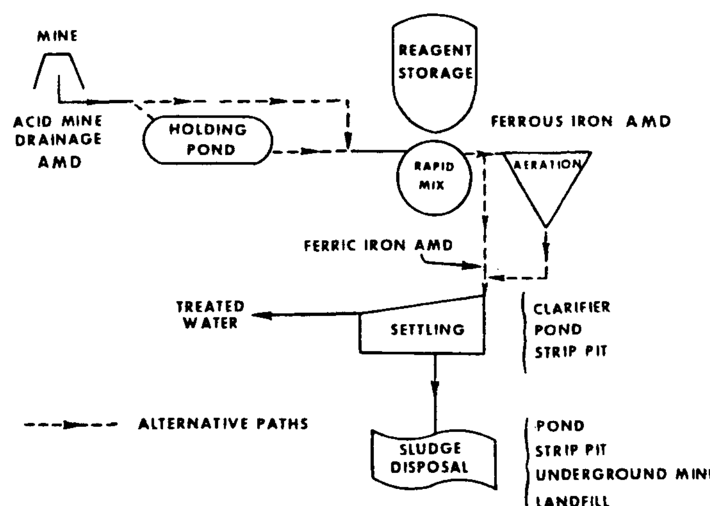

Figure 1. Typical treatment plant.

$$3Ca(OH)_2 + Fe_2(SO_4)_3 \rightarrow 2\ Fe(OH)_3 + 3\ CaSO_4 \quad (3)$$
(Hydrated Lime) + (Ferric Sulfate) → (Ferric Hydroxide) + (Calcium Sulfate)

If the concentration of calcium sulfate exceeds about 4,000 mg/l then the excess is likely to precipitate as gypsum ($CaSO_4 \cdot 2H_2O$). In a typical treatment facility, AMD is discharged directly to a rapid-mix chamber or to a holding/flow-equalizing pond where it flows to the rapid-mix chamber. Hydrated lime is fed either as a slurry or dry to the rapid-mix chamber. If the ferrous iron concentration is low (less than 50 mg/l), the water is treated to a pH of 6.5 to 8 and flows directly to a settling chamber. If ferrous iron is high, the water is usually treated to raise the pH to 8 to 10, and then passed to an aeration tank where the ferrous hydroxide precipitate is converted to ferric hydroxide. Then the water flows to a settling chamber. The settling chamber may be a clarifier or pond. Here the iron, aluminum, calcium sulfate, and other heavy metals precipitate. The supernatant is the treated water. The precipitate or sludge is removed from the settling chamber and disposed of in a second pond, mine pit, underground mine, or landfill. In some cases, the pond serves as a settling chamber and permanent storage place for the sludge.

Except for large surface mines, lime systems are usually much less sophisticated than the one described above. They may be as simple as catching all the AMD in a small pond, then hand broadcasting lime on the surface of the pond. This is effective only when the pond is less than 1,000 square meters (0.25 acres). Excess lime is required in this system because mixing of the lime and acid water is poor. After the water is treated, it is pumped from the pond.

Acid water can be treated as it is pumped from the pit by connecting a lime slurry tank to the suction end of the pump. As water is pumped, the lime slurry is drawn into the AMD by the suction of the pump; the pump also serves to mix the lime and acid water. Discharge from the pump should pass through a settling pond to remove any precipitates.

Limestone reacts with AMD as follows:

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2O + CO_2 \quad (4)$$
(Limestone) + (Sulfuric Acid) → (Calcium Sulfate) + (Water) + (Carbon Dioxide)

$$3CaCO_3 + Fe_2(SO_4)_3 + 3\ H_2O \rightarrow 3\ CaSO_4 + 2\ Fe(OH)_3 + 3\ CO_2 \quad (5)$$
(Limestone) + (Ferric Sulfate) + (Water) → (Calcium Sulfate) + (Ferric Hydroxide) + (Carbon Dioxide)

Although limestone is a cheaper reagent than lime and produces less and denser sludge, it has not received wide acceptance for several reasons: (1) the carbon dioxide produced buffers the reaction, and it is difficult to raise the pH above 6 without using excessive material; (2) limestone is ineffective with water high in ferrous iron; (3) the size, characteristics, and method of application of the limestone are critical; and (4) the system is usually more complex than a hydrated lime system.

Several different treatment schemes have utilized limestone. Those most applicable to surface mine situations are streambed and ground limestone techniques. The simplest method is the placement of limestone in a streambed. The acid water is treated as it flows through the bed. However, this method has proven ineffective in most cases because the limestone quickly becomes coated with various iron precipitates, calcium sulfate, sediment, and biological growths that prevent acid water from reacting with the limestone. The method may have application for short-term situations not exceeding a month. In such an installation, a trench leading from the surface mine should be dug and filled with crushed limestone (2.5 centimeters or 1-inch size). Basins should be used to settle out silt before it reaches the trench and to settle out the precipitate beyond the trench. Surface water should be diverted away from the trench to prevent the limestone from being washed out during storms. If the limestone bed loses its effectiveness, the stone should be replaced or a new trench dug.

Pulverized limestone can be used like lime. The following factors should be considered in the selection of a limestone: (1) high calcium carbonate content, (2) low magnesium content, (3) low amount of impurities, and (4) large surface area, i.e., smallest particle size within economic bounds (200 mesh or smaller is preferable). Pulverized limestone can be fed as a slurry or dry. Two to three times the stochiometric amount of limestone will probably be required, and even then pH will only reach 6 to 6.5. The reaction of pulverized limestone is much slower than that of hydrated lime, and up to 30 minutes of mixing should be provided.

The split treatment of AMD with limestone and hydrated lime may offer some advantages in cost and improved sludge characteristics. It might also be used on ferrous-iron AMD. A two-step process is required. First, the AMD is treated with limestone to a pH of 4.0 to 4.5 to take advantage of the pH range where limestone is most effective. The water then passes to a second reactor where hydrated lime is applied to raise the pH to the desired level. This process may have a cost advantage over hydrated lime alone.

Anhydrous ammonia will neutralize acid as shown in equation 6 and has been utilized for the neutralization of AMD.

$$NH_3 + H^+ \rightarrow NH_4^+ \quad (6)$$
(Gaseous Ammonia) + (Acid) → (Ammonium)

Such a system is easy to operate and maintain. Usually, the only equipment used is a tank of anhydrous ammonia, a length of hose to discharge the material into the AMD, and a valve to control the flow of gas. Anhydrous ammonia is usually supplied by the dealer in pressurized tanks mounted on wheels. The tanks are easily moved from site to site and can be set up in a matter of minutes.

The disadvantages of anhydrous ammonia are: (1) ammonia is lost to the atmosphere by diffusion or by air-stripping where aeration is practiced; (2) more sludge may be produced; (3) the reagent costs more than hydrated lime or limestone; (4) ammonia-neutralized AMD may have a detrimental effect on a receiving stream because of the toxicity of ammonia to fish and aquatic life, the depression of dissolved oxygen levels as a result of nitrification, and nitrate enrichment, which may lead to accelerated eutrophication; and (5) ammonia may oxidize in the streams to nitrate and acid, thus eventually reacidifying the stream in accordance with the reaction:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+ \quad (7)$$
(Ammonium) + (Oxygen) → (Nitrate) + (Water) + (Acid)

It is clear from equations 6 and 7 that ammonia has the potential for eventually generating twice as much acid as it initially neutralized.

The detrimental effect on receiving streams is significant enough to warrant the recommendation that anhydrous ammonia not be used to treat AMD except under special conditions. Levels of ammonia nitrogen and nitrate nitrogen far beyond the acceptable limits for streams have been found in AMD treated with anhydrous ammonia. The only situation where anhydrous ammonia may be acceptable is where small volumes of AMD are to be treated, and the treated water is applied to spoil banks as irrigation water so no runoff occurs.

Sodium carbonate neutralizes acid, as shown in equation 8, and has been utilized for the treatment of AMD because simple feeders have been developed.

$$Na_2CO_3 + 2H^+ \rightarrow 2\ Na^+ + H_2O + CO_2 \quad (8)$$
(Sodium Carbonate) + (Acid) → (Sodium) + (Water) + (Carbon Dioxide)

In most cases, soda ash briquettes have been used. A portion or all of the AMD is passed through a container holding the briquettes. The briquettes dissolve, neutralizing the water. These systems, which are usually used on small flows, are temporary and are easily moved. Their disadvantages are that good control of pH cannot be maintained, and very high flows cannot be adequately treated. Also, the higher cost of soda ash militates against its use.

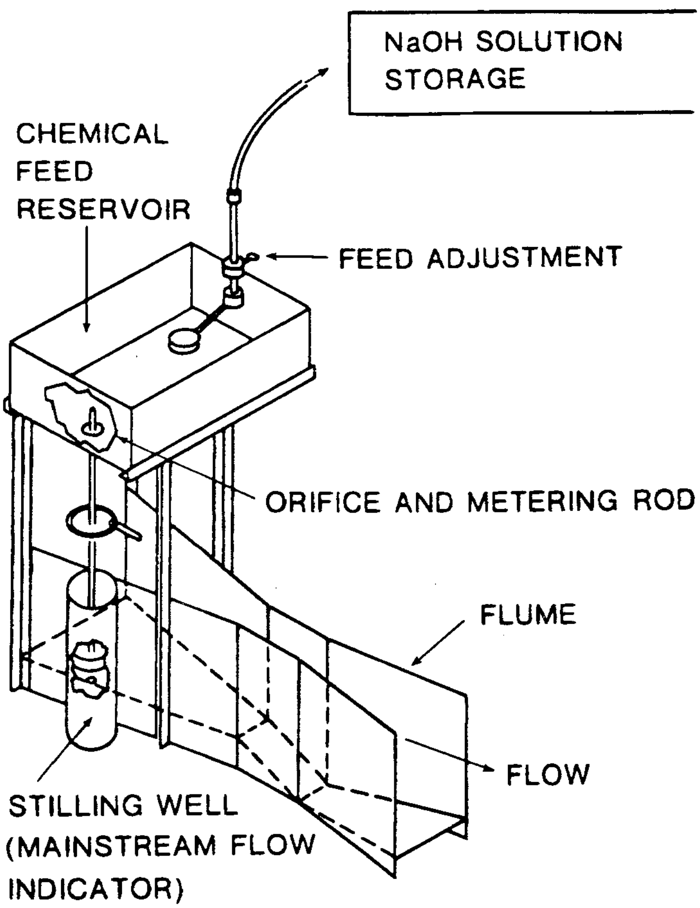

Figure 2. Chemical feeder for treating AMD.

One neutralizing system uses sodium hydroxide to neutralize acid as shown in equation 9.

$$NaOH + H^+ \rightarrow Na^+ + H_2O \quad (9)$$
(Sodium Hydroxide) + (Acid) → (Sodium) + (Water)

The addition of sodium hydroxide is controlled by the water level in a small flume (Fig. 2). The device may be suitable for remote locations because it is easily moved, requires no electricity or power, and is simple to operate. The device is best suited to small flows. A baffle to ensure good mixing is desirable for best operation. Sodium hydroxide costs more than hydrated lime or limestone.

Stream Diversions

Stream diversions are important in the control of water and sediment in many areas. Diversions are often used to intercept clean runoff and streamflow and convey it around the working area. Diverting overland flow before it enters the mine area also helps to keep the working areas dry. Where overburden contains acid-forming materials, diversion of water around the workings will reduce the formation of AMD. Often the diverted flow can be routed to the receiving water course below sediment control structures. In such cases, diversions reduce the amount of flow that must be passed through sedimentation ponds, allowing smaller sedimentation structures to be used.

Sedimentation Ponds

If runoff water is impounded along the way, some of the suspended solids will settle out. The amount of material that will settle depends upon the detention time, the size of the suspended particles, and the amount and valence of electrolytes dissolved in the water. Large heavy particles settle rapidly but small particles may take days to settle (Fig. 3). In some cases settlement can be speeded by adding flocculants to the water. Location, design, construction, and maintenance of sediment ponds are critical to their performance.

Handling Pit Water

Water that accumulates in the mine pit is likely to be polluted with suspended particles or dissolved salts or both. Pit water is exposed to rock dust, coal dust, and associated pyritic materials. Oxidation of pyrite produces acid; dust becomes suspended in the water. Therefore, pit dewatering is likely to result in pollution of receiving waters. If the coal lies below the groundwater table, pumping to keep the pit dry may lower the water table and reduce the yield of nearby wells, springs, and seeps. In most instances, it is economically advantageous to the operator to minimize the volumes of pit water.

Haul Roads

Significant amounts of land affected by surface mining are devoted to access and coal haul roads. The quality of a road depends largely on its drainage facilities. Improper design, construction, and maintenance of haul roads and faulty attempts to bed down the roads after mining operations are completed can lead to erosion and sedimentation. These problems can be minimized by proper construction, proper routine maintenance of haul road surfaces and drainage structures, and control of road gradients during design and field location. Steep gradients tend to increase erosion and may require more maintenance.

Terraces

A terrace is a bench with a reverse grade that intercepts runoff. There are two distinct types of terraces: the level terrace, as implied, is level and simply intercepts and impounds runoff. A gradient terrace is graded to direct water along its length to an outfall on stable ground. The gradient terrace is the most common.

Terraces reduce erosion by intercepting runoff on long slopes and conveying it at nonerosive velocities to a drain or disposal area. Length of slope is an important factor affecting the amount of erosion. Generally, the longer the slope, the greater will be the runoff for a given precipitation event. Erosive capacity, and consequently the formation of rills and gullies, increases with flow volume and velocity. Terracing controls runoff and significantly reduces erosion. Terracing on gently sloping spoils can cut storm peak runoff rates and sediment yields by as much as 50 percent.

By slowing runoff, terraces will also cause more water to infiltrate the regraded spoil. This has two important implications:

- Infiltration into the spoil mass may reduce its shear strength and result in instability and slumping of the mass. Great care should be taken to ensure that runoff does not pond on the terraces where mass instability may become a problem, but flows steadily at a uniform gradient to stable ground.
- Increased infiltration will tend to increase the availability of water for plants, resulting in improved survival and growth of vegetation.

Terraces are commonly used on excess spoil disposal sites, such as head-of-hollow fills, valley fills, and steep outslopes. In such circumstances, a terrace may increase mass stability as well as intercept runoff.

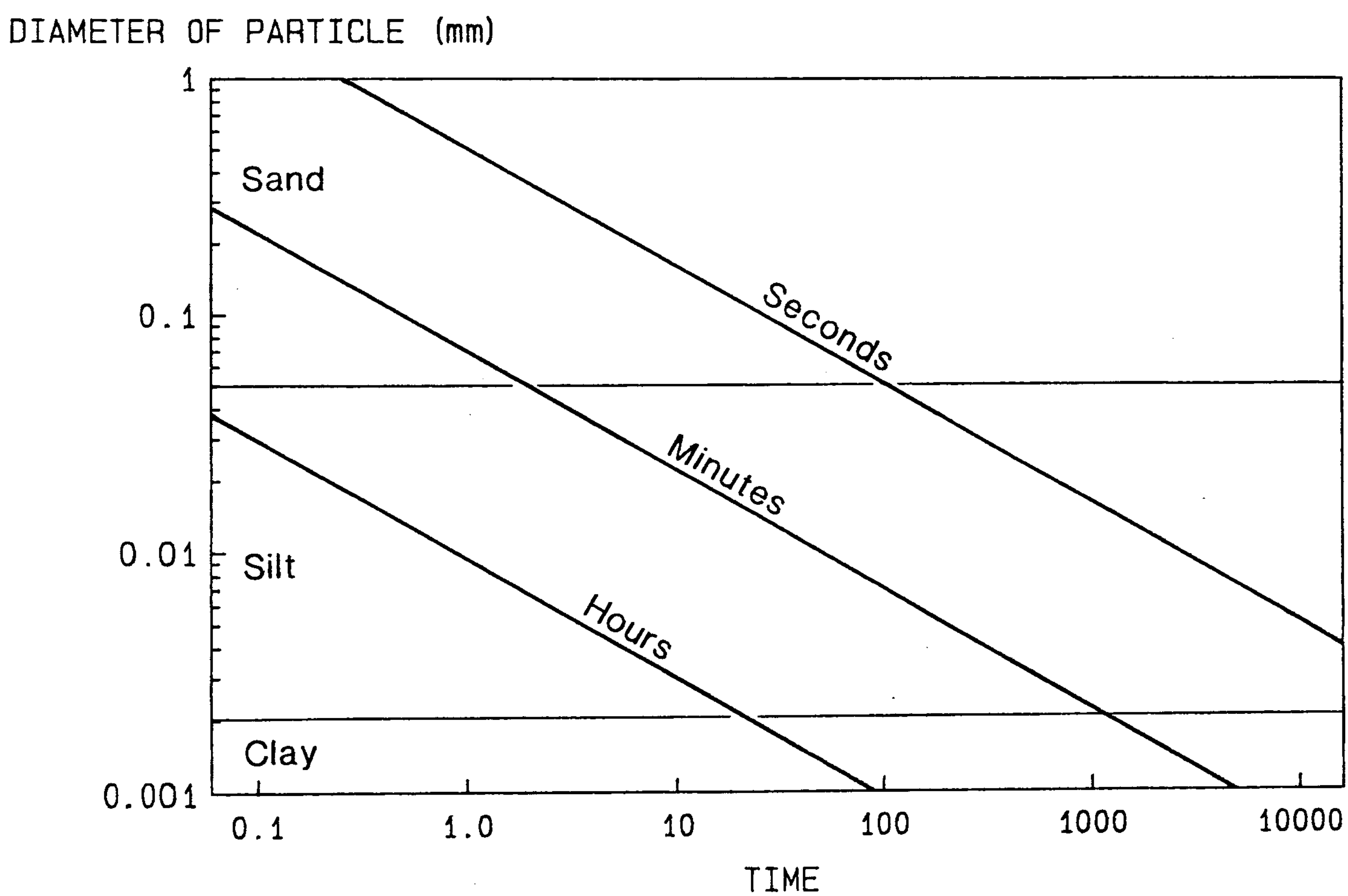

Figure 3. Time required for particles of various sizes to fall 1 foot based on Stoke's law assuming 25 °C and specific gravity of 2.65.

Grass Waterways

Grass waterways are used to convey water at nonerosive velocities to a safe disposal point. Grass waterways may be either temporary or permanent. They carry runoff during heavy rainfall but are otherwise dry. When possible, they should be constructed in natural drainage swales.

Underdrains

Underdrains may be necessary in special cases, such as where the proposed post-mining use is cropland or where overly wet conditions may cause erosion problems in grass waterways. Underdrains are a significant feature of fill construction where they serve to prevent saturation of the fill mass and the formation of a slip-surface between the fill materials and the original ground surface.

Mulches

Where soil surfaces are highly susceptible to erosion, as on steep or long slopes, mulches can provide protection against erosion. Mulches reduce evaporation and increase the availability of soil moisture to young plants. When they decompose most organic mulches provide a small amount of plant nutrients. Mulch will protect soil from the impact of rain and reduce formation of a soil crust. Mulches intercept and disperse much of the radiant energy of sunshine and the kinetic energy of rainfall. Mulches reduce the velocity of runoff, and hence its erosive capacity. Mulches may be mechanically applied to the soil surface or they may be "home grown" in the form of cover crops or plant litter.

Vegetation

A good permanent vegetative cover can be highly effective in controlling runoff, erosion, and sedimentation. The choice of species to be seeded or planted depends upon short-term and long-term needs and the post-mining land use. Choices may include temporary cover crops, permanent herbaceous species, permanent trees and shrubs, or any combination thereof. Each class of vegetation has its place in reclamation programs. Diversity of species is usually desirable to encourage soil stabilization at various depths and to perform functions such as nitrogen fixation.

Cover Crops

Many farm crops make good temporary cover and local agricultural practices and expertise can be used. Extended use of farm crops will normally require that certain criteria for harvest and yield be met.

The use of cover crops for temporary protection on erosion-prone areas is important in the following situations:

- Where both topsoil storage piles and temporary spoil heaps must be protected.
- Where the mining operation results in large quantities of spoil being stored temporarily outside the pit.
- On steep or highly erodible sites where it is feared that the speed of growth of the permanent crop may not give the necessary immediate erosion protection. In these cases the annual cover may be underplanted with the permanent seed mix.
- On sites where topsoil substitutes are being used, a two-step reclamation may give more reliable results. A cover crop is seeded onto the regraded area after the topsoil substitute and necessary amendments have been applied. In late summer the cover crop may be disked into the ground and the permanent vegetation seeded immediately. In lieu of disking, the cover crop may be killed with an herbicide and the permanent vegetation seeded directly. The dead crop then acts as a mulch. These techniques increase the organic matter in the soil and may also make it easier to identify trouble spots.
- On sites with highly variable physical conditions where little or no topsoil is available, cover crops are extremely useful as indicator crops. They can indicate areas where soil conditions are not favorable for plant growth, allowing remedial measures to be taken.
- In some cases, where a site has been regraded but topsoil cannot be redistributed immediately, it may be desirable to seed a temporary cover crop onto the regraded spoil to preserve the spoil texture and resist erosion.
- Cover crops on storage piles of topsoil may help prevent nutrients from being leached out of the soil during the storage period, by transpiring water that would otherwise percolate through the storage pile, and by utilizing and thus stabilizing those nutrients in the surface layers of the pile.

Generally, quick-growing annual grasses or cereals are used for cover crops. Often they are used as an in situ mulch. These include rye, wheat, Japanese millet, and foxtail millet. When these species are seeded in combination with perennial species, care should be taken to insure that the cover crop's vigor or shade does not seriously inhibit the perennial species. Rye has been found to be tolerant to the high levels of aluminum and manganese, which are common in surface-mine spoils.

Herbaceous Species

Herbaceous species may be subdivided into four groups: grasses, herbs, sedges, and rushes. Early establishment of an herbaceous cover is usually an effective erosion control measure. Early establishment is especially important on sites and materials that are highly susceptible to erosion.

Trees and Shrubs

Trees and shrubs are not as effective as herbaceous cover in the initial control of erosion on fresh spoils. Consequently, herbaceous cover is almost always seeded first, even though the approved post-mining land use may call for trees and/or shrubs.

Trees are not an effective erosion control in the early stages of growth, but as crown closure and litter formation occur they can provide long-term or permanent cover and site protection.

Techniques and Devices Used to Control Drainage and Erosion

In the following paragraphs an attempt is made to identify in a general way several methods, techniques, and devices, commonly used in mine site reclamation, that relate to hydrology. Their effects are important to the post-mining hydrology and they impose design and functional constraints upon structures built to control surface and subsurface flows onto, through, and from disturbed areas.

For convenience the methods and techniques are grouped into three use categories, ranging from areawide to site-specific. A fourth category covers remedial techniques and maintenance measures. This category includes methods and measures that are often applicable when maintenance is required, where previously constructed facilities are deteriorating, or where remedial reclamation measures are needed before a bond is released.

Category 1. Measures applied broadly to parts of the disturbed land:

A. Topographic reconstruction allows the mine operator to exert various degrees of control over post-mining slope length, steepness, and direction. Topographic elements can be managed to influence the:
   - Balance between surface and subsurface flows from the treated area;
   - Stream flow hydrograph—both base flow and stormflow;
   - On-site storage of both groundwater and surface water;
   - Erosion forces active on the area; and
   - Extent to which toxic spoils are in contact with water flowing from or to the surface.

B. Mechanical measures applied to the surface of a rebuilt, regraded topography include any activity that modifies the microtopography of that surface. Activities such as compaction or use of a bulldozer to "track" a slope will decrease roughness, while activities such as disking, scarifying, plowing, or ripping will increase roughness. Such mechanical treatments may be used to:
   - Modify infiltration rates and soil/water storage capacities;
   - Forestall erosion;
   - Eradicate slight erosional effects that already exist;
   - Strengthen the mechanical bond at the spoil-topsoil interface; or
   - Increase permeability and capillary flow through the spoil-topsoil interface.

   Of course, mechanical treatments may also change those physical characteristics of the surface that influence its serviceability as a seedbed and plant growth medium.

C. Materials applied to or spread upon the reconstructed topographic surface may include mulches, topsoil, or preselected spoils that have superior growth medium characteristics. The direct hydrologic influences expected from placement of superior spoil or topsoil are similar to those listed in the previous paragraph. The effects can be enhanced or weakened by superimposing mechanical treatment. However, mulches will exert other influences upon elements of the hydrologic cycle and site hydrology such as: reduce evaporation, increase resistance to erosion, and stabilize conditions conducive to infiltration.

Category 2. Measures applied to distinct zones or portions of the disturbed area

Quite often, because of their size, location, and the time in the sequence of operations when they were installed, or because the need for them decreased with progressively improving vegetative cover, the structures included in this category may be classed as temporary. Modifications to the basic reconstructed topography allow a greater degree of control over specific segments of the hydrologic cycle and their effects, and allow that control to be exerted at locations and positions when or where it is needed most. Measures include contour furrows, lister pits, diversions and ditches, and devices for dissipating flow energy or spreading flow.

A. Furrows and pits momentarily detain water at or near the raindrop impact point. This serves to:
   - Increase temporary on-site storage of surface water;
   - Promote infiltration;
   - Decrease the incidence of concentrated surface flow and forestall initiation of erosion;
   - Reduce the volume of surface flow from the treated area; and
   - Increase the duration of both surface and subsurface flow from the treated area.

B. Diversions and ditches provide prepared pathways for movement of surface flow from one area to another. They facilitate:
   - Drainage of low areas;
   - Rapid removal of waters from zones where infiltration might be undesirable;
   - Rapid movement of water to zones where infiltration is thought to be desirable — or at least not detrimental; and
   - Erosion control on long slopes, by removing water before highly erosive flow volumes and velocities can build up. (Used as an alternative to furrows and pits.)

C. Flow-energy dissipators serve to decrease the erosive power of flowing water by slowing it down or spreading it out. They can take many forms, may be constructed of a variety of materials, and are useful in many situations. Their end result is to disperse concentrated flows of surface water in much the same fashion as contour furrows and lister pits control the smaller concentrations of water in their smaller zones of influence.

   They may take the form of a permeable wall or sill of rock, brush or straw; a bed or pile of durable stones, a small check dam, or a fence of any of the above materials; or a check structure of posts, hog wire, and cables. They may simply be small topographic depressions which serve as stilling basins from which the outflow may be either surface or subsurface flow.

   Energy dissipators promote infiltration at the outfall of diversion ditches, road culverts, contour trenches and flows from terraced face slopes of valley fills, etc. They also forestall initiation of the erosion process at outfall locations and physically terminate ongoing or incipient erosion processes.

Category 3. Measures, devices and structures used at specific, well-defined locations within the permit area

Several treatments and structures included in this category have counterparts in Category 2 B and C. There, however, the devices are generally small, built to deal temporarily with relatively small, ephemeral flows, and may be "situation-specific" rather than "site-specific." Category 2 measures are installed on the disturbed area itself, whereas Category 3 measures are usually installed at the boundary between disturbed and undisturbed areas or entirely upon otherwise undisturbed land. Scaled and dimensioned drawings and construction details for Category 3 structures may be required.

The primary responsibility for the inspection of these devices during their construction generally lies with a professional engineer. The reclamation inspector assures that the plans have been certified by an RPE and are constructed in accord with plans. But after construction, all subsequent inspections and evaluations of functionability and safety may fall to the reclamation inspector.

Some of the most commonly used structures and measures are:

A. Interception ditches — Large ditches or channels that collect water from lands that will not be disturbed by the mining and route it around the zone of planned disturbance to a point below the downstream-most control structure. Flow gradients usually will be designed on the order of 1 to 3 percent unless measures are taken to prevent channel scour and bank erosion.
B. Terraces — Those portions of a fill face slope that are nearly level or slightly backsloped in cross section and slightly graded (1 to 3 percent in profile) and serve to move water from the fill slope face to protected drainways. (See Flume/chutes below)
C. Flumes/chutes — Those portions or sections of prepared channels, diversions, terraces, etc. that because of topographic constraints must have gradients steep enough to need protection from erosion. Normally, the protection is provided by stone riprap or masonry work, but metal culverts, plastic pipes, plastic sheeting, concrete or metal channel linings, or log structures can serve.
D. Debris/sediment and runoff-detention basins — These structures are installed in natural drainage channels or where artificial channels divert the flow. Their primary purpose is to detain water long enough for suspended solids to settle. Sometimes the waters thus detained are chemically treated before being released into the natural drainage system. Detention also tends to lessen stormflow peaks. Usually these structures are required to have both a primary and an emergency spillway.
E. Contour trenches — Small ponds, usually long in proportion to their width and depth, constructed at and along the contour at the lower boundary between disturbed and undisturbed areas on a mining operation. A single long trench may be divided into cells by check dams or dikes; or shorter individual trenches may be placed to allow a gradual step-up or step-down effect. Flow may be routed from cell to cell with a single outfall to serve several cells, or the convention of one outfall for each cell may be used.
F. Mine access and haulage roads — On many mining operations the haul road is the single most important drainage control structure. On some operations it is the only on-site structure that provides drainage and erosion control. Structural elements important to the drainage control function are roadside ditches, ditch relief culverts, energy dissipation at ditch and culvert outfalls, stilling basins at culvert entrances, road profile gradients, and road cross-section shape and gradient.

   Road location is important: distance from live streams, the relation of ditch relief structures to natural cross drains, and the steepness of the terrain between the route and any natural drainway below it. It is important that maintenance be performed correctly and at the proper time.

Category 4. Remedial measures, treatments, maintenance, and repairs

To a large extent the principles that govern repairs and maintenance are the same ones on which the treatment methods and structures already identified and discussed under Categories 1, 2, and 3 are based. However, the scale of application, and the techniques, equipment, and materials appropriate to maintenance and repair work can differ greatly from those used in the original construction.

If inspections have been thorough and timely, the period of deterioration has not been lengthy, and no catastrophic event has occurred, structures such as those discussed in Category 3 will seldom require replacement. For most structures, only occasional repair will be needed, but the drainage control elements of roads require continual maintenance.

The duties of an inspector in relation to repair and maintenance work are:

1. Recognizing situations and circumstances that call for repair or maintenance;
2. Evaluating each situation or circumstance with respect to the:
   a. Degree of imminent danger to life and property;
   b. Probability of increased danger to life and property;
   c. Time frame within which that probability is set;
   d. Remedial measures that are reasonable to apply under the circumstances;
   e. Extent or degree to which the measure would have to be applied in order to be effective;
   f. Time frame within which remedial actions can reasonably be initiated and completed;
   g. Disturbance to other areas or structures which likely would result from the remedial work;
   h. Chances of problem recurring after bond release.

Factors that bear on the evaluation process and govern the nature and extent of appropriate remedial work include:

- The gross location of the site where the damage is occurring:
  - Is it on or off the permit area?
  - Will it be necessary to get a right-of-way easement to access the work area?
- The physical, chemical, and vegetational characteristics of that area, zone, or structure identified as the source or cause of the damage:
  - What are its topographic and hydrologic parameters?
  - Is a selected or designated vegetation growth medium (topsoil or selected spoil) present?
  - What is the stage of vegetation establishment in and near the damage source area? (No vegetation planted; poor, good, nearly ready for bond release, etc.)
  - To what degree has the damaging circumstance or condition (rill or gully depth, acid water production, severity, or seepage flow quantity, exposure of toxic spoil, etc.) developed?
- The climate and season of the year as they pertain to precipitation patterns, potential for establishing temporary or permanent vegetation, freeze and thaw frequency, etc.
- The position of the damage source and the area where the damage is occurring with respect to its potential for becoming more serious.
  - Is there (little, moderate, great) potential for the present damage level to — intensify, extend?
    - Is the damage area on moderate or steep terrain?
    - Is it on the surface or below—in a stream, or aquifer?
    - Is it primarily a problem of size, of position, or of quality?
  - If the damage does grow what are the chances that it will pose a threat to property or life or permanent change in the character of downgradient ecosystems?
- The planned (as presented in the approved Permit Application Package) post-mining land use.
  - Will the remedial measures chosen (proposed by the operator) be compatible, have little impact, be detrimental, or improve, the implementation of the post-mining land use?
    - How soon can treatment be started? Completed?
    - Historically, has a problem of this type been amenable to treatment of the type proposed?
    - Are the equipment and materials required to implement the proposed measure available?
- The prospects for the problem to recur before or after bond release.
  - Is it appropriate to seek a "permanent" solution at this time?
  - Is the planned post-mining land use such that it would be reasonable to expect continued remedial treatment applications when such are needed in the future?
  - Is the nature of the problem and are its surroundings and contributing conditions such that it is reasonable to expect recurrence?
  - If the problem should recur after bond release is it likely to develop to the degree that life, property, and/or ecosystem values are threatened? Is it likely to be limited to levels such that its surroundings will buffer its effects and keep them within tolerable limits?

Sampling Site Selection and Sampling Frequency

Water-quality sampling sites for enforcement purposes should be selected so as to assess clearly the impact of mining activities on the water resource and to assure that comparisons can be made with subsequent samples. Because physical conditions at mining sites are continually changing, a sampling scheme must have enough flexibility to provide comparable data over a wide range of physical and hydrologic conditions. In addition, permitted point-source discharges from disturbed areas are always considered in sampling because of specific operator liabilities for discharge quality.

Effluent violations are most likely to occur during very low or very high flows. For surface water the common ions (calcium, magnesium, sodium, potassium, sulfate, chloride, and bicarbonate) and total dissolved solids are usually near their maximum when flows are very low. Suspended solids, on the other hand, are generally highest during high flows.

Inspection personnel are required to collect samples of surface water and groundwater from such diverse sources as: streams, impoundments, wells, mine openings, and springs and seeps.

Emphasis is placed on the need to obtain representative samples, properly collected and adequately documented in the field at the time of collection. The inspector should exercise proper care and custody of samples until they are delivered for appropriate analysis. The following pages present a general discussion of sample site selection and sampling frequency for the source mentioned above.

No one scheme can be considered the only correct approach to selecting water-quality sampling sites and establishing sampling frequency. One or a combination of schemes may be utilized by either the inspector or the operator to verify the extent to which requirements set forth in the Permit Application Package are being met.

Long-term monitoring sites may be needed for:

- stream quality during and after mining, to determine the success of reclamation or to provide information for bond-release analysis;
- well-water sampling during and after mining to determine off-site impact.

Short-term sampling sites can be established to collect data on:

- surface water or groundwater, to evaluate ambient conditions before mining
- stream discharge during high flow to evaluate the effectiveness of sediment-control measures.

Streams

The customary approach to determining the effects of mine drainage is to sample the receiving stream above and below inflow from the mine area. This scheme is useful to both the inspector and the operator in evaluating the extent to which the receiving stream has changed. Flow measurements of both the mine discharge and receiving stream are also needed. In cases of nonpoint discharges to streams, the effect of mine drainage may be gradually imposed on the receiving stream over a geographically wide front. In such cases it may be necessary to sample the receiving stream at a number of points along the affected portion to identify reaches receiving the major impact from mining.

It is important to choose sampling sites that will minimize the "masking" effect of extraneous inflow from tributaries or other nonpertinent sources. Avoid sampling streams at points, such as backwaters, that are not representative of the main body of flowing water. If streaks or swirls of sediment or color are apparent in the flowing stream, include a representative portion of each in the sample. Prior planning with maps and a sampling outline will often reduce effort and prove more effective, especially when multiple samples are to be collected at various locations.

The frequency with which streams are sampled for background information will vary according to the quantity and quality of disturbed-area discharge, the rate of streamflow, and the relation of natural daily and seasonal variations to water-quality characteristics. In some cases where effluent violations are suspected, one-time samples may provide the data necessary for enforcement decisions. Other cases, for example where stream contamination is apparently related to precipitation events, may require that sampling be coordinated with changing streamflow or stage. Suspected instances of deliberate pollution require preparation and often unusual inspection hours and techniques.

Impoundments

Because effluents from sediment ponds are usually sampled at the point of discharge there is little flexibility in selecting sites. Sampling can usually be facilitated by "catching" the sample as it falls from the discharge pipe. Point source discharges are subject to permitting and reporting requirements of the National Pollutant Discharge Elimination System and the applicable effluent limits of the issued permit.

It is difficult to obtain representative samples from impoundments. Standing bodies of water become stratified after a time, and physical influences that control chemical and biological activities tend to become layered. In small sheltered ponds, extreme temperature and chemical stratifications can be observed. If it is necessary to sample an impoundment, collect several discrete samples representing water from different areas and depths of the impoundment, and analyze each individually.

If there is interest in the pH of ponded water which is subsequently to be released, it is important to know inflow and outflow pH values, as well as pH in the cross-sectional area of the pond. Unless there is a boat available, however, it will be impossible for the inspector to collect cross-sectional samples. As an alternate, several pH measurements taken along the periphery of the pond can be useful in mapping pH variations. Because impounded waters may be poorly mixed, different releases of water from the same impoundment but from different levels or at different times may differ markedly in quality.

The inflow of mine discharge may change the dissolved-oxygen concentration, pH, and rates at which metals precipitate. Chemical precipitation, mixing, turbulence, treatment, and other changes may be in progress during sampling. Unless the ultimate extent of such changes is known, the inspector may have no way of reliably predicting the quality of water to be released.

Wells

The inspector is to assure that the operator is monitoring groundwater according to the permit requirements. Well location, sampling frequency, and parameters to be measured will vary from site to site, but all are usually specified in the Permit Application Package. On a given permit site the operator may be required to verify that existing wells have been inventoried and to obtain drilling and other construction data in addition to sampling such sources for water-quality data.

Observation-well data are used to determine the effects of mining activities on groundwater quantity and quality and to predict quality changes in streams during low flows when streamflow consists mainly of the groundwater component. Existing wells are not always suitably located to provide all the data that may be needed. Permit application packages often note that the wells of nearby residences will be used to monitor changes in groundwater elevations or characteristics. In some areas, these may be above or below the strata being mined. Horizontal movement just above an impermeable stratum is much more likely than downward percolation of water. A relatively small number of groundwater samples may be adequate to describe water-quality characteristics in an unmined area. Random sampling may suffice in undisturbed areas or in areas where groundwater is not extensively used. However, in mining areas where groundwater must be pumped for disposal or where excavation appreciably influences recharge or discharge, it may be necessary to collect samples more frequently. At times the inspector may find it desirable to collect a well-water sample in order to validate or supplement those supplied by the operator.

Underground Mine Openings

Occasionally, groundwater samples may be taken from underground mine openings (shafts, drifts, slopes, tunnel outflows). Such samples may be useful in determining the source of intercepted water at a surface mine. Generally, it is difficult to relate the quality of water standing in a mine to the quality of water moving through the rocks. Stratification may occur in mine water pools in the same way that it occurs in impoundments, resulting in some of the same sampling and data-interpretation difficulties. In mines where water is standing several tens or hundreds of feet deep, temperature variations of several degrees typically exist, and the oxidizing potential for metals may vary from a strong oxidizing environment near the surface to a reducing environment at depth.

Water sampling in mine shafts should be correlated with major changes in the water level in the shafts. These changes may easily be determined by measuring the distance from the ground surface or some reference point to the water level. Where extensive underground mining has been conducted, sudden unexplained flow increases at openings or adjacent to the mine area may be the result of subsidence activity. The subsiding material displaces water that must flow out.

Springs and Seeps

Springs and seeps, when they occur, provide a means of assessing groundwater quality. It is essential that ground water from springs be identified as to the geologic horizon from which the water discharges. Map location and elevation should be noted. Collect samples from springs and seeps as near as possible to the point of discharge before surface contamination can occur. Reference the location of the discharge to area maps and geologic cross-section materials for more meaningful evaluation.

Sampling

A great variety of water sources must be sampled by inspection personnel. Therefore, a knowledge of many water-quality sampling techniques will be useful. Collecting a sample from a discharge pipe requires one technique, whereas collecting a sample from a flowing stream requires another.

The purpose of this section is to describe sampling techniques most likely to be used by mining and reclamation inspectors. Brief mention will also be made of some other sampling methods that inspectors should know about. The decision on what method to use will be dictated by the existing field conditions and the judgment of the inspector. Always give highest priority to recognized, accepted practices, particularly when the data may result in enforcement actions.

Wells, springs, seeps, and other difficult-to-sample sources may require makeshift sampling techniques. Once a sample is obtained from any source, the processing and preservation techniques are identical to those described in the next section, "Sample Preparation, Treatment, Documentation, and Field Analysis."

The sampling method used should be stated on the sample label and eventually reported with the analytical results.

Guidelines for Representative Samples

A sample is worthless unless it adequately represents the water in the stream or impoundment being sampled. To obtain representative samples, follow these guidelines:

1. Collect the sample where the water is well mixed, if possible immediately downstream from a point of hydraulic turbulence such as a waterfall or flume. Samples may also be collected from free-falling water (as in a small waterfall); however, care should be taken to move the sampling device through the full thickness of the falling water at several points so that a fully representative sample is obtained.
2. Avoid sampling where floating solids and oil tend to accumulate, such as downstream from certain types of weirs and flumes.
3. In a well-mixed stream, collect the sample in the center of the channel at from 4/10 to 6/10 of its depth where the velocity of flow is average or higher than average. This depth avoids the inadvertent collection of part of the stream bottom or top-floating materials such as oil, grease, or debris. In streams that may not be well mixed, force the mouth of the sampling vessel across the entire cross section of the stream to the fullest extent possible without collecting bottom materials or surface scum and debris. If the surface scum, oil, or grease is flowing with the stream (not just accumulated in a stagnant area) there may be need to include a representative portion of these materials in the sample—but only if the analysis is to include these parameters.
4. To avoid contaminating the sample, collect samples with the mouth of the sample bottle pointed upstream. Keep hands and other potential contaminants away from the mouth of the bottle.
5. Do not walk on, or in any way disturb, the stream bottom upstream from the sampling site.
6. Do not sample backwaters or deep standing pools found along the stream.
7. Do not sample streams immediately below tributaries or other significant points of inflow. Sample far enough downstream for thorough mixing to have occurred, or sample both main stream and tributary just above their confluence.
8. Wide shallow streams should be sampled using the equal width increment (EWI) technique described later in this section. Shallow lakes or impoundments should be sampled at several points and the samples analyzed either as individual samples or as a composite sample.
9. Water quality can vary with depth so deep lakes or streams should be sampled with depth-integrating samplers, or samples should be taken at different depths for analysis as individual or composite samples.
10. Collect sufficient sample volume to allow duplicate analyses and quality assurance testing. The required sample volume is the sum of the volume required for each analysis requested. Refer to the laboratory director for minimum volumes to be collected.
11. Not all sample containers should be filled to the same level. Sample bottles should be filled completely if the samples are to be analyzed for O_2, CO_2, H_2S, free chlorine, volatile organics, oil and grease, pH, SO_2, NH_3, NH_4^+, Fe^{++}, and acidity or alkalinity. Full bottles must be protected from freezing. When sampling for bacteria or suspended solids, it is desirable to leave an airspace in the sample container to facilitate mixing before subsampling in the laboratory. In depth-integrated sediment samples it is essential that the sample bottles not be filled more than ¾ full.
12. If samples are taken from a closed conduit via a valve or faucet, allow sufficient flushing time to insure that the sample is representative of the supply, taking into

account the diameter, length of the pipe to be flushed, and the velocity of the flow.

13. Maintain an up-to-date log book in which to note possible interferences, environmental conditions, and problem areas.

Streams

Grab Samples

Grab sampling, collecting a single-point, instantaneous sample, is generally not considered a good method for sampling a flowing stream unless the stream is very narrow (5 feet or less) or very shallow (10 inches or less). But since most mine effluents are smaller than this, grab sampling will of necessity be the method most commonly used by mine inspectors. Normally a grab sample should be collected near the center of the main flow of the stream. When the stream is not well mixed, some attempt should be made to make the sample as representative as possible by moving the collecting bottle across flowing portions of the stream. More information relevant to grab samples can be found in the first seven guidelines for representative samples in the preceding section.

Point Sampling

For streams with a stable cross section and a rather uniform lateral distribution of suspended solids, sampling at a single vertical (near the center of the stream) will usually be adequate.

Equal Width Increment (EWI) Samples

To collect an equal width increment (EWI) sample, the width of a stream is divided into segments, each segment is sampled and its discharge is measured, then volumes of these samples are measured out proportional to the flow of their respective stream segments. The samples are combined to give the composite EWI sample.

Depth Integrated Samples

For a sample from a deep stream, lake, or impoundment to be representative, it usually must be depth-integrated. Samples for total suspended solids or other constituents, such as total iron and total manganese, may be collected with a US-DH-48 depth-integrating suspended-sediment sampler or similar sampler when the water is deep enough. If a Teflon nozzle and O-ring are used with the DH-48 sampler, the sample can be analyzed for almost any chemical pertinent to coal mining situations. However, if nozzles and fittings are of other materials — brass, aluminum, etc. — analysis may be somewhat restricted. More than one bottle of water may be required, depending upon the laboratory determinations to be made and the preservation techniques employed in the field. The following procedure should be used when collecting samples for subsequent analyses:

- Place a clean bottle in the US-DH-48 sampler.
- Lower the sampler into the water and collect a small amount of sample.
- Rinse bottle thoroughly and discard the water, making sure no solids remain.
- Replace bottle, lower sampler at a uniform rate from the surface to the bottom, then raise it at a uniform rate. DO NOT STRIKE BOTTOM.
- Repeat previous step at all verticals necessary for representative sample.
- Fill the bottle no more than 3/4 full. If it is filled beyond that volume, all water must be discarded and a new sample collected.

High velocity, floating debris, very shallow water, or other conditions may preclude the use of a sediment sampler. In that case, grab samples should be collected in a clean, rinsed container. When grab samples are collected in wide, relatively shallow streams, it is important that several verticals be sampled because the distribution of suspended solids is probably uneven. A single bottle may be filled through quick dips at several verticals, avoiding the necessity of compositing samples or collecting multiple samples.

Flow Proportional Compositing

A flow-proportional composite sample should represent the total volume of water flowing past the sampling site during a given period of time. This composite sample is composed of a number of discharge-weighted subsamples collected at uniform time intervals, perhaps a day or a week apart. For example, the composited portion of a subsample collected at a discharge of 15 ft^3/s would have 5 times the volume of the composited portion of a subsample collected at a discharge of 3 ft^3/s.

Sequential Compositing

A series of small samples collected at uniform time intervals is combined to produce a sequential-composite sample representative of the period of time over which the individual samples were collected. The main advantage of sequential compositing is economy. However, this type of sampling is limited by its "averaging" effect, which tends to mask the influences of significantly large changes in both streamflow and water quality.

Springs, Seeps, and Very Shallow Streams

Unless pools are present, samples cannot be dipped in the normal way from springs, seeps, and very shallow streams. Water may be collected with a syringe from shallow water as long as it does not draw up particulate matter from the bottom. It is frequently necessary to place a clean flat rock or piece of glass on the stream bottom, so the syringe tip will not be close to the loose bottom materials. Sometimes it is necessary to excavate a small pool or depression so the water will be deep enough to sample. After disturbing the stream bed in any way it will be necessary to let the flowing stream wash itself clean of sediment and turbidity before samples are taken.

Water flowing over a smooth rock face can be especially difficult to sample; however, a straw or a stick can usually be used to lead it to the sample container.

Springs and seeps in unconsolidated material may sometimes be sampled using a slotted pipe as described in the later section on sampling equipment.

Lakes, Ponds, and Impoundments

Shallow lakes and impoundments should be sampled at several points and the samples analyzed either as individual samples or as a composite sample. Water quality can vary with depth so deep lakes should be sampled with depth-integrating samplers, or samples should be taken at different depths for analysis as individual or composite samples.

Wells

Because the quality of the water standing in an unused well may not be representative of the quality of the water in the aquifer, a well must be pumped or bailed until the temperature, pH, and specific conductance are constant. Usually the last parameter to attain a reproducible reading and consequently, the most sensitive test for wells, is pH. Standby or little-used wells may require a lengthy period of pumping before the quality of the discharge stabilizes.

It may be impossible to obtain stabilized readings of pH, specific conductance, and temperature — even after lengthy pumping or bailing. If this is the case, a more practical option would be to pump for a specific period of time, say one hour, before collecting the samples.

Perhaps the easiest way to collect samples from existing wells with plumbing is, after sufficient pumping, to take the sample from a faucet or hose. However, if the pump intake is near the water surface or if there are air leaks in the pumping system, dissolved-oxygen contamination may result in the precipitation of metals even before the sample is collected. Water softeners, iron-removal filters, and storage tanks are sources of contamination and chemical change to water from a plumbing system. If it is impossible to avoid them, the installation of observation wells may be necessary. There are few well-defined criteria for sampling wells. Sampling technique will have to be adapted to existing field conditions.

Sample Preparation, Treatment, Documentation, and Field Analysis

Samples must be properly collected, preserved, and identified if they are to serve their intended purpose. Some parameters must be measured in the field; others can be determined in the laboratory.

Sample Preparation

- For suspended solids, cap and chill sample.
- At least two bottles will be needed if both "dissolved" and "total" constituents are to be determined (for example, dissolved iron and total manganese). For the "dissolved" constituents, a small part of the sample must be passed through a 0.45-micron membrane filter as follows:
  - Use a 50-milliliter plastic hand syringe and draw a few milliliters of sample water into the syringe for rinsing. Discard this rinse water.
  - Draw 50 milliliters of sample water.
  - Insert syringe outlet tip into the upper surface of membrane filter holder. Force sample through filter into sample bottle.
  - If metals are to be determined, acidify samples immediately with concentrated nitric acid (HNO_3) at the approximate ratio of 1 milliliter of nitric acid per 16-ounce (pint) sample.
  - Rinse filter holder and syringe with deionized water.

Recording Field Data and Identifying Sample

The inspector should keep a log or field-data sheet describing in detail the methods used in sample collection and the physical and climatic conditions under which the sample was collected. The log should contain:

- Field data such as pH, visible turbidity, specific conductance, temperature, etc.
- Name or initials of the individual collecting the sample
- Exact sample location (map location, longitude-latitude, or other)
- Date and time of sampling
- General climatic conditions
- Names of any witnesses to the sampling
- Flow rate including a description of the method used to determine it
- Sample identification number
- Name of mine and company.

Sample treatment:

RU—raw, unacidified	FU—filtered, unacidified
RA—raw, acidified	FA—filtered, acidified
RC—raw, chilled	FC—filtered, chilled

The sample container should be labeled with a waterproof marking pen on a pressure-sensitive label. Use permanent gummed labels. The sample container label should contain:

1. Sample identification
2. Time (military)
3. Date of collection
4. Name or initials of the person collecting the sample
5. Sample treatment (preservation)
6. Discharge (ft^3/s or gal./min.)
7. Presence of a calcium-based (or other) treatment system (so that the analyst can determine if there is a potential gypsum suspended-solids problem)
8. Remarks

The name of the coal company and location should not appear on the sample containers; rather, they should be kept in a separate log.

Upon completion of sampling and field-data recording, the samples should be transferred to the laboratory under appropriate conditions. For example, a chilled "C" sample should be shipped in an ice chest. The acid-preserved samples may also be stored in the ice chest as a matter of convenience. A chain of custody form (see Appendix D-11, 12, and 13) should be filled out by the individual doing the sampling and signed by each individual accepting custody of the sample. The samples should be locked in the shipping container or it should be sealed with pressure-sensitive, permanent printed tape to guarantee their security. If sealing tape is used, the laboratory manager responsible for the analysis must sign the chain of custody form stating that the tape sealing the container has not been tampered with.

Field Analyses

Temperature

Water temperature is important because it may indicate thermal pollution and it influences other physical, chemical, and biological activities in water. Gas-diffusion rates, chemical-reaction rates, and the settling velocity of particles are just a few of the many important variables that are related to water temperature. In addition, temperature differences between different water sources and seasonal variations of temperature make temperature useful in hydrologic investigations, particularly those that involve the mixing of groundwater and surface water.

For economy and ease of use, the liquid-in-glass thermometer is recommended for field use. A pocket-sized thermometer protected by a metal case is recommended. A mercury-filled stem, with a yellow or red background is desirable. To eliminate the problem of column separation, it is best to use a thermometer with gas-filled capillary.

Most thermometers shipped from the manufacturer are not highly accurate. Before each new thermometer is issued for field use, it should be checked for accuracy. This is done by comparing the field thermometer to a precise instrument such as an ASTM calibration thermometer at three points. The comparison is usually made in a water bath to eliminate erratic readings. Any thermometer found to be off by more than 0.5°C should be rejected.

Temperature data are generally reported in degrees Celsius, generally to the nearest 0.5°. The following formulae can be used to convert between the Fahrenheit and Celsius scales:

$$°C = 5/9\ (°F - 32) = (°F - 32)/1.8$$
$$°F = 9/5\ °C + 32 = 1.8°C + 32$$

Temperature measurements should be made directly in the source if possible. Water in wells, mine shafts, and underground-mine effluents presents special problems and the measurements obtained will be less than the ideal. Unusual circumstances, such as standing water, plumbing, or treatment facilities, that may affect temperature should be noted. The following steps should be taken when making temperature measurements:

- Check thermometer for liquid-column separation.
- Immerse bulb into source.
- Allow the reading to stabilize.
- Read temperature with bulb immersed (removing the bulb from water can result in rapid temperature changes).
- If temperature cannot be measured in the source, collect at least an 8-ounce bottle or cup of water and measure the temperature immediately. Keep bottle out of the sun and wind while measuring.
- Return thermometer to protective case.

pH

Because the pH of some samples can change in a short time, ideally it should be measured in the field with a reliable instrument or field test kit. At least two different methods may be used to determine the pH of water.

Colorimetric Measurement. A wide variety of chemical reagents that display color changes over narrow ranges of pH changes are used as indicators to show the approximate pH of the solution. Field kits can be used to estimate the pH of colorless, nonturbid, well-buffered water solutions, provided the reagents are fresh. The reliability of indicators for most mine-drainage testing is poor. Field data obtained with colorimetric kits may indicate possible violations; however, it will still be necessary to perform the analysis in the field with a reliable pH meter or collect a sample for laboratory analysis. Litmus paper and other chemically treated papers can also be used to indicate the approximate pH of a solution.

pH Meter. The pH meter used in conjunction with a glass electrode and reference electrode (or a combination glass plus reference electrode) develops a voltage potential in response to the hydrogen-ion activity without interference from most other ions. This method of measurement has become the standard for accurately determining pH in the field and laboratory.

It is important that semiannual maintenance and calibration be provided for all pH meters. If the pH meter is properly maintained and calibrated, field values obtained by the inspector should be acceptable in litigation.

Calibration of Meter. Before calibration of a new or untested meter, test meter response by making a 3-buffer check using solutions of pH 4, 7, and 10. Place electrode in the pH 7 buffer and adjust "standardize" knob to make meter read 7. Rinse the electrode with distilled water, dry with soft tissue, and place it in pH 4 buffer solution; the meter should read approximately 4. Rinse and dry again and place electrode in pH 10 buffer solution; meter should read approximately 10.

Calibrate meter and electrode according to manufacturer's instructions using two buffer solutions (for example 4 and 7, or 7 and 10). Use last the buffer having a pH nearest that anticipated for the sample. To avoid contamination of buffers, calibration and meter checks should be conducted in buffer solution in separate containers, such as small disposable paper cups. Buffer solutions should be discarded after use. Proceed to calibrate as follows:

- Check battery.
- Expose filling opening to atmosphere by uncovering opening during measurements.
- Place function switch on "standby" or "ready".
- Measure temperature of buffers.
- Set temperature compensator to temperature of buffers.
- Rinse electrode with deionized or distilled water thoroughly before placing it in a different buffer or into the sample.
- If the approximate pH of sample *is* known (based on field-kit or multi-range pH paper results), place electrode in a buffer solution having pH near that anticipated for the sample. Turn function switch to "measure." Adjust meter to read pH of buffer by turning "standardize" knob. Repeat this procedure using another buffer to closely "bracket" the anticipated pH of the sample, this time adjusting the meter reading with the "slope" knob (or equivalent) until the meter reads the pH of this second buffer.
- If the pH range of the sample is *not* known, place electrode in pH 7 buffer. Turn function switch to "meas-

ure." Adjust meter to read pH 7 by turning "standardize" knob. Then, place electrode in the sample to determine an "anticipated" or "approximate" pH value for that sample.

- Complete calibration by "bracketing" the approximate pH value of the sample.

When only occasional pH measurements are made, calibrate the instrument before each measurement. When frequent measurements are made, the meter calibration should be checked at least twice a day. If the meter is drifting appreciably it will need to be recalibrated more frequently — or it may need new electrodes. In all cases where readings indicate a violation, it is advisable to calibrate the instrument and double-check readings.

Measurement of pH.

- Place electrode into sample to a depth of approximately 1 inch.
- Measure temperature.
- Set temperature compensator to temperature of sample.
- Turn function switch to "measure."
- Allow meter readout to stabilize. This may take several minutes if the electrodes are old.
- Record pH to nearest 0.1 pH unit.
- Rinse electrode with deionized water.
- Cover electrode with protective cap of water or pH 7 buffer.

If litigation is anticipated, repeat measurement (record all readings; do not average values).

Precautions.

- Never remove electrode from buffer or sample unless meter is in "standby" or "off" position. To do so may polarize the electrodes, permanently damaging them and resulting in unstable meter readings.
- Dirty connectors on pH electrodes may result in erroneous readings; do not handle the plug; if it is dirty, clean it with ethanol or isopropyl alcohol.
- Static electricity on meter face may be reduced by an antistatic cloth such as those used on phonograph records. If problem continues, check for broken or loose cable-shield wire.
- Keep electrode filled with the recommended solution to within ½ inch of filling opening. Do not substitute a filling solution of different chemical composition made for another electrode. Keep the fill hole closed when the electrode is not in use to prevent evaporation of the filling solution.
- Keep electrode tip moist by filling the provided rubber cap with either pH 7 buffer solution or deionized water. If the tip dries out, soak it in pH 7 buffer solution for 24 hours.
- Never immerse the electrode to such a depth that the surface of the filling solution is below that of the test solution.
- The temperature compensator on most meters must be set for the temperature of the sample that is being measured; however, on several brands of cheap meters the "temperature" compensation knob is also used as a "slope" knob to calibrate the meter to the second buffer. When these meters are used the buffers must be at the same temperature as the water being sampled. This can be accomplished by immersing the container of buffer in the stream being sampled until the temperatures are similar.
- Do not let the electrodes freeze.
- Avoid contamination of buffer. Use a separate container (cup) and discard it after use.
- Broken or scratched electrodes can give erroneous readings.
- Do not leave meter exposed to extreme weather conditions.

Iron (total)

Generally, field determination of iron with a portable kit is not reliable and, at best, the test result should be considered only an indicator. If a violation is suspected a raw acidified (RA) sample should be collected and preserved according to the method outlined in Appendix D7.

Manganese (total)

Most field procedures for the determination of total manganese are not very precise but they can indicate the presence or absence of manganese. A raw acidified (RA) sample for laboratory determination of total manganese should be collected and preserved according to the method outlined in Appendix D7.

Suspended Solids

There is no practical field method for determining suspended solids. Therefore, if a violation is suspected it will be necessary to collect a raw, chilled (RC) sample according to the method outlined in Appendix D6.

Specific Conductance

Because it is easy to measure, the inspector may find specific conductance useful in estimating the concentration of dissolved solids in water. For example, it can be used to determine the progressive dilution of an effluent downstream or possibly to aid in identifying the source of abandoned mine drainage or "breakthrough" water from an underground mine.

Rather precise field measurements of specific conductance can be made with a specific conductance meter. Most conductance meters are an adaptation of the Wheatstone resistor bridge with built-in circuitry capable of converting resistance values (ohms) to conductivity values (mhos). Most natural waters have a conductivity of much less than 1 mho, and to avoid decimals, values are usually reported in micromhos—the observed value in mhos times 1,000,000. Most field instruments are calibrated in micromhos, though some older models may be graduated in millimhos (mhos times 1000) or even in megohms.

Conductance is dependent upon water temperature, and by convention, values are adjusted to 25°C. (In most solutions an increase of 1°C increases conductance by about 2 percent). Many field instruments have temperature compensators, either automatic or manual. If this feature is not built into the instrument, it is necessary to use a temperature-adjustment graph or the temperature factors given in Table 1 to adjust the values to 25°C.

Specific-conductance electrodes should be rinsed occasionally in a hydrogen peroxide solution or a weak acid solution (5 percent) to prevent debris and algae from accumulating. It is a good practice to provide semiannual maintenance and calibration services for all conductance meters in use.

Calibration of Meter and Measurement of Specific Conductance Using Meter With Manual Temperature Compensation.

- Check battery.
- Measure temperature of standard.
- Set temperature compensator to temperature of standard.
- Check instrument against at least two known standards before every field trip.
- Rinse electrode with sample water.
- Return electrode to sample for temperature equilibration.
- Measure temperature of sample.
- Set temperature compensator to temperature of sample.
- Read conductance according tc manufacturer's instructions.
- Keep removing and reinserting the probe until two consecutive readings are in exact agreement. Air bubbles trapped in the probe will give erroneous readings.
- Record specific conductance in micromhos at 25°C to two significant figures. Examples: Measured value of 1926 is reported as 1900; measured value of 48.6 is reported as 49.
- Remove probe from sample and rinse thoroughly with deionized or distilled water.
- If the specific conductance meter does not have temperature compensation then the readings must be corrected to 25°C in accordance with instructions given in Table 1.

Table 1. Temperature factors for correcting conductivity data from meters without temperature compensating devices to the standard temperature of 25°C. Electrical conductivity @ 25°C = measured electrical conductivity x temperature factor for the temperature at which the conductance was measured.

°C	Temperature Factor	°C	Temperature Factor
0	1.87	16	1.25
1	1.82	17	1.19
2	1.76	18	1.16
3	1.71	19	1.14
4	1.66	20	1.11
5	1.61	21	1.09
6	1.57	22	1.06
7	1.53	23	1.04
8	1.49	24	1.02
9	1.45	25	1.00
10	1.41	26	0.98
11	1.37	27	0.96
12	1.34	28	0.94
13	1.31	29	0.92
14	1.28	30	0.91
15	1.25		

Precautions.

- Gently agitate electrode in sample to eliminate air bubbles.
- Allow water temperature and electrode temperature to equalize.
- Make temperature correction (Automatic or manual compensator or by table).
- Make sure electrode is clean.
- Do not leave meter exposed to extreme weather conditions.

Discharge (flow)

The inspector may find it desirable to measure streamflow at the time of water-quality sampling. The streamflow data could be useful in evaluating the water quality data and assessing any violations.

The Price current meter is a commonly used instrument for measuring stream velocity. The meter assembly consists of a cup wheel rotating about a vertical axis and tail vanes to keep the meter headed into the current.

The flow of water causes the cup wheel to turn. The number of revolutions, which is directly related to the velocity of the stream, is signaled to a set of earphones or a counter by electrical contacts powered by a battery.

To measure velocity, set the meter at a desired depth and start the counter if there is one, or start a stop watch on an initial signal (click) of the rotor. The next click is counted as one. Count the number of clicks for at least 40 seconds. After the number of revolutions and time have been determined, the stream velocity is obtained from a calibration chart furnished with the meter. For high velocities, the meter can be set to click on every fifth revolution. The number of revolutions then would be 5 times the number of clicks.

In shallow water the meter may be attached to a rod for wading measurements. In rivers and streams that cannot be waded, the meter is suspended from a bridge or boat by a cable. In that case a weight will be needed to keep the meter as nearly vertical as possible.

If the stream is over 2.5 feet deep, measurements should be taken at 2/10 and 8/10 of the depth of the stream. The average of these two measurements is nearly equal to the mean velocity in a vertical section. A single measurement at 6/10 depth is taken for streams less than 2.5 feet in depth.

Streamflow measurement is made by determining the mean velocity in a number of partial sections across the total cross section of a stream. For small streams, flowing less than 2 cubic feet per second, a minimum of three partial sections should be used. Each partial section should contain approximately the same flow. In general, for larger streams, each partial section should contain no more than 5 percent of the total flow. Stated differently, very large streams should be divided into at least 20 partial sections.

The flow in any partial section is equal to the area of that section times the mean velocity of the section: $q = av$

Where:

q = discharge in any partial section
a = cross-sectional area of partial section
v = mean velocity in partial section

The total discharge of the stream is the sum of the discharges in the partial sections: $Q = q_1 + q_2 + q_3 + \ldots q_n$

Where:

Q = total discharge of stream

q_1 = discharge of stream section 1

q_2 = discharge of stream section 2

q_n = discharge of last stream section.

The following characteristics should be sought when selecting a reach of stream for discharge measurement:

- A straight reach with the velocity threads parallel to each other
- Stable streambed free of large rocks, weeds, brush, or other obstructions that would create turbulence
- A flat streambed profile to minimize vertical components of velocity.

Effluents or streams too small to be measured with a current meter may sometimes be accurately measured volumetrically with a bucket and timer. Results obtained in gpm (gallons per minute) may be converted to ft^3/s as follows:

Cubic feet/sec = gpm × 2.228 × 10^{-3}

Inspectors are not normally equipped to measure large streams. If such measurements are needed, get help.

Sampling Equipment

Many varieties of field-testing equipment, sampling devices, and sample containers are in use by State and Federal agencies. The purpose of this section is to describe basic items. Many years of field experience by Federal agencies such as the U. S. Geological Survey, Environmental Protection Agency, and Federal Highway Administration have shown the items described here to be satisfactory. The following discussion is for identification purposes only. It does not imply endorsement nor does omission of certain brands imply that they are unsatisfactory.

Field-testing Equipment

The instability of certain chemical and physical constituents in natural water and waste water makes it desirable that some measurements be made on site or shortly after sample collection. Inspectors should know the operation and field use of these types of equipment:

pH meter
pH field testing kit (indicator only)
Specific conductance meter
Thermometer
Alkalinity kit
Acidity kit
Iron kit (indicator only)

These items must be transported and handled with care. Even though some have been designed for field use, they are subject to damage from shock, dust, and moisture. Use cushioned, waterproof carrying cases with all of these instruments.

Each instrument should be given frequent periodic calibration and maintenance. Meters measuring pH are routinely calibrated against standard buffered solutions; specific conductance meters are calibrated against a standard resistor or a standard potassium chloride solution.

Check all instruments frequently for corrosion on terminals and batteries and for moisture and dust on controls and circuitry. Because testing kits are subject to contamination and decomposition of reagents, keep glassware scrupulously clean and reagents freshly stocked from a quality-controlled supply.

Sampling Devices

The contaminants in water associated with mining operations are present in both liquid and solid states. To be representative, a water sample from a mining area must contain liquid water, dissolved solids, and undissolved solids in proportion to their occurrence in the source. Undissolved solids may include both suspended solids, such as clay, and transported solids, such as sand. The devices described in this section will provide a practical means of obtaining a representative sample with a minimum of effort.

Suspended-Sediment Samplers

An inspector will rarely need to sample streams so large as to require special depth-integrating samplers, but such devices may be needed to sample larger impoundments.

The Federal Inter-Agency Sedimentation Project of the Inter-Agency Committee on Water Resources, St. Anthony Falls Hydraulic Laboratory, has developed standard samplers and methods. The two depth-integrating samplers most likely to be used by inspection personnel are the US-DH-48 and the US-DH-59.

The US-DH-48, which is suitable for wadable streams at least 3.5 inches deep, consists of an aluminum casting and glass or plastic bottle. The sample is collected through a brass or Teflon nozzle. The sampler weighs about 4½ pounds and is held by a 3- or 4-foot rod.

The US-DH-59, which is used for larger streams that cannot be waded, is heavier and can be suspended by rope from a bridge or boat. The body consists of a bronze casting, weighing about 24 pounds. The DH-59 has a choice of nozzle sizes, depending upon flow velocity.

If Teflon nozzles and gaskets are used, both the DH-48 and DH-59 are suitable for collecting the kinds of samples upon which most inorganic, organic, and physical tests can be made.

Most discharges from mine sites will not be deep enough to permit use of these samplers. Neither will discharges move fast enough (1.5 ft/sec or more) for the standard suspended-sediment samplers to fill properly.

Bottle

Open-mouth bottle samples can be taken when stream velocities are low (less than about 2 feet per second) and the flow is tranquil, when only fine silt- and clay-sized particles are in suspension, and suspended-solids concentrations do not vary greatly either vertically or laterally. Standard suspended-sediment samplers do not fill properly at velocities less than about 1.5 ft/s.

Open-mouth bottle samples should be depth-integrated. A depth-integrated sample is one in which all depths accessible to the sampling device are uniformly represented. A narrow-mouth bottle, usually one liter or more in size, is commonly used. By equipping a sample bottle with tubing of the type shown in Figure 1 it is possible to control the rate of intake and thus facilitate the collection of a representative depth-integrated sample.

The sample bottle should be weighted so that it will sink readily to the bottom, taking sample on the trip from the surface to near the bottom and back to the surface. The trip must be at a uniform rate. Each point at which the sampling device is lowered to the bottom and hauled back is called a "vertical". The rate of lowering and raising the sampler must be such that the bottle is not more than three-fourths full, otherwise it will not contain a sample equally representative of all depths. If the bottle fills slowly or the stream is shallow, the sample bottle may be filled at more than one vertical or by lowering and raising several times at the same vertical.

Open-mouth bottle samples should be taken at several verticals in the cross-section to allow for the vertical and lateral variations in water quality that frequently exist in slowly moving waters. The number of verticals sampled is largely a matter of intuition; large variations in the water quality in the cross section will require sampling at more verticals than little variation.

A bottle is also acceptable for collecting samples from pipe discharges from streams that are too shallow (less than 3.5 inches) to accommodate a suspended-sediment sampler. Where the stream or pond is very shallow, it may be necessary to "dip and pour" from one container into another. Be careful not to scoop up any bottom material with the sample and be careful to transfer all of any suspended matter that may tend to settle out.

Pipe

Springs and groundwater seeps in unconsolidated material may sometimes be sampled by driving a slotted metal or plastic pipe a few feet into the source. Use a plastic pipe when samples for metal ions are being collected. Water flowing from the pipe will be relatively free of particulate matter and dissolved oxygen. The absence of dissolved oxygen is desirable when samples are being collected for dissolved trace metals or other easily oxidizable materials.

Thief Sampler or Bailer

For wells that do not have pumping facilities, a hand-operated thief sampler, such as the Forest sampler, is a practical method of collecting a sample. When the sampler is at the desired depth, a messenger weight is dropped to activate spring-tensioned rubber stoppers at each end of the sampler. The sample is lifted to the surface and poured into an appropriate container. A simple hand bailer may be used to collect water from near the surface after the "stale" water has been removed by bailing.

Syringe

Frequently small streams, springs, and seeps are so shallow that a grab sample cannot be dipped from them in the usual way. A 50-ml plastic syringe can be used to collect water from such sources for transfer to the final sample containers. This same syringe may also be used to force water through filters directly into bottles for the filtered samples. In using a syringe to collect water, care must be taken not to draw up any bottom material with the sample. It may be necessary to place a flat rock or a piece of metal or glass on the stream bottom, allow time for the stream to clear itself of any sediment stirred up in the process, then place the syringe tip on or above this solid material when the sample is being drawn up.

Sample Containers

Though there are few established rules that specify container size, shape, construction, or composition, the following should be considered:

- volume of sample
- stability of container in field
- storage convenience
- ease of sealing
- ease of labeling.

Do not use a sample container made of a material chemically similar to anything that is to be analytically determined. For example, samples to be analyzed for organic carbon should be collected in glass containers instead of plastic. Samples for boron analysis should be collected in a plastic container rather than a glass container. Make sure the bottle cap will not contaminate the sample.

Disposable plastic bottles (polyethylene) will serve as excellent sample containers for most of the routine analytical determinations required. Depending upon laboratory requirements, 8-ounce or 32-ounce bottles will suffice for most samples. The most common bottle design is the modern round one. It is easy to label, fits conveniently into weighted sampling devices, and is disposable.

Collapsible plastic containers are also suitable. They are easy to store when empty, but they are difficult to inflate and label and will not conveniently fit weighted sampling devices.

Water samples may be collected in presterilized plastic bags. The six-ounce bags are adequate for most samples. The bags are easily labeled with a waterproof marker directly on the outer surface.

Glass milk bottles have been used for years to collect sediment samples with the FISA samplers. Milk bottles are easy to use in the field and in the laboratory, but they are subject to breakage and are heavy to transport. Because of their initial cost they are not considered disposable and, therefore, must be thoroughly washed and rinsed before reuse.

Accessories

Other equipment required for sample identification, labeling, preservation, and shipping includes:

- acid preservative (nitric acid, hydrochloric acid)
- membrane filter, 0.45 micron
- filter holder
- syringe, plastic
- rope or nylon cord
- buffer solutions, pH 4, pH 7, pH 10
- specific conductance standards
- marker, waterproof

- labels, permanent
- bottle caps
- bottles
- tape for sealing sample (preferably "evidence" tape)
- chain of custody form
- sample log book with: sample number, time, date, temp., weather, refrigerated, who, split sample

Inspection: Procedures and Pitfalls

This section addresses procedural aspects of inspection. Its purpose is to help inspectors avoid enforcement pitfalls. Each program has different performance standards, language, structure, types of enforcement activities, and required documentation. Therefore, the information given below should not be interpreted as policy, but simply as points to consider.

When a potential violation related to water is detected, the inspector should approach each aspect of sample collection and documentation as though all issues surrounding the violation and its documentation would be subjected to formal review proceedings. This extra care will facilitate any enforcement actions that may later be necessary. The following discussion addresses hydrologic problems as they relate to a "generalized" set of performance standards. It also mentions items of reference that might be considered before enforcement. Each citation given here—the language, documentation methods, details, and the style and content of the narrative—is intended simply as a generalized example. Greater detail is not presented in the examples because site-specific conditions in actual cases and the remedial requirements of each real enforcement action will differ.

Permits and Hydrology

Point-Source Discharges

As a rule, an NPDES or an equivalent State water discharge permit (sometimes both) are required before establishing the location of a "point source," or any limits on the quality of effluents discharging from that location. Circumstances and requirements differ, but operators are generally required to have such permits "in hand". Generally the permit must state the effective period, the identity of the points of discharge, and the parameters to be monitored.

Keys:
- — the Permit Application Package usually contains a list of other permits required for the operation.
- — the Permit Application Package usually contains a copy of the discharge permit application.
- — check with the discharge-permitting authority to see if a permit has been issued or applied for.
- — discharge permits may be issued for other than "point source" discharge — examples are multiple point sources, for drainage areas rather than individual outflows, for deep mine bore holes, for sewage treatment, etc.
- — the point source for enforcement is usually where discharge flows from the permit or disturbed area onto an adjacent area.

Typical Citation:

Failure to have an approved point source discharge permit as required prior to the construction of, or discharge from, a point source.

Documentation:
- — photo of the discharge point and its relationship to the permitted area.
- — record of conversations or discussions with the permittee/operator concerning permit availability for inspection.
- — references to pertinent regulations.
- — records — lab analyses, etc. — pertinent to the waters discharged from the point source in question.

The narrative report should clearly indicate the requirement for a permit, the efforts made by the inspector to document its existence, and any correspondence or applications in which the operator/permittee acknowledged the need for such a permit.

Groundwater Problems

The sequence or other operational aspects of mining such as overburden handling or blasting can cause unanticipated disruption of groundwater flow as well as degradation of groundwater quality. Issues related to groundwater are often brought into question when a complaint is raised or when there is an obvious change in flow volume or pressure at sampling points on either the permit or adjacent areas. Since determinations of cause and effect relationships are usually interpretive and sometimes complicated or extremely technical, the inspector may want additional technical assistance before drawing conclusions as to the cause of any observed effects. Before requesting help, an inspector should reread the Permit Application Package as it relates to the problem and make a tentative finding of cause for the observed effect.

Keys:
- — collect all information relevant to the site and the known affected area.
- — investigate other possible water sources and users who may also be affected to determine the probable scope of the problem.
- — consult the Permit Application Package geology and hydrology sections of the permit in question for premine conditions.
- — review the Permit Application Package(s) for adjacent or nearby permits having similar geologic and hydrologic structure and problem histories.
- — examine the PHC and CHIA for the permit.
- — contact local sources of information, including the operator, to accumulate a working reference of site conditions for obvious clues.
- — judge current conditions against previous conditions in light of mining sequence or techniques.

— ascertain whether structures (i.e., fills, ponds, etc.) actually or potentially involved have been properly built.
— collect evidence documenting the nature and degree of any off-site damage.
— obtain photos showing poor or improper mining practices (improper spoil placement, mishandling of acid/toxic materials, reopening of old mine workings, mining outcrop barriers, unapproved diversions, etc.) which may be causative factors.
— make a record of conversations with all parties interviewed regarding the problem or the probable cause.
— determine what would be necessary to present convincing proof of a violation to a third party.
— determine whether:
  • significant aquifers are involved
  • the coal seam is a significant aquifer
  • there is perched water in the area.

Typical citation:

Failure to conduct surface coal mining and reclamation operations in a manner which minimizes disturbance to the hydrologic balance within the permit and/or adjacent areas.

or: Failure to conduct surface coal mining and reclamation operations in a manner which will prevent material damage beyond the permit area.

Documentation:

— Photographic documentation of adverse conditions such as flooding, seepage, dry streams or ponds, or earth movement suspected of being related to the violation; and document the methods and results of pertinent measurements or tests.

The narrative report should discuss the chronological sequence of events before the inspection, steps of the investigation, the methods and models used to determine possible cause and effect relationships, references to factual documents, a statement of conclusions, and records of any requests for, or assistance obtained in completing the investigation.

Groundwater Monitoring

In general, regulations regarding groundwater monitoring require use of methods approved by the permitting authority. Monitoring of one or more of a great variety of quality and flow characteristics may be specified in the operating guidelines. Monitoring is usually required before mining, often for 6 months, to determine pre-mine groundwater condition. It continues through bond release or until such time as the regulatory authority has determined that postreclamation conditions are suitable. Acceptable limits for changes in groundwater flow and quality, as detected by the program, are set forth in the Permit Application Package groundwater monitoring plan. These limits differ considerably from permit to permit. The characteristics addressed by monitoring programs also may differ from permit to permit. This leads to great diversity; therefore, questions of compliance may have to be judged in accord with particular permits rather than by standards of performance.

Keys:
— is monitoring being conducted?
— is monitoring according to the Permit Application Package plan?
— do the required wells and monitoring points exist at the site?
— do the wells actually contain water?
— what do reports indicate, as compared to site conditions?
— do accesses to monitoring points and facilities appear to be used on a routine basis?
— does the person responsible for sampling know the locations of the monitoring points and the requirements of the permit?
— do monitoring reports contain all information required in the approved plan?
— are correct techniques being used by the person collecting samples? Can he or she describe the correct procedure?
— has approval for reduced monitoring been received in writing for a reclaimed site?

Typical Citation:

Failure to conduct groundwater monitoring in a manner that demonstrates compliance with the approved permit's groundwater monitoring plan.

Documentation:

— request copy of monitoring reports from the operator.
— copy essential report dates and information during review of these reports, when available, and note when such records are not available or are incomplete.
— confirm attempts to obtain missing records and data by appropriate reference to the lab which usually performed the analysis.
— record all requests for and conversations concerning monitoring records and information.

The narrative should document requests for and efforts to locate monitoring reports, and should describe information required by the monitoring plan. Statements by permittee or operator that indicate noncompliance or confusion about the monitoring requirement should be related. Include reasoning which leads to the conclusion that specifics of the permit monitoring plan were not followed, or that actual monitoring was inappropriate or was incomplete.

Surface Water Monitoring

Like groundwater monitoring, surface-water monitoring needs to be in accord with the permit and with the requirements of NPDES or other water permit authorities. Therefore, only a few items in addition to those mentioned previously under groundwater monitoring will be mentioned here. Keep in mind that programs differ in their monitoring requirements and that specific conditions or requirements may be imposed for individual permits.

Keys:
- when possible, observe the operator's sample-collection procedures.
- question sample-handling techniques and elapsed time between collection and lab analysis.
- compare reports with known high- or low-flow data.
- cross-check analysis if suspicious of sampling procedures or data.
- observe pond conditions in relation to sediment suspension and short circuiting.
- where continual treatment is necessary (AMD plants, etc.), check whether facilities appear to be maintained and operational during all required periods.
- look for telltale signs of sampling activity at monitoring discharge points.
- see whether monitoring reports and lab data for the permit area generally agree with those of nearby permits in the same area or drainage basin.

Acid and Toxic-Forming Materials

Surface and ground water contamination with acid or toxic-forming materials is commonplace in areas disturbed by mining. Surface waters and groundwaters in Appalachia may be degraded by iron and pH changes, while water in the Midwest may be high in manganese and western waters may have salinity problems. Various "best technology" approaches to handling potential problem materials have evolved, but no system has proven totally effective, even when properly planned and implemented. Many of the facilities and techniques currently used in mining were also used during the prelaw era. Their environmental effects are well known. An inspection of the handling and treatment of acid- or toxic-forming materials must consider the entire scope of operations if it is to address water quality problems properly and provide a basis for constructive solutions.

Keys:
- what is the relevance of acid- or toxic-forming materials as discussed in the Permit Application Package? Have the materials pertinent to the question at hand been identified?
- what aspects of the permit or treatment facility are associated with those materials?
- is volume of surface or groundwater influencing the nature or degree of the problem?
- what does the monitoring plan indicate for the mine and adjacent areas?
- are material handling, treatment, and placement operations consistent with those of the permit and with their applicable performance standards?
- what facilities or practices were to be built or implemented in order to minimize water contact with acid or toxic materials, and are they properly designed, constructed, and maintained?
- how long is the current situation likely to last?

Typical Citation:

Failure to [(use appropriate one or combination) identify, treat, handle, bury, or store] acid- and toxic-forming materials in a manner that will prevent or minimize, to the extent possible, adverse effects on the quality of surface water and groundwater.

Documentation:
- samples of problem-causing materials and the results of tests run on those materials.
- water samples and test results that demonstrate a cause-and-effect relationship with materials mismanagement.
- photos showing improper handling, placement, compaction, covering, or treatment of materials.
- photos or documentation showing the absence or ineffectiveness of runoff diversions or other schemes for preventing contact between water and potentially acid or toxic materials.
- evidence of improper or long-term storage of materials.
- previous inspection reports or other documentation of similar problems on prior occasions.

The narrative should clearly delineate the various factors and actions associated with the handling of acid- or toxic-forming materials as they pertain to the violation. It should construct a chronological, historical chain of events and actions from initial cause(s) of current problems (example: "On June 9, 1983 at 3:15 p.m. seepage was noted near the toe of the embankment of sediment control structure designated A-12 on Permit No. ________. The seepage was at a point 25′ left of the main spillway, approximately 42.5′ right of the emergency spillway, and at an elevation 5.5′ above the flow line of the main spillway outlet. The inspection report for this structure dated October 15, 1983 documents that underdrains were not installed at the time of its construction. There is no documentation or field evidence that underdrains have since been installed."). Indicate what differences there are between material handling practices and the results obtained at this operation and those at other comparable operations in the general vicinity.

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Appendix A
The Hydrologic Cycle

The unending circulation of the earth's water through the atmosphere, land, and oceans, has no beginning or end, but we can think of it as beginning with the waters of the oceans. Water from the surface is evaporated into the atmosphere, is lifted, and is eventually condensed and falls back as precipitation.

The precipitation that falls as rain, hail, dew, snow, or sleet on lands within mining permit boundaries is of particular concern to the inspector.

Some of the precipitation, after wetting the foliage and ground, runs off over the surface. It is this runoff that sometimes causes erosion and is the main contributor to floods. Of the precipitation that soaks into the ground, some is available for plant growth, some is evaporated, and some reaches the deeper zones and slowly percolates back to the surface through springs and seeps. This water maintains streamflow during dry periods. The streams eventually flow back to the oceans, where the cycle begins anew.

Precipitation Interception

Water is delivered to the land as rain, hail, snow, and sleet. What happens to it after that depends on its state, rate of delivery, and on the character of the plants, soil, and underlying material. Its fate, in turn, largely determines the severity of floods and erosion, the quantity and quality of water supplies, and the production of vegetative cover.

Only a part of the rain or snow from each storm event reaches the soil without interference. Vegetation interposes leaves, branches, and litter, affecting the quantity, distribution, and kinetic energy of precipitation that reaches the soil surface. Rain and snow are affected differently in some respects. Part of each passes through the canopy of vegetation without being caught, but if the canopy is dense, a large part strikes leaves or branches. Leaf cover can be seasonal so interception can also be largely seasonal, particularly in temperate regions of the world.

Of the part thus intercepted some spills from drip points, some flows to the ground along stems, and some is held and evaporates without ever having reached the land surface. Rain wets the vegetative surface it strikes. It can form only a thin water layer before it starts flowing toward the ground. Snow may wet the surfaces it strikes, but whether it does or not, it can pile up to a considerable depth. A good deal more snow than rain can thus be intercepted by vegetation.

The quantity of precipitation that is intercepted by vegetation and then evaporated depends on the kind and size of storm, the kind and extent of vegetative cover, and the temperature and humidity of the ambient air. It represents, however, a fairly constant percentage of annual precipitation under the same vegetation conditions. Where interception has been measured, it generally has been found to be between 5 and 15 percent of the annual precipitation.

Vegetation and its debris act to disperse the energy of falling rain, hail, or sleet and thus constitute a first line of defense against runoff and erosion.

Infiltration

Rain that reaches the soil surface is wholly or partly absorbed by the soil in the process of infiltration. How much of it enters the soil depends upon the rate of rainfall and the infiltration rate of the soil. Runoff or surface flow results when water is delivered to the soil faster than it can be absorbed. Surface flow is generally undesirable because it may erode the soil and because it may produce flash floods during storms. Because of the damaging consequences of surface-flowing water, many land management practices are designed to induce as high an infiltration rate as possible.

Infiltration rate is controlled by a combination of factors—some natural and some the result of modifications imposed by use of the land. Infiltration rate is naturally greater in sandy soil than in clay. Ordinarily, the finer the soil texture, the lower the rate of infiltration. But the effect of texture is modified greatly by the aggregation of the soil particles and by the structure of the soil. A surface soil that is well supplied with organic matter is ordinarily far more receptive to water than a soil consisting mainly of mineral material. Maintaining an organic-reinforced open structure is one of the objectives of mulching.

Percolation

Water entering the soil either increases the moisture content of the soil or drains through it. If the soil is dry, water entering it wets successively deeper horizons to field capacity, which is the moisture content to which a soil must be raised before water can drain through it. Until the entire soil profile has been wetted to field capacity, water movement is basically downward. When field capacity is reached, additional waters entering the soil will move laterally in the saturated zones to emerge in springs and seeps. When little or no lateral movement occurs, these waters simply raise the elevation of the water table.

Water draining through the soil feeds streams longer and more evenly than water flowing over the soil. For maximum water control the best reclamation practices are those that induce the most water to enter the soil, except where the lateral movement of subsurface water might endanger the stability of fragile natural slopes or constructed embankments.

Evaporation and Transpiration

Water held within the soil after drainage has ceased can be transpired by plants or lost by evaporation. Plants cannot utilize all water stored in the soil; they can dry the soil only to the wilting point. The wilting point is that moisture content at which the surface tension force holding water to the soil particles equals the maximum water-absorbing force of plant roots. Just as clay soils can hold more water at field capacity than sands, so also is the wilting point of a clay higher than that of a sand. Both the upper and lower limits of the available moisture range, between wilting point and field capacity, are determined primarily by soil texture and organic matter content (Fig. 4).

Evaporation can dry soil below the wilting point. In the evaporation process, soils dry from the surface downward. All soil water lost by evaporation must rise to the soil surface and pass through it. Given sufficient time without water additions, soils may dry many feet deep. Ordinarily, evaporation significantly affects only soils near the surface.

Evaporation and transpiration together take their toll of soil water in response to a number of conditions. If the soil surface is free of plants but thickly covered with an insulating layer of litter, evaporative loss will be much less than if the vegetation-free soil is bare. A soil loses less water under a cover of shallow-rooted plants than under plants whose roots reach to the full depth of the soil. Where a water table exists a short distance below the root zone, the lower soil layers may not dry perceptibly, although large quantities of water may be withdrawn from the water table.

Evapotranspiration rates and volumes can be modified in various ways. Protective mulches can be placed on the soil surface to reduce evaporation. The loss of plant leaves can reduce transpiration to nearly zero during winter or extreme drought. Transpiration can be reduced by removing or thinning undesirable vegetation. Shallow-rooted plants can be grown on soils previously occupied by plants with deep roots. On the other hand, deep-rooted plants may be used to remove soil moisture, where an excess of moisture might be undesirable. There are, however, limitations to how far transpiration losses can be modified. It is obviously not desirable to reduce the density of plant cover so much that the soil is insufficiently protected against storm runoff and erosion.

Typical Water-Holding Characteristics of Different-Textured Soils

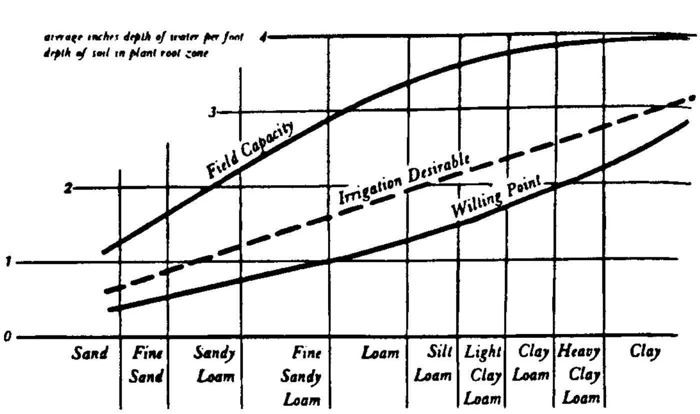

Figure 4. Typical water-holding capacities of different-textured soils.

Ground-water Zones and Belts

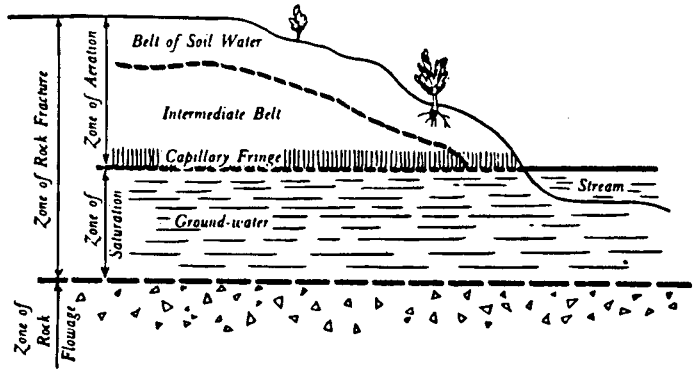

Figure 5. Schematic of groundwater zones and belts.

Perhaps the most important point regarding transpiration is that it is a natural process that occurs wherever there is vegetation. While transpiration and evaporative water losses can sometimes be reduced by treating the soil and its cover, they cannot be eliminated.

Subsurface Water

Water that has infiltrated into the soil is known as subsurface water. It may be evaporated from the soil; it may be absorbed by the plant roots and then transpired; or it may percolate downward to groundwater reservoirs and move laterally into streams. Subsurface water occurs in that zone between the ground surface and the lower limits of porous, water-bearing rock formations. This zone is designated as the zone of fractured rock and is subdivided into the zone of aeration and the zone of saturation (Fig. 5).

The zone of aeration is further divided into three belts—the belt of soil water, the intermediate belt, and the capillary fringe. The belts vary in depth and are not sharply defined by physical changes in the soil. Indeed, depending upon differences between inflow and outflow rates, the belt boundaries on any given site will fluctuate. In natural soils generally there is a gradual transition from one belt to another; however, on reclaimed mines the transition may be sharp. In considering the movement of water through the soil profile, however, it is desirable to delineate zones or belts that have different effects on the subsurface movement of water.

The upper belt, or belt of soil water, consists of the topsoil and subsoil from which water is returned to the atmosphere by evaporation and transpiration. As water passes through the surface and enters this belt, it is acted upon by gravity and molecular attraction. Gravity tends to pull the water downward. Molecular attraction tends to hold the water in a thin film over the surfaces of soil particles and in the very minute spaces between the particles. Only when sufficient water has entered this belt to satisfy the storage requirements due to molecular attraction does water start to percolate downward under the force of gravity.

The belt of soil water is of particular importance to reclamation because it furnishes the plant-available moisture necessary for vegetation to grow. The depth of the belt of soil water varies with the soil type and the vegetation rooting depth, and its thickness may vary from a few feet to several tens of feet. Water passing downward from the belt is beyond the reach of plant roots and is no longer available to support plant growth. However, the roots of some plants extend to the water table, especially if the water table is not too far down.

Water passing through the belt of soil water enters the intermediate belt and continues its movement downward by gravitational action. Like the belt of soil water, the intermediate belt holds water suspended by molecular attraction. In this belt, however, suspended water can be considered dead storage, since it is not available for use. In the hydrologic cycle, this belt serves only to provide a passage for water from the belt of soil water to the capillary fringe. The intermediate belt may vary in thickness from zero to several hundred feet; its thickness has a significant effect on the time it takes water to pass through the belt and reach the water table or to exit as seeps or springs.

The capillary fringe lies immediately below the intermediate belt and above the zone of saturation. It contains water that is held above the zone of saturation by capillary force. The amount of water held and the thickness of the capillary fringe depend on the type of material in which the capillary fringe is located. In silty material it may extend 2 feet or more above the zone of saturation. In a coarse, gravelly material it may extend less than an inch. As in the intermediate belt, water is stored in the capillary fringe. Water moved by gravity from the surface to the zone of saturation passes through the capillary fringe.

Groundwater

The zone of saturation, or groundwater, forms a natural reservoir that feeds springs, streams, and wells. Water moving by gravity through the three belts of the zone of aeration enters the upper surface of the zone of saturation, which is referred to as the water table. With the possible exception of some with entrapped air, all the pores and spaces in this zone are filled with water. The depth of the zone depends on the local geology. It may include loose, unconsolidated deposits of sand and gravel, as well as porous rock formations such as sandstone and limestone. Its lower limit is that point where the rock formation becomes so lacking in pores and joints and cracks that water cannot penetrate it. The zone of saturation may vary in thickness from a few feet to hundreds of feet.

The zone of saturation is extremely important because it provides water for wells and the normal, relatively uniform flow of streams. It receives water during wet periods so that the water table rises as water drains into it from above. It can thus store huge supplies of water which, because of the slowness of its lateral movement through the zone, is discharged at a slow and relatively uniform rate.

The top of the zone of saturation is generally called the water table. The action of gravity tends to make the water table a level surface. However, because movement of water is relatively slow through soil and rock formations, the frequent additions and withdrawals do not usually permit the water table to become a truly level surface.

During periods of low flow, the level of the water surface in a stream may drop below the level of the water table (Fig. 6). Groundwater will then seep into the stream and the slope of the water table will dip toward the stream in the direction of groundwater flow. When the stream is flowing at a level above the water table, seepage moves in the opposite direction and the water table rises. Because of the constant changes resulting from increased supply to groundwater or the increased demand from groundwater, the level of the water table is constantly changing.

Geologic formations also affect the water table. Where there are layers of impervious material, it is possible to have water tables at different elevations (Fig. 7). Water may be confined in a permeable layer between two impervious layers. Such confined waters may be under hydrostatic pressure. Occasionally pressures are sufficient to cause the water to rise in a well above the land surface, creating a flowing well.

Conditions differ greatly under different geologic formations, but in the hydrologic cycle the principal functions of the ground water zones are as follows:

- Zone of aeration—receives and holds water available for plant use in the belt of soil water and allows the downward movement of excess water.
- Zone of saturation—receives and stores water, and provides a natural regulated discharge to wells, springs, and streams.

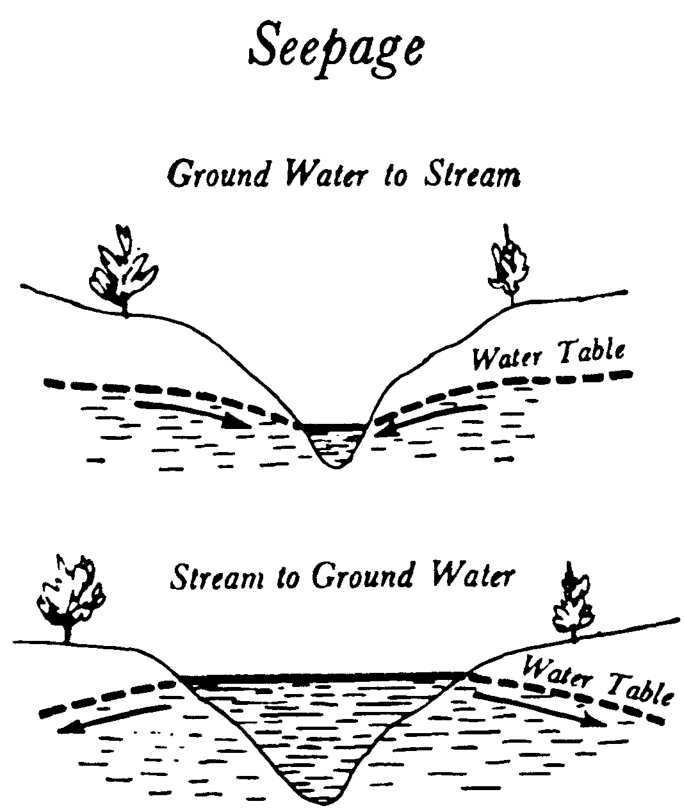

Figure 6. Seepage between the water table and stream.

Runoff

Broadly speaking, runoff is composed of water from both surface flow and subsurface flow.. It is an extremely important segment of the hydrologic cycle, since, on the average, about 20 percent of all precipitation is carried to the ocean by streams and rivers. When precipitation does not have an opportunity to infiltrate the soil and flows across the land surface in very thin layers, it is referred to as sheet flow. Eventually, most of the surface runoff enters stream channels which carry it to the ocean. Once in channels, the surface flow is referred to as streamflow.

Inspectors are directly concerned with the surface flow portion of runoff. They need to understand the factors that affect the volume and rate of surface flow so that they can recognize situations and land management practices that are beneficial as well as those that may lead to disastrous effects during periods of high flow.

The amount and the rate of precipitation affect the volume and peak flow of a stream. Similarly, temperature may influence runoff. During periods of low temperatures, precipitation may accumulate in the form of ice or snow. This is particularly important in areas high in latitude or elevation. Rapid temperature rises often result in exceedingly rapid snowmelt. This in turn may cause high rates of surface runoff, particularly when the soil is frozen.

The physical characteristics of a watershed indicate what might be expected in total storm runoff volume and peak rate of runoff. A relatively impervious, steeply sloping watershed may shed most of the precipitation falling on it, but a level or gently sloping watershed with deep, permeable, well-protected soils may absorb essentially all of the precipitation.

In the first instance, high peak rates of flow and sharp rises and falls in flow rates would be expected. In the latter case the peak flow would be considerably less, and flow rates would change relatively slowly. However, the flow volumes produced over a long period would not necessarily be significantly different. Steep slopes produce high peak rates of runoff but have little effect on the total volume of runoff. Good vegetative cover and a layer of surface debris tend to foster infiltration, thus materially reducing the rate

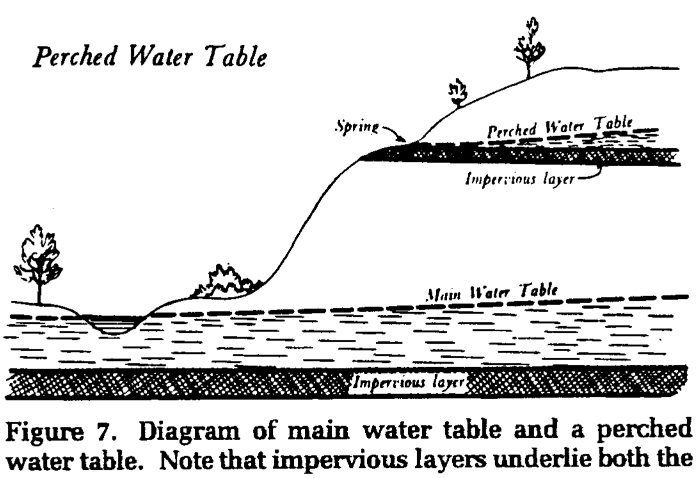

Figure 7. Diagram of main water table and a perched water table. Note that impervious layers underlie both the water tables.

at which water reaches the stream channels. As surface flow volume decreases, the volume slowly passing through the soil or spoil and entering the stream as seepage flow increases.

Lakes, ponds, swamps, and reservoirs also act to lower peak flows and to extend flow duration in the streams they feed. Generally, there is but little loss of flow to groundwater from natural lakes and swamps since they are usually where the ground surface intersects the local water table. However, artificial impoundments, properly located, designed, constructed, and maintained, can be used effectively on surface-mined land to control or regulate runoff.

Among the many factors that affect runoff to some degree are: barometric pressure, which can affect the flow of springs and artesian wells; seepage from stream channels; and evaporation from streams. The degree to which such factors must be considered depends on the particular situation. No two streams or watersheds are alike; each has its own characteristics.

Hydrologic Balance

Although the amount of water with which we are concerned in the hydrologic cycle remains essentially constant, its distribution within any given watershed or area of interest is continually changing. The hydrologic balance within a watershed is the relationship between water input, water storage, and water output. Before mining, the hydrologic system as a whole is in balance, although some or all of the elements of the balance may be changing. Normally, precipitation is the primary mode of water input. However, there are situations where aquifers also are important means of supply. In certain cases streams originating outside the area to be mined must also be considered a source of water supply to the mined area. Waters stored on a site may be in the form of groundwater, soil moisture, or surface water. Water output is primarily in the form of streamflow or evapotranspiration, but sometimes groundwater is also important. Sometimes water is imported to the area or is consumed within the area. When that is the case, these factors must be considered in the hydrologic balance.

Surface coal mining and reclamation can affect all three phases (input, storage, and output) of the hydrologic balance in many ways. The effects may occur both on and off the mine site. Mining and reclamation can directly affect onsite groundwater storage capacity, groundwater movement, water table levels, surface drainage channels, surface water storage, and evapotranspiration. All of the changes in the hydrologic system on site can combine to cause changes in the quantity and quality of both surface and groundwater output (water yield). This can lead to adverse effects downstream, including scour and sedimentation in stream channels, disruption of aquatic habitats, and changes in both the quantity and quality of the water supplies to public or private users. The frequency, magnitude, and duration of floods may also be affected.

Appendix B
Water Data Collection and Analysis

Basic Water Data Collection

Water quality, streamflow, and groundwater level data that are presented in permit application packages are to be collected, analyzed, and presented in a manner consistent with requirements. Generally, these data are in a format that makes them readily available to the public. Use of such a format may minimize data collection requirements for future permits. Applicable procedures for data collection, data processing, and laboratory analyses are described in the Office of Water Data Coordination's National Handbook for Water Data Acquisition (U.S. Geol. Survey 1977).

The recommended minimum duration of basic data collection for specific parameters includes appropriate seasonal high and low flow periods characteristic of the region under study. Because this short period of data collection may not reflect long-term variations in hydrologic conditions, the representativeness of the hydrologic data is evaluated by standard hydrologic statistical techniques or by comparison with long-term regional hydrologic norms.

It is recommended that an elevation datum at each monitoring station be established by level altimeter survey or other approved method, and be referenced to mean sea level. Determining the longitude and latitude of all monitoring stations facilitates storage and retrieval of data for future use, whether for the same permit or for others in the same area. Longitude and latitude are required if the data are to be entered into the national data base.

Surface Water

Surface water quantity and quality are normally measured on streams draining the area to be mined, as well as adjacent areas that may be affected by mining. For small operations these measurements may be made downstream from the mine plan area. Where perennial or intermittent streams transect the mine plan area, it may be appropriate to take additional measurements upstream from the proposed mine area.

Monitoring sites in and near the mine plan area that are to provide data used to estimate seasonal characteristics of the surface water should be chosen so that the following characteristics of surface water can be evaluated:

Surface Water Parameters and Frequency

Seasonal streamflow characteristics can be estimated from site-specific peak flow and low flow data collected during the pre-mine inventory. If models applicable to the area are not available, partial record stations equipped with crest-stage gages and staff gages for correlation (by graphical or statistical methods) with long-term flow data from nearby stations are often used.

Peak or Flood Flows

Peak flows during the sampling period can be determined by direct measurements or by indirect methods such as slope area, culvert computation, contracted opening, or other appropriate method. They should involve storm events. The return periods for these peak flows can be developed from flow frequency relationships, which may have to be indirectly estimated as described below. The storm runoff volume should also be estimated from peak flow and precipitation data.

Estimates of pre-mining flood flows may be available from published sources such as the statewide flood frequency reports of the U.S. Geological Survey. McCuen and others (1977) published a literature evaluation of techniques for determining flood flow frequency for ungaged natural watersheds. In addition, appropriate regional hydrologic models or techniques, including Soil Conservation Service methods described by Haan and Barfield (1978), may be useful to develop flood flow characteristics for desired frequencies.

Low Flows

Low flow is normally coincident with base flow and is highly dependent upon groundwater discharge into streams. Flow information is often collected at the surface-water monitoring sites. Flow calculations can be made using a standard current meter to determine velocity at a known cross-section. Estimates derived from open channel flow models or with a flume, weir, or similar device with an established rating can also be used. For very low flow situations, a calibrated container and a stop watch may be the most appropriate equipment. Flow data can be estimated from baseflow relationships of a nearby watershed for which long-term streamflow data are available. It is best if the nearby watershed is similar in area as well as topographic and vegetative characteristics.

Flow Duration

Flow duration estimates for the surface-water monitoring sites show the percentage of time that any flow may be equaled or exceeded. If sufficient data cannot be gathered at the monitoring sites to produce a flow duration curve, then data that are collected can be compared to duration curves of nearby gaged streams, and a duration curve can be synthesized for the monitoring sites. Where available, an appropriate regional model may be used to synthesize flow duration curves. Also, flow duration estimates can be calculated using regression equations based on basin characteristics and streamflow statistics for the state or the general area.

Models

Models may be useful to predict post-mining surface water conditions. Models may be calibrated for pre-mining conditions with data from nearby areas. Independent variables can be changed to reflect post-mining values and the models used to predict post-mining conditions. Another approach is to use nearby watershed studies and apply the ratio of pre-mining to post-mining effects to the pre-mining parameters in the mine plan area to predict post-mining effects on the watershed.

Modeling may be used to *estimate* impacts of mining upon aquatic biota. However, because modeling is an emerging art, models may not yet be available for *predicting* the consequences of mining on aquatic biota. At present, predictions are normally made on the basis of actual measurements of streams in the region, where water quality and flow regimes are similar to those in the area to be mined.

Chemical Water Quality

Field Measurements. The following parameters are normally measured at each surface-water monitoring site:

- Temperature, in degrees C
- pH, in standard units
- specific electrical conductance, in micromhos per centimeter at 25°C
- acidity titrated to pH 8.3, in mg/l as $CaCO_3$
- alkalinity titrated to pH 4.5 in mg/l as $CaCO_3$

Appendix D contains a quick reference guide for water quality sampling.

Laboratory Measurements. Samples are submitted for laboratory analysis for total dissolved solids, total iron, total manganese, dissolved iron, and total suspended solids. The results are expressed in milligrams per liter.

The samples are often analyzed for the major inorganic constituents (dissolved calcium, magnesium, sodium, potassium, chloride, nitrate, bicarbonate, and sulfate) and other relevant chemical constituents. These data can be used to aid in characterizing the chemical water type and the buffering and assimilation capacity of the streams.

On-site Erosion and Sediment

On-site erosion before mining should be evaluated for the same storms during which the peak flows are determined. Suspended solid samples should also be collected for these storms at the surface-water monitoring sites. Runoff volume, discharge peaks, and sediment loads could then be estimated for each of the storms.

Two approaches to erosion and sediment prediction and measurement are often used, one to estimate the average annual onsite erosion rate, the other to estimate the stream sediment loads resulting from a selected individual storm.

Onsite erosion rates can be estimated for the monitored storms using a modified universal soil loss equation (USLE) as described by Williams (1975). The watershed LS factor should be determined by the technique of Williams and Berndt (1976). The K and T factors are described by the Soil Conservation Service (1975a). Erosion estimates for the interior U.S. are discussed by the Environmental Protection Agency (1977); see also Wischmeier and Smith (1978). After the onsite erosion estimate is made, it should be compared with the suspended solids data to see whether a relationship can be demonstrated and the USLE parameter values validated. Data for the average annual erosion rate should then be developed for the same site for which the storm erosion estimates were made.

There are several approaches to predicting average annual on-site erosion. The USLE procedures were originally developed for agricultural use. A modification of the USLE has been developed for nonagricultural land use by Wischmeier (1975). Additional coefficient modifications pertinent to forest land management use were made by the U.S. Forest Service. Before these modified equations are used, the appropriate State or Federal forestry agency should be contacted for a copy of the appropriate guidelines.

An alternative approach to evaluating average annual onsite erosion that utilizes the USLE, but without the complex measurements, is described by the Soil Conservation Service (1975). Haan and Barfield (1978) also summarized the USLE approaches. Once the estimates of the parameters in the USLE have been validated for the premining conditions, certain of these parameters can be estimated for future conditions, and predictions can be made. If these predictions are to be translated to other locations, a sediment delivery ratio will have to be considered. This approach to sediment delivery must be used with caution because adjustments must be made for differing stream locations, changes in terrain due to mining, and the destruction of ground cover between the minesite and the stream.

Aquatic Biology

High flows may carry large volumes of sediment and organic matter, cause channel scour and redeposition, lower the dissolved oxygen concentration, and thereby change the habitat for fish and the organisms they eat. Disruption of continuous flows or frequent low flows containing acid or other toxic substances can also impair the aquatic (biologic) balance of the stream. Thus, to understand the complete hydrologic balance of an area, elements of the aquatic biologic community must be determined before mining to estimate what changes will occur as a result of mining. The macroinvertebrate population is considered a good indicator of a stream's "health."

The aquatic biology in perennial streams is identified by sampling. Sampling during low flows (preferably in early summer) can be used to estimate communities of biota. Considerations in defining the sample area include width, depth, riffle and pool areas, and sinuosity of the stream. Standard techniques for collecting macroinvertebrate samples allow for species identification, diversity, and density. The following physical parameters are normally recorded and considered in the analysis of the biologic community: streamflow, type of substrate, past or present watershed disturbance that may contribute effects to the sample site, and vegetative canopy over the stream. Biological sampling is often coordinated with routine monthly water quality sampling.

Groundwater

The effects of mining on the groundwater system can be estimated with appropriate groundwater flow and solute transport models, or from data collected before and after mining operations at nearby watersheds or research watersheds. Bachmat and others (1978) summarize many available models that simulate groundwater systems. Changes in groundwater characteristics can affect the water quality and flow characteristics of surface water streams. Baseflow characteristics are particularly susceptible to impact.

Groundwater Inventory

During an inventory of groundwater wells and springs the following information, if available, is usually collected:

- Depth of well
- Diameter of well
- Depth of casing and location of perforated or screened intervals
- Date drilled
- Use of water
- Static water level
- Yield of well
- Formation name and rock type of the aquifer(s)
- Location (elevation or depth below surface) of water-yielding zones
- Land surface elevation at well site
- Water quality
- Type of water treatment, if applicable
- Estimated amount of water used daily
- Permission to use the well for monitoring purposes or to test for hydraulic characteristics.

Groundwater Monitoring

Groundwater monitoring sites may consist of a combination of observation wells (appropriate existing wells or wells drilled specifically to monitor groundwater conditions) and existing springs.

For groundwater quality monitoring, emphasis should be on locating sites generally downgradient from the mine area because this is where the impacts of mining generally will be detected. The number of monitoring sites will depend upon the number of aquifers, whether they are present above and below the coal to be mined, and on the size of the mine area. Where coal seams are themselves aquifers, it may be necessary to install observation wells in the coal seams and to sample any water discharged from underground mines.

At least one observation well should be drilled for quality and water level monitoring unless sufficiently detailed information on groundwater is available or existing wells can be utilized for groundwater monitoring. The need for additional wells can be judged from the first well. Generally, the areal distribution and number of groundwater monitoring sites should be such that gradients and directions of flow can be defined. Under certain conditions, such as in fractured bedrock, these points of measurement may be quite variable. Unless there is no hydraulic connection between the proposed disturbed area and the underlying aquifer, it will be necessary to monitor groundwater in the first aquifer beneath the coal. The importance of wells above the coal is to document any dewatering of the aquifer as a result of mining. Further, where observation wells are drilled, those wells completed above the coal seam to be mined may have to be located close to those wells completed in the first saturated stratum below the coal seam so that potential vertical movement between aquifers can be evaluated.

Groundwater Parameters and Frequency

Water Level Elevations. Water levels are measured in observation wells. A well may be equipped with a continuous recorder or measured on a schedule so that a hydrograph of water levels can be prepared.

Field Water Quality. Samples for groundwater quality determinations are normally collected at times that correspond to seasonal high and low water levels and an intermediate time during the sampling period. Observation wells should be pumped or bailed until a representative sample of aquifer water can be obtained for water quality analysis as described earlier in this section.

Aquifer Characteristics. Aquifers are tested through observation wells. There are several types of tests: a standard pump test, instantaneous injection or withdrawal test, or bailer test. Water level data are analyzed to provide values of transmissivity, hydraulic conductivity, and specific capacity. Field tests may be required to determine storage coefficients. Existing boreholes or coreholes may be used for observation wells in storage coefficient tests.

Data Analysis. The observed data are tabulated and described relative to high and low water levels and water quality variations. Aquifers are classified according to the presence of unconfined (water table) or confined (artesian) conditions. Recharge and discharge areas for the aquifers are normally described on maps and cross sections showing groundwater levels, horizontal extent during seasonal high and low water levels, and other observed water level information. If more than one aquifer is present, groundwater level relationships and vertical movement between aquifers are usually described for seasonal high and low water levels. Also, a description of the present or potential future use of any aquifer is usually prepared.

Appendix C
Acid Mine Drainage

The oxidation of pyritic materials is not completely understood but has often been described by the following equations:

$$FeS_2 + 3\frac{1}{2}\,O_2 + H_2O \rightarrow Fe^{++} + 2SO_4^{=} + 2H^+ \quad (1)$$
$$Fe^{++} + \frac{1}{4}\,O_2 + H^+ \rightarrow Fe^{+++} + \frac{1}{2}\,H_2O \quad (2)$$
$$Fe^{+++} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+ \quad (3)$$

These three equations may be added to give the overall stoichiometric relation:

$$FeS_{2(s)} + 3\frac{3}{4}\,O_2 + 3\frac{1}{2}\,H_2O \rightarrow 4H^+ + 2SO_4^{=} + Fe(OH)_3 \quad (4)$$

The slow oxygenation of ferrous iron (Fe^{++}) shown in equation 2 has generally been considered to be the rate-determining reaction; however, this rate can increase 500,000 fold in the presence of the iron bacteria *Thiobacillus ferrooxidans*, normally associated with pyrites in mine spoils (Bruynestein and Hackl 1982). This step is followed immediately by the rapid oxidation of more iron disulfide by the newly formed ferric iron (Fe^{+++}). The equation for this reaction may be written:

$$FeS_{2(s)} + 14Fe^{+++} + 8H_2O \rightarrow 15Fe^{++} + 2SO_4^{=} + 16H^+ \quad (5)$$

Rewriting equation 2 to show the oxidation of 14 moles of ferrous iron gives:

$$14Fe^{++} + 3\frac{1}{2}\,O_2 + 14H^+ \rightarrow 14Fe^{+++} + 7H_2O \quad (6)$$

Adding equations 5 and 6 gives the overall reaction:

$$FeS_{2(s)} + 3\frac{1}{2}\,O_2 + H_2O \rightarrow Fe^{++} + 2SO_4^{=} + 2H^+ \quad (7)$$

Equations 1 and 7 are identical, showing that by either path (O_2 or Fe^{+++} as the oxidizing agent) the net reaction is the same. In both cases oxygen must be supplied to the system at a rate equivalent to the rate of iron disulfide oxidation.

When large concentrations of dissolved iron are found in streams or lakes it is almost always in the ferrous form. Ferrous iron exposed to oxygen from the atmosphere will oxidize as shown in equation 6, then hydrolyze to form a ferric hydroxide precipitate as shown in equation 3.

As shown in equation 4, the products of iron disulfide oxidation are: (1) hydrogen ions that lower the pH and increase the acidity of the receiving water, (2) sulfate ions that contribute to the salinity of the receiving water, and (3) ferric hydroxide that is essentially insoluble in water and precipitates as the yellow-orange deposit commonly referred to as "yellow-boy." Complex iron compounds such as basic ferric sulfate and jarosite may also be major components of "yellow-boy" (Bruynestein and Hackl 1982).

Of the three major end products of acid mine drainage (AMD) shown in equation 4, the hydrogen ion (H^+) or acid is the one of greatest environmental concern. AMD commonly has pH values ranging from 2 to 4.5. At these low pH values metals such as iron, aluminum, copper, and nickel enter into solution to further pollute the water. Water of this type supports only limited life, such as acid-tolerant molds and algae; it will not support fish; destroys and corrodes metal piers, culverts, barges, etc.; increases the cost of water treatment for power plants and municipal water supplies; and leaves the water unacceptable for recreational uses.

Enough water to satisfy equations 1, 3, 4, 5, and 7 is usually available in the overburden and coal or from humidity in the atmosphere. Water also serves as the transport medium that removes the oxidation products from the mining environment into streams.

Appendix D
Quick-Reference Field Guides for Water Quality Sampling

1. Conditions That May Warrant Collection of a Water Quality Sample

Condition	*Analyze for*
Muddy water	Total suspended solids
Black water	Total suspended solids, pH*
High-flow conditions	Total suspended solids
Clear water devoid of life	pH, acidity
High total iron	pH
High specific conductance	pH
Groundwater with bubbles	pH, acidity
High sulfur coal seam	pH, sulfate
Presence of treatment facilities	Total suspended solids, total iron, pH
Low pH	Total iron, total manganese, acidity
Red, orange, or red-brown water	pH, total iron
Black, oily appearance	Total manganese
"Yellow boy" stains	pH, total iron
High pH	Alkalinity
Muddy water with low pH	Dissolved iron
Citizens complaint alleging:	
Presence of metals in water	Specific conductance,* pH, dissolved metals, total metals
Inorganic constituents	Specific conductance, pH, major ionic constituents
"Contamination" of water supply	Specific conductance, pH, temperature

*Temperature measurements should be made simultaneously with all pH and specific conductance measurements made with field meters.

2. Measurement of Temperature

Temperature measurements should be made directly in the source, if possible.

1. Check thermometer for liquid-column separation.
2. Immerse bulb into source.
3. Allow reading to stabilize.
4. Read temperature with bulb immersed.
5. Report temperature to the nearest degree C.
6. Return thermometer to protective case.

If temperature cannot be measured in the source, collect at least an 8-ounce bottle of water and measure temperature immediately.

3. Measurement of pH

Calibration of Meter

Calibrate meter using two buffer solutions, 4 and 7 or 7 and 10, using last the buffer having a pH nearest that of the sample.

1. Check battery.
2. Expose filling opening on electrode to atmosphere.
3. Place function switch on "standby" or "ready."
4. Measure temperature of buffers.
5. Set temperature compensation to temperature of buffers.
6. Rinse electrode with deionized water and blot dry.
7. Place electrode into buffer.
8. Place function switch on "measure."
9. Adjust "standardize" knob to pH of buffer.
10. Place function switch on "standby."
11. Rinse electrode thoroughly with deionized water.

Measurement of pH

1. Place electrode into sample to a depth of approximately 1 inch.
2. Measure temperature of sample.
3. Set temperature compensator to temperature of sample.
4. Turn function switch to "measure."
5. Allow meter readout to stabilize.
6. Record pH to nearest 0.1 pH unit.
7. Rinse electrode with deionized water.
8. Cover electrode with moist protective cap containing distilled water or buffer.

If litigation is anticipated, repeat measurement and record all readings. Do not average values.

Precautions:

1. Never remove electrode from buffer or sample unless meter is in "standby" or "off" position.
2. Dirty connectors on pH electrodes may result in erroneous readings.
3. An unstable reading may indicate either static electricity (reduce with an antistatic cloth) or a broken or loose cable shield wire.
4. Keep electrode filled with the recommended solution to within ½ inch of filling opening.
5. Keep electrode tip moist by filling the provided rubber cap with either pH 7 buffer solution or deionized water.
6. Never immerse the electrode to such a depth that the surface of the filling solution is below that of the test solution.
7. Follow instructions which accompany the meter on use of the temperature compensator. This knob may serve more than one function.
8. Do not let the electrodes freeze.
9. Avoid contamination of buffer. Use a separate container (cup) and discard it after use.
10. Broken or scratched electrodes can give erroneous readings.
11. Do not leave meter exposed to extreme weather conditions.

4. Measurement of Specific Conductance

Check instrument against at least two known standards before every field trip.

1. Check battery.
2. Rinse electrode with sample water.
3. Return electrode to sample for temperature equilibration.
4. Agitate electrode in sample to eliminate air bubbles.
5. Measure temperature of sample.
6. Set temperature compensator to temperature of sample.
7. Read conductance according to manufacturer's instructions.
8. Remove electrode from sample, then reinsert it and repeat steps 4 through 7 until two consecutive readings are in agreement.
9. Record conductance in micromhos at 25°C.
10. Remove electrode from sample and rinse thoroughly with deionized water.

Precautions:

1. Gently agitate electrode in sample to eliminate air bubbles.
2. Allow water temperature and electrode temperature to equalize.
3. Make temperature correction (Automatic or manual compensator or by table).
4. Make sure electrode is clean.
5. Do not leave meter exposed to extreme weather conditions.

5. Sample Collection— Raw Untreated Sample (RU)

Depending upon flow conditions, use either a US-DH-48 sediment sampler with a clean bottle, or only a clean narrow-mouth bottle to collect the sample.

1. Rinse sampler and sample container by collecting a small amount of native water. Discard water after rinsing.
2. Lower and raise the sampler at a uniform rate. DO NOT STRIKE BOTTOM.
3. Repeat step No. 2 at all points (verticals) deemed necessary to collect a sample representative of the cross-sectional flow.
4. Cap sample tightly.

"RU" samples collected in the above manner can be used for the determination of inorganic, nonmetallic constituents such as:

Acidity
Settleable matter

6. Sample Collection—Raw Chilled Sample (RC)

Depending upon flow conditions, use either a US-DH-48 sediment sampler with a clean bottle, or only a clean narrow-mouth bottle to collect the sample.

1. Rinse sampler and sample container by collecting a small amount of native water. Discard water after rinsing.
2. Lower and raise the sampler at a uniform rate. DO NOT STRIKE BOTTOM.
3. Repeat step No. 2 at all points (verticals) deemed necessary to collect a sample representative of the cross-sectional flow.
4. Cap sample tightly and CHILL.

"RC" samples collected in the above manner can be used for the following determinations:

Nonfilterable residue (total suspended solids)
Alkalinity

7. Sample Collection— Raw Acidified Sample (RA)

Depending upon flow conditions, use either a US-DH-48 sediment sampler with a clean bottle, or only a clean narrow-mouth bottle to collect the sample. Acidified samples are collected in acid-rinsed bottles *only*.

1. Rinse sampler and sample container by collecting a small amount of native water. Discard water after rinsing.
2. Lower and raise the sampler at a uniform rate. DO NOT STRIKE BOTTOM.
3. Repeat step No. 2 at all points (verticals) deemed necessary to collect a sample representative of the cross-sectional flow.

4. Acidify immediately with concentrated nitric acid.
5. Cap tightly.

"RA" samples collected in the above manner can be used for the determination of total concentrations of the following metals: aluminum, manganese, arsenic, mercury, cadmium, nickel, chromium, selenium, iron, zinc, and lead.

8. Sample Collection— Filtered Unacidified Sample (FU)

Depending upon flow conditions, use either a US-DH-48 sediment sampler with a clean bottle, or only a clean narrow-mouth bottle to collect the sample.

1. Rinse sampler and sample container by collecting a small amount of native water. Discard water after rinsing.
2. Lower and raise the sampler at a uniform rate. DO NOT STRIKE BOTTOM.
3. Repeat step No. 2 at all points (verticals) deemed necessary to collect a sample representative of the cross-sectional flow.
4. The sample must be field-filtered through a 0.45-micron membrane filter as follows:
   a. Using a 50-milliliter syringe, draw a small amount of sample water to rinse syringe. Discard water. Repeat this rinsing procedure once again.
   b. Draw sample water into syringe.
   c. Insert syringe outlet tip into filter holder and force sample through filter into sample bottle. Repeat as necessary to obtain required volume.
5. Cap sample tightly.

"FU" samples collected in the above manner can be used for the determination of some dissolved major ionic constituents—for example, one or more of the following:

dissolved solids (180 °C);
chloride, dissolved; silica, dissolved; and
fluoride, dissolved; sulfate, dissolved.

9. Sample Collection— Filtered Chilled Sample (FC)

Depending upon flow conditions, use either a US-DH-48 sediment sampler with a clean bottle, or only a clean narrow-mouth bottle to collect the sample.

1. Rinse sampler and sample container by collecting small amount of native water. Discard water after rinsing.
2. Lower and raise the sampler at a uniform rate. DO NOT STRIKE BOTTOM.
3. Repeat step No. 2 at all points (verticals) deemed necessary to collect a sample representative of the cross-sectional flow.
4. The sample must be field-filtered through a 0.45-micron membrane filter as follows:
   a. Using a 50-milliliter syringe, draw a small amount of sample water to rinse syringe. Discard water. Repeat this rinsing procedure once again.
   b. Draw sample water into syringe.
   c. Insert syringe outlet tip into filter holder and force sample through filter into sample bottle. Repeat as necessary to obtain required volume.
5. Cap sample tightly and CHILL.

A sample collected in the above manner can be used for all the dissolved major ionic constituents listed under the filtered unacidified sample (FU) plus the following:

nitrate, dissolved; and
phosphate, ortho, dissolved.

10. Sample Collection— Filtered Acidified Sample (FA)

Depending upon flow conditions, use either a US-DH-48 sediment sampler with a clean bottle, or a narrow-mouth bottle to collect the sample. Acidified samples are collected in acid-rinsed bottles *only*.

1. Rinse sampler and sample container by collecting a small amount of native water. Discard water after rinsing.
2. Lower and raise the sampler at a uniform rate. DO NOT STRIKE BOTTOM.
3. Repeat step No. 2 at all points (verticals) deemed necessary to collect a sample representative of the cross-sectional flow.
4. The sample must be field-filtered through a 0.45-micron membrane filter as follows:
   a. Using a 50-milliliter syringe, draw a small amount of sample water to rinse syringe. Discard. Repeat this rinsing procedure once again.
   b. Draw sample water into syringe.
   c. Insert syringe outlet tip into filter holder and force sample through filter into sample bottle. Repeat as necessary to obtain required volume.
5. Acidify immediately with concentrated nitric acid.
6. Cap sample tightly.

"FA" samples collected in the above manner can be used for the determination of dissolved metals and some dissolved major ionic constituents. For example, one or more of the following: Metals: aluminum, arsenic, cadmium, chromium, iron, lead, manganese, mercury, nickel, selenium, and zinc. Major Ionic Constituents: calcium, magnesium, potassium, and sodium.

11. Chain of Custody Record

SURVEY				SAMPLERS: (Signature)					
Station Number	Station Location	Date	Time	Sample Type Comp.	Grab.	Other	Seq. No.	No. of Containers	Analysis Required

Relinquished by:		Received by:	Date/Time
Relinquished by:		Received by:	Date/Time
Relinquished by:		Received by:	Date/Time
Relinquished by:		Received by Mobile Laboratory for field analysis	Date/Time
Dispatched by:	Date/Time	Received for Laboratory by:	Date/Time
Method of Shipment:			

12. Chain of Custody Form for Water Samples

PERSON DELIVERING SAMPLE: ____________________
(Signature)

FIELD SAMPLE NUMBER(S): ____________ ____________

____________ ____________

____________ ____________

____________ ____________

DATE AND TIME DELIVERED TO LABORATORY: ____________________

LABORATORY NAME AND ADDRESS: ____________________

REPRESENTATIVE RECEIVING SAMPLE(S): ____________________
(Signature)

Optional Section:

TO THE LABORATORY:
Test the parameters checked below:

1. __________ pH
2. __________ Total Acidity
3. __________ Total Alkalinity
4. __________ Total Iron
5. __________ Dissolved Iron
6. __________ Total Manganese
7. __________ Specific Conductance
8. __________ Total Suspended Solids
9. __________ Other (Specify)

13. Chain of Custody Within Office

I, ______________________________ have received
Name and Title

______________________________ ______________________________*
Number of Samples Sample Numbers

from ______________________________ on ______________
Name and Title Date

______________ at ______________________________.
Time Place

Source of Samples

Name of Coal Company: ______________________________

Location: ______________________________

*______________________________ ______________________________

______________________________ ______________________________

______________________________ ______________________________

______________________________ ______________________________

______________________________ ______________________________

______________________________ ______________________________

______________________________ ______________________________

______________________________ ______________________________

______________________________ ______________________________
Signature of Sample Submitter Signature of Sample Receiver

14. Water Discharge Sampling Log

Inspector: ______________________________
(signature)
ID Number: ______________________________

WATER DISCHARGE SAMPLING LOG

Name of Company or Facility: ________________________ Permit Number: ____________

Sample Number: ______________________________

Name of individual collecting sample: ______________________________

Date and time of sampling: ______________________________

General climatic conditions: ______________________________

Names of any witnesses to the sampling: ______________________________

General Surveillance Parameters:
1. Field pH ______________. Method: ______________________________
2. Describe visible turbidity: ______________________________
3. Temperature: ____________________
4. Specific conductivity: ____________________
5. Preservation method: ______________________________

Provide *rough sketch* of where sample was taken in relation to minesite location, drainage courses, natural drainways, stream confluences, or other physical features: (Indicate North Arrow)

Give a brief description of site conditions: ______________________________

____

____

If Deep Mine: Description of sample discharge
Ancillary area discharge (non-refuse surface areas of the mine including haul roads) __________
Refuse area discharge __________ Borehole discharge __________ Treatment plant discharge __________
Preparation plant discharge __________ Sedimentation pond discharge __________ Uncontrolled discharge __________
Other: ______________________________

If Surface Mine: Description of sample discharge
Sedimentation pond discharge __________ Uncontrolled channel discharge __________ Uncontrolled discharge (Non-channeled surface runoff) __________ Other: ______________________________

Specify:
1. Is there any chemical treatment being done on the water being sampled?
2. Discharge source: ______________________________

____

Appendix E
Glossary of Geohydrologic Terms

Numbers at the end of the definitions, in parentheses, indicate the source. References for the glossary terms are listed at the end of this chapter. Definitions by U. S. Department of the Interior, Office of Surface Mining, Permanent Regulatory Program (Title 30, Chapter VII, part 701) have priority over other available definitions, are quoted from the regulations, and are indicated by (9). Almost all other definitions are directly quoted from the source. Minor rewriting exists for greater clarity.

Acid-base accounting—A criterion to evaluate the potential toxicity of overburden materials, which consists of two measurements: (1) total or pyritic sulfur and (2) neutralization potential. (6)

Acidity—The capacity of a water solution to neutralize basic or alkaline solutions. Acidity in water is due to the presence of excess hydrogen ions. (5)

Acid drainage—Water with a pH of less than 6.0 and in which total acidity exceeds total alkalinity, discharged from an active, inactive or abandoned surface coal mine and reclamation operation or from an area affected by surface coal mining and reclamation operations. (9)

Acid-forming materials—Earth materials that contain sulfide minerals or other materials which, if exposed to air, water, or weathering processes, form acids that may create acid drainage. (9)

Acid mine drainage—Water discharged from mines and mine wastes with a pH range of 2.0 to 4.5. Acidity results from the oxidation of sulfides exposed during mining, which produces sulfuric acid and sulfate salts. The acid dissolves minerals in the rocks, further degrading the quality of the drainage water. (8)

Adit—A horizontal passage from the land surface into a mine. Sometimes called a tunnel. (8)

Adjacent area—The area outside the permit area where a resource or resources, determined according to the context in which adjacent area is used, are or reasonably could be expected to be adversely impacted by proposed mining operations, including probable impacts from underground workings. (9)

Affected area—Any land or water surface which is used to facilitate, or is physically altered by, surface coal mining and reclamation operations. It includes the disturbed area; any area upon which surface coal mining and reclamation operations are conducted; any adjacent lands the use of which is incidental to surface coal mining and reclamation operations; . . . any areas upon which are sited structures, facilities, or other property material on the surface resulting from, or incident to surface coal mining and reclamation operations; and the area located above underground workings. (9)

Alkalinity—The capacity of a water solution to neutralize acid solutions. This property is attributed largely to the presence of the bicarbonate ion (HCO_3^-) in solution; other ions such as carbonate (CO_3^-) and hydroxyl (OH^-), may contribute to this property. (5)

Alluvial aquifer—An aquifer within unconsolidated stream deposits of comparatively recent time. (10)

Alluvial valley floors—The unconsolidated stream-laid deposits holding streams with water availability sufficient for subirrigation or flood irrigation agricultural activities but does not include upland areas which are generally overlain by a thin veneer of colluvial deposits composed chiefly of debris from sheet erosion, deposits formed by unconcentrated runoff or slope wash, together with talus, or other mass-movement accumulations, and windblown deposits. (9)

Alluvium—A general term for clay, silt, sand, gravel, or other similar material deposited in a streambed, on a flood plain, delta, or at the base of a mountain during comparatively recent geologic time. (14)

Anion—A negatively charged ion; for example, Cl^-(chloride) and SO_4^-(sulfate). (10)

Anisotropy—A condition of having different properties in different directions; example: a geologic stratum that transmits ground water at different velocities in the vertical direction than in the horizontal direction. (8)

Anthracite—Coal of the highest metamorphic rank, in which fixed-carbon content is between 92% and 98% (on a dry, mineral-matter-free basis). It is hard and black, and has a semimetallic luster and semiconchoidal fracture. (8)

Anticline—An upfold or arch of stratified rock, generally convex upward, whose core contains the stratigraphically older rocks. (8)

Apparent specific yield—The specific yield determined near the beginning of the pumping period (the first day) of an aquifer test of a water-table aquifer. This determined value would be less than the maximum specific yield obtained from a long-term pumping test period, for example, several weeks.

Aquifer—A zone, stratum, or group of strata that can store and transmit water in sufficient quantities for a specific use. (9)

Aquifer boundaries—Recharge (positive) and impermeable (negative) boundaries modify groundwater flow conditions:

— Recharge boundary is a boundary in which there is significant increase in transmissivity; for example, where a permeable material is in direct connection with a surface body of water or a permeable material is faulted against a more permeable material. This boundary influences a discharging well by retarding drawdown or stopping the expansion of the cone of depression; increases specific capacity at the well; the drawdown stabilizes between the well and the boundary. (13)

— Impermeable boundary is a boundary in which there is significant reduction in transmissivity; for example, where a permeable material abuts against a buried valley wall of impermeable granite or shale. This boundary influences a discharging well by retarding or stopping the expansion of the cone of depression, which results in increased drawdown between the well and the boundary; decreases specific capacity at the well. (13)

Aquifer system—A heterogeneous body of intercalated (interbedded) permeable and less permeable material that acts as a water-yielding hydraulic unit of regional extent. (8)

Aquifer test—A test or controlled field experiment involving either the withdrawal of measured quantities of water from, or addition of water to, a well (or wells) and the measurement of resulting changes in head in the aquifer both during and after the period of discharge or addition. (7)

Artesian aquifer—See confined aquifer.

Artesian water—Groundwater that has artesian pressure head; groundwater that is under sufficient pressure to rise above the zone of saturation. (3)

Artesian well—A well deriving its water from an artesian or confined aquifer. The water level in an artesian well stands above the top of the artesian aquifer tapped by the well. (1)

Backwater—At a stream site, backwater is the difference in elevation between the observed stage and the stage that should exist at the site for the discharge measured, as indicated by the stage-discharge relation (which applies to normal or natural flow conditions). Backwater, or the backing up of stream water, can be caused by temporary obstructions such as ice, uprooted trees, and trash blocking a bridge opening or caught on the stream reach control. (2)

Base flow (or base runoff)—Sustained or fair-weather flow in a stream composed largely of groundwater discharge. (10)

Bedding—The arrangement of a sedimentary rock in beds or layers of varying thickness and character; the general physical and structural character or pattern of the beds and their contacts within a rock mass, such as cross bedding and graded bedding; a collective term denoting the existence of beds. (8)

Bedding plane—A planar or nearly planar bedding surface that visibly separates each successive layer of stratified rock (of the same or different lithology) from the preceding or following layer; a plane of deposition. (8)

Bedrock—A general term for the rock, usually solid, that underlies soil or other unconsolidated surficial material. (8)

Brackish water—Water having a dissolved material content in the range 1,000 to 30,000 mg/L (milligrams per liter), but not necessarily corresponding to ocean water with respect to ionic ratios. (4)

Brine—Water having more than 30,000 mg/L (milligrams per liter) dissolved material, but not necessarily corresponding to ocean water with respect to ionic ratios. (4)

Cation—A positively charged ion; for example, Na^+ (sodium) and K^+ (potassium). (10)

Clastic—Pertaining to a rock or sediment composed principally of broken fragments that are derived from preexisting rocks or minerals and that have been transported some distance from their places of origin. (8)

Clastic dike—A sedimentary dike consisting of a variety of clastic materials derived from underlying or overlying beds. (8)

Clay—A rock or mineral particle in the soil, having a diameter less than 0.002 mm (2 microns). (8)

Clay vein—A body of clay, usually roughly tabular in form like a dike or vein, that fills a crevice in a coal seam. (8)

Cleat—In a coal seam, a joint or system of joints along which the coal fractures. There are usually two cleat systems developed perpendicular to each other. (8)

Coal—A readily combustible rock containing more than 50 percent by weight and more than 70 percent by volume of carbonaceous material, including inherent moisture, formed from compaction and induration of variously altered plant remains similar to those in peat. (8)

Coal classification—(a) The analysis or grouping of coals according to a particular property, such as degree of metamorphism (rank), constituent plant materials (type), or degree of impurity (grade); (b) the analysis or grouping of coals according to the percentage of volatile matter, caking properties, and coking properties. (8)

Coal cleat—A joint, or system of joints, along which the coal fractures. (9)

Coal well—A well that receives ground water from a coal bed.

Coefficient of permeability—See hydraulic conductivity.

Coefficient of storage—See storativity.

Coefficient of transmissibility—See transmissivity.

Colluvium—Any . . . loose, incoherent mass of soil material and (or) rock fragments deposited by rainwash, sheetwash, or slow continuous downslope creep, usually collecting at the base of gentle slopes or hillsides. (8)

Columnar section—See geologic column.

Cone of depression—A depression in the potentiometric surface of a body of groundwater that has the shape of an inverted cone and develops around a well from which water is being withdrawn. It defines the "area of influence" of a well. The shape of the depression is due to the fact that the water must flow through progressively smaller cross sections as it nears the well, and hence the hydraulic gradient must be steeper. (8)

Confined aquifer—An aquifer bounded above and below by impermeable beds, such as clay or unfractured shale, or by beds of distinctly lower permeability than that of the aquifer itself; an aquifer containing confined groundwater. (8)

Confined groundwater—Groundwater under pressure significantly greater than that of the atmosphere. Its upper surface is the bottom of an impermeable bed or a bed of distinctly lower permeability than the material in which the water occurs. (8)

Confining bed—A body of "impermeable" material stratigraphically adjacent to one or more aquifers. The hydraulic conductivity of the confining bed is distinctly lower than that of the adjacent aquifers. This term supplants the terms aquiclude, aquitard, and aquifuge. (1)

Connate water—Water entrapped in the interstices of sedimentary rock at the time of its deposition. (8)

Consolidation—Any process whereby loosely aggregated soft or liquid earth materials become firm and coherent rock; . . . the lithification of loose sediments to form a sedimentary rock. (8)

Contaminant—Any physical, chemical, biological, or radiological substance in water. (9)

Cumulative hydrologic impact assessment (CHIA)—A premining analysis of the probable cumulative hydrologic impacts of the proposed operation and all anticipated mining upon the surface water and groundwater systems within the cumulative impact area; and prepared by the regulatory authority.

—An assessment sufficient to determine, for purposes of permit approval, whether the proposed (mining) operation has been designed to prevent material damage to the hydrologic balance outside the permit area. (9)

Cumulative impact area—The area, including the permit area, within which impacts resulting from the proposed operation may interact with the impacts of all other nearby mining, on surface water and groundwater systems. (9)

Dip (structural geology)—The angle that a structural surface, such as a bedding or fault plane, makes with the horizontal, measured perpendicular to the strike of the structure and in the vertical plane. (8)

Discharge—Outflow, or rate of flow, measured in volume per time unit, such as cubic feet per second, that describes the flow of water from a pipe, a mine entry, a drainage basin, or at a stream site. (2)

Discrete groundwater zones—The occurrence of groundwater in distinct and separate zones within an anisotropic and heterogeneous media.

Dissolved material—All material which passes through a filter having a pore size of 0.45 um. (4)

Dissolved solids—A term that expresses the quantity of dissolved material in a sample of water, "either the residue on evaporation, dried at 180°C, or, for many waters that contain more than about 1,000 parts per million, the sum of determined constituents," generally reported in milligrams per liter. (8)

Disturbed area—An area where vegetation, topsoil, or overburden is removed or upon which topsoil, spoil, or coal processing waste, underground development waste, or noncoal waste is placed by surface coal mining operations. (9)

Divide (groundwater)—A ridge in the water table or other potentiometric surface from which the groundwater represented by that surface moves away in both directions. (8)

Divide (stream)—The line of separation, or the ridge, summit, or narrow tract of high ground that marks the boundary between two adjacent drainage basins or dividing the surface waters that flow naturally in one direction from those that flow in the opposite direction; the line forming the rim of, or enclosing a drainage basin; a line across which no water flows. (8)

Drainage area (of a stream at a specific stream site)—That area, measured in a horizontal plane, enclosed by a drainage divide. (8)

Drainage basin—A region or area bounded by a drainage divide and occupied by a drainage system; specifically, the tract of country that gathers water originating as precipitation and contributes it to a particular stream channel or system of channels, or to a lake, reservoir, or other body of water. (8)

Drawdown—(a) The lowering of the water level in a well as a result of withdrawal. (b) The difference between the height of the water table and that of the water in a pumped well. (c) the reduction of the pressure head as a result of the withdrawal of water from a well. (8)

Draw slate—In coal mining, shale that occurs above a coal seam and collapses during or shortly after removal of the coal. (8)

Drift (glacial)—A general term applied to all rock material (clay, silt, sand, gravel, boulders) transported by a glacier and deposited directly by, or from the ice, or by running water emanating from a glacier. (8)

Drift (mining)—A horizontal or nearly horizontal underground opening driven along a vein. (8)

Drift mining—The extraction of near-surface coal seams by underground inclined tunneling rather than by open cut mining or vertical-shaft methods. (8)

Effective porosity—The amount of interconnected pore space available for fluid transmission. (1)

Effluent stream—See gaining stream.

Ephemeral stream—A stream which flows only in direct response to precipitation in the immediate watershed or in response to the melting of a cover of snow and ice, and which has a channel bottom that is always above the local water table. (9)

Equipotential line—A contour line on a potentiometric-surface map; a line along which the pressure head of groundwater in an aquifer is the same. (8)

Essential hydrologic functions—The role of the alluvial valley floor in:

—collecting water, storing water, regulating flow, and making the natural flow of surface water or groundwater, or both, usefully available for agricultural activities. . . .

—collecting water includes accumulating runoff and discharge from aquifers in sufficient amounts to make the water available at the alluvial valley floor greater than the amount available from direct precipitation.

—storing water involves limiting the rate of discharge of surface water, holding moisture in soils, and holding groundwater in porous materials.

—regulating the natural flow of surface water results from the characteristic configuration of the channel flood plain and adjacent low terraces.

—regulating the natural flow of groundwater results from the properties of the aquifers which control inflow and outflow.

—making water usefully available for agricultural activities results from the existence of flood plains and terraces where surface and groundwater can be provided in sufficient quantities to support the growth of agriculturally useful plants. (9)

Evapotranspiration—Water withdrawn from a land area by evaporation from water surfaces and from moist soil and by plant transpiration. (2)

Face cleat—The major cleat system or jointing in a coal seam. (8)

Facies—(a) The aspect, appearance, and characteristics of a rock unit, usually reflecting the conditions of its origin. (b) A mappable, areally restricted part of lithostratigraphic body, differing in lithology or fossil content from other beds deposited at the same time and in lithologic continuity. (c) A distinctive rock type, broadly corresponding to a certain environment or mode of origin. (8)

Facies map—A map showing the gross areal variation or distribution (in total or relative content) of observable attributes or aspects of different rock types occurring within a designated stratigraphic unit, without regard to the position or thickness of individual beds in the vertical succession. (8)

Fault—A fracture or zone of fractures along which there has been displacement of sides relative to one another parallel to the fracture. (8)

Fault breccia—A "tectonic breccia" composed of angular fragments resulting from the crushing, shattering, or shearing of rocks during movement on a fault, from friction between the walls of the fault, or from distributive ruptures associated with a major fault. (8)

Fault gouge—Soft, uncemented pulverized clayey or clay-like material, commonly a mixture of minerals in finely divided form, found along some faults or between the walls of a fault, and filling or partly filling a fault zone; a slippery mud that coats the fault surface or cements the "fault breccia." (8)

Fault plane—A fault surface that is more or less planar. (8)

Fault surface—In a fault, the surface along which displacement has occurred. (8)

Fence diagram—A drawing in perspective of three or more geologic sections showing their relationships to one another. (8)

Fissility—A general term for the property possessed by some rocks of splitting easily into thin layers along closely spaced, roughly planar, and approximately parallel surfaces, such as bedding planes in shale. . . (8)

Flow-duration curve—A cumulative frequency curve that shows the percentage of time that specified discharges (generally stream flow) are equaled or exceeded. (2)

Flowing well—A well that yields water at the land surface without pumping. (8)

Flow line—The path that a particle of water follows in its movement through saturated, permeable material (soil or rock). (7)

Formation—A body of rock strata, of intermediate rank in the hierarchy of "lithostratigraphic units," which is unified with respect to adjacent strata by consisting dominantly of a certain lithologic type or combination of types or by possessing other unifying lithologic features. (8)

Fracture (structural geology)—A general term for any break in a rock, whether or not it causes displacement, due to mechanical failure by stress. A fracture includes cracks, joints, and faults. (8)

Fracture trace—A natural linear feature less than one mile long and best seen on aerial photographs (scale 1:20,000); a surface manifestation of subsurface fracture zones, or almost vertical zones of fracture concentrations; identified by dark or light tonal lines (on aerial photographs) in the soil, alignments of vegetation, topographic sags, aligned gaps in ridges, and (or) other similar features. (17)

Fresh water—Water having less than 1,000 milligrams per liter dissolved material. (4)

Gaging station—A particular site on a stream, canal, lake, or reservoir, where systematic streamflow measurements and other hydrologic data are obtained. (10)

Gaining stream—A stream, or reach of stream, whose flow is being increased by the inflow of groundwater. (1)

Geohydrologic system—A system which includes: aquifer thickness and extent, aquifer boundaries, variations and approximate values of transmissivity and storage coefficient, and magnitude of control to be imposed on the aquifer(s), such as change in discharge or head. (6)

Geohydrologic unit—An aquifer, a confining unit (aquiclude or aquitard), or a combination of aquifers and confining units, comprising "a framework for a reasonably distinct hydraulic system." (8)

Geologic column—A composite diagram that shows in a single column the subdivisions of part, or all, of geologic time, or sequence of stratigraphic units of a given locality, or region (the oldest at the bottom and the youngest at the top, with dips adjusted to the horizontal), so arranged as to indicate their relations to the subdivisions of geologic time and their relative positions to each other. (8)

Gob—Materials which are separated and wasted from the coal during cleaning, concentrating, or other processing or preparation of coal. (9)

Graben—An elongate, relatively depressed crustal unit, or block, that is bounded by faults on its long sides. (8)

Grid—(a) A network composed of two sets of uniformly spaced parallel lines, usually intersecting at right angles and forming squares (or rectangles), superimposed on a map, chart, or aerial photograph, to permit identification of ground locations by means of a system of coordinates and to facilitate computation of distance and direction. (b) A systematic array of points or lines. (8)

Groundwater—Subsurface water that fills available openings in rock or soil materials to the extent that they are considered water saturated. (9)

Groundwater barrier—A natural or artificial obstacle, such as a dike or fault gouge, to the lateral movement of groundwater, not in the sense of a confining bed. It is characterized by a marked difference in the level of the groundwater on opposite sides. (8)

Groundwater basin—(a) A subsurface structure having the character of a basin with respect to the collection, retention, and outflow of water. (b) An aquifer or system of aquifers, whether basin-shaped or not, that has reasonably well defined boundaries and more or less definite areas of recharge and discharge. (8)

Groundwater budget—See hydrologic budget.

Groundwater discharge—Release of water from the zone of saturation. (8)

Groundwater divide—See divide (groundwater).

Groundwater model—Simulated representation of a groundwater system to aid in the understanding of the behavior of the system when stressed by discharges and recharges and to aid in decision making for groundwater resources management. (7)

Groundwater reservoir—All rocks in the zone of saturation; same as aquifer, or aquifer system, or groundwater system. (7)

Groundwater runoff—That part of the runoff which has passed into the ground, has become groundwater, and has been discharged into a stream channel as spring or seepage water. (2)

Groundwater storage—Water in the zone of saturation.

Groundwater system—A groundwater reservoir and its contained water.

Group—A formal lithostratigraphic unit next in rank above formation. A group includes two or more contiguous or associated formations with significant lithologic features in common. (8)

Hardness—A property of water, that causes formation of an insoluble residue when the water is used with soap and a scale in vessels in which water has been allowed to evaporate. It is primarily due to the presence of ions of calcium and magnesium, but also to ions of other alkali metals, other metals (such as iron), and even hydrogen. Hardness of water is generally expressed as parts per million as $CaCO_3$ (40 ppm Ca produces a hardness of 100 ppm as $CaCO_3$); also as milligrams per liter; and as the combination of carbonate hardness and noncarbonate hardness. (8)

Head (static)—The height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point. (1)

Headwater—The source (or sources) and upper part of a stream, especially of a large stream or river, including the upper drainage basin. (8)

Heavy metals—Metallic elements with high molecular weights generally toxic in low concentrations to plants and animal life; such metals exhibit biological accumulation. (16)

Highwall—The face of exposed overburden and coal in an open cut of a surface coal-mining activity or for entry to underground mining activities. (9)

Homogeneous aquifer—Hydraulic properties throughout the aquifer are identical everywhere. (1)

Hydraulic conductivity—The volume of fluid, at the existing kinematic viscosity, that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. (1)
—Describes the ability of aquifer material to transmit water. Values for horizontal and vertical flow through the same material may differ.

Hydraulic diffusivity—The hydraulic parameter of transmissivity divided by storage coefficient (storativity); the conductivity of the saturated medium when the unit volume of water moving is that involved in changing the head a unit amount in a unit volume of medium. (1)

Hydraulic discharge—See groundwater discharge.

Hydraulic gradient—In an aquifer, the rate of change of "total head" per unit of distance of flow at a given point and in a given direction. (8)

Hydraulic head—The height of the free surface of a body of water above a given subsurface point. (8)

Hydraulic permeability—The ability of a rock or soil to transmit water under pressure. It may vary according to direction; see hydraulic conductivity. (8)

Hydrograph—A graph of stream stage, discharge, water level, velocity, or other property of water with respect to time. (2)

Hydrologic balance—The relationship between the quality and quantity of water inflow to, water outflow from, and water storage (changes in storage) in a hydrologic unit, such as a drainage basin, aquifer, soil zone, lake, or reservoir.
—A water budget that encompasses the dynamic relationships among precipitation, surface runoff, evaporation, and changes in surface water and groundwater storage. (9)

Hydrologic budget—An accounting of the inflow to, outflow from, and changes in storage in a hydrologic unit such as a drainage basin, aquifer, soil zone, lake, reservoir, or irrigation project. (2)

Hydrologic cycle—The constant circulation of water from the sea, through the atmosphere, to the land, and its eventual return to the atmosphere by way of transpiration and evaporation from the sea and the land surface. (8)

Hydrologic properties—Those properties of a rock that govern the entrance of water and the capacity to hold, transmit, and deliver water, for example, porosity, effective porosity, specific retention, permeability, and direction of maximum and minimum permeability. (8)

Hydrologic regime—The entire state of water movement in a given area.
—A function of the climate and includes the phenomena by which water first occurs as atmospheric water vapor, passes into a liquid or solid form, falls as precipitation, moves along or into the ground surface, and returns to the atmosphere as vapor by means of evaporation and transpiration. (9)

Hydrologic unit—A geographic area representing part or all of a surface drainage basin or distinct hydrologic feature, as delineated by the Office of Water Data Coordination (U. S. Geological Survey) on the State Hydrologic Unit Maps. (10)

Hydrostatic head—The height of a vertical column of water whose weight, if of unit cross section, is equal to the hydrostatic pressure at a given point; "static head" as applied to water. (8)

Hydrostatic level—The level to which the water will rise in a well under its full pressure head. It defines the potentiometric surface. (8)

Hydrostatic pressure—The pressure exerted by the water at any given point in a body of water at rest. The hydrostatic pressure of groundwater is generally due to the weight of water at higher levels in the zone of saturation. (8)

Hydrostratigraphic unit—A body of rock having considerable lateral extent and forming "a geologic framework for a reasonably distinct hydrologic system." (8)

Impermeability—The condition of a rock, sediment, or soil that renders it incapable of transmitting fluids under pressure. (8)

Induced infiltration—Recharge to groundwater by infiltration, either natural or manmade, from a body of surface water as a result of the lowering of the groundwater head below the surface water level. (8)

Induced recharge (aquifer)—Recharge to an aquifer by inflow of stream water, generally caused by the cone of depression intersecting the surface water body.

Indurated—A condition of a rock or soil hardened or consolidated by pressure, cementation, or heat. (8)

Influent flow—Flow of water into the ground from a body of surface water; for example, the seepage of water from an influent stream to the zone of saturation. (8)

Influent stream—A stream or reach of a stream that contributes water to the zone of saturation and develops bank storage; its channel lies above the water table (8); synonymous term is losing stream.

Instantaneous discharge—The discharge at a particular instant in time. (10)

Insulated stream—A stream or reach of a stream that is separated from the zone of saturation by an impermeable bed and neither contributes water to the zone of saturation nor receives water from it. (8)

Integrated drainage—The drainage developed where various higher local base levels of small basins are incorporated into a large basin which has a single lower base level. (8)

Intermittent stream—(a) A stream or reach of stream that drains a watershed of at least one square mile, or (b) a stream or reach of stream that is below the local water table for at least some part of the year, and obtains its flow from both surface runoff and groundwater discharge. (9)

Ion—An atom, group of atoms, or molecule that has acquired a net electrical charge. (10)

Isopach—A line drawn on a map through points of equal true thickness of a designated stratigraphic unit or group of stratigraphic units. (8)

Isopach map—A map that shows the thickness of a bed, formation, sill, or other tabular body throughout a geographic area by means of isopachs at regular intervals. (8)

Isotropy—A condition of having properties that are uniform in all directions. (8)

Joints—System of fractures in rocks along which no movement parallel to the fracture surface has occurred (as opposed to faults). In coal, joints and fractures may be termed "cleats". Joints and fractures are some of the most important water-bearing and transmitting openings in rock formations, and provide secondary hydraulic conductivity, (secondary permeability). (1)

Key bed—(a) A well-defined, easily identifiable stratum or body of strata that has sufficiently distinctive characteristics (such as lithology or fossil content) to facilitate correlation in field mapping or subsurface work. (b) A bed, the top or bottom of which is used as a datum in making structure-contour maps. (8)

Land Surface Datum (LSD) Correction—The vertical distance from the measuring point (MP), usually from the top of the well (or casing) to the ground surface. (6)

Leachate—A solution obtained by leaching; such as water that has percolated through soil containing soluble substances and that contains certain amounts of these substances in solution. (8)

Leaching—(a) Separation, selective removal, or dissolving-out of soluble constituents from a rock, or orebody, by the natural action of percolating water. (b) The removal in solution of nutritive or harmful constituents (such as mineral salts and organic matter) from an upper to a lower soil horizon by the action of percolating water, either naturally (by rainwater) or artificially (by irrigation). (8)

Lignite—A brownish-black coal that is intermediate in coalification between peat and subbituminous coal; consolidated coal with a calorific value less than 8,300 BTU per pound on a moist, mineral-matter-free basis. (8)

Limestone—A sedimentary rock consisting chiefly (more than 50 percent by weight or by areal percentages under the microscope) of calcium carbonate, primarily in the form of the mineral calcite, and with or without magnesium carbonate; specifically, a carbonate sedimentary rock containing more than 95 percent calcite and less than 5 percent dolomite. (8)

Lineaments—Linear features on aerial photographs or imagery formed by the alignment of stream channels or tonal features in soil, vegetation, or topography. (15)

Linear (adj.)—Arranged in a line or lines; pertaining to the line-like character of some object or objects. (8)

Lithification—The conversion of a newly deposited, unconsolidated sediment into a coherent, solid rock, involving processes such as cementation, compaction, desiccation, crystalization. It may occur concurrent with, soon after, or long after deposition. (8)

Lithify—To change to stone, or to petrify; especially to consolidate from a loose sediment to a solid rock. (8)

Lithofacies map—A "facies map" based on lithologic attributes, showing areal variation in the overall lithologic character of a given stratigraphic unit. (8)

Lithologic map— A type of geologic map showing the rock types of a particular area. (8)

Lithology—The description of rocks, especially in the hand specimen and in outcrop, based on such characteristics as color, mineralogic composition, and grain size. (8)

Lithostratigraphic unit—A body of rock that is unified by consisting dominantly of a certain lithologic type or combination of types, or by possessing other unifying lithologic features. (8)

Losing stream—A stream, or reach of a stream, that is losing water into the streambed and recharging the underlying aquifer. (1)

Low flow—The flow of a stream when less than an average minimum flow occurs for an indicated period of days; see base flow.

Low-flow frequency curve—A graph showing the magnitude and frequency of minimum flows for a time period of a given length. The frequency is generally expressed as the average interval, in years, between recurrences of an annual minimum flow equal to or less than shown by the magnitude scale. (2)

Marker bed—(a) A geologic formation serving as a marker. (b) "Key bed". (8)

Materially damage the quantity or quality of water—With respect to alluvial valley floors, to degrade or reduce by surface coal mining and reclamation operations the water quantity or quality supplied to the alluvial valley floor to the extent that resulting changes would significantly decrease the capability of the alluvial valley floor to support agricultural activities. (9)

Mean discharge—The arithmetic mean of individual discharges during a specific period of time. (10)

Member—A lithostratigraphic unit of subordinate rank, comprising some specially developed part of a formation. It may be formally defined and named, informally named, or unnamed. (8)

Micromho—The unit used in reporting specific conductance of water per centimeter at 25°C. (15)

Micron (**μm**)—A unit of length that is equal to one-millionth of a meter; it is also known as a micrometer. (5)

Mine drainage—Surface water and groundwater drainage from mines.

Mine plan area—The area of land and water within the boundaries of all permit areas during the entire life of the surface coal mining and reclamation operations. (9)

Monocline—A local steepening in an otherwise uniform gentle dip. (8)

Node—A point within a digital groundwater model at which hydraulic properties, boundary conditions, and hydraulic head can be fixed, or referenced, in space.

Observation well—A special well installed in a selected location for the purpose of observing hydrologic variables, such as water levels, pressure changes, groundwater quality. (8)

Open hole well—A well which is drilled and does not contain any casing, grouting, or other well construction features.

Overburden—Material of any nature, consolidated or unconsolidated, that overlies a coal deposit, excluding topsoil. (9)

Paludal (adj.)—Pertaining to a marsh. (8)

Particulate material—Material that is retained by a filter having a pore size of 0.45 micron. (4)

Perched groundwater—Unconfined groundwater that is separated from an underlying body of groundwater by an unsaturated zone and by a confining bed (also called the perching bed).

—The perched zone of saturation may be either permanent, where recharge is frequent enough to maintain a saturated zone above the perching bed, or temporary, where recharge is insufficient to prevent the perched water from disappearing as a result of drainage over the edge of or through the confining or perching bed. (1)

Perched water table—The water table of a body of perched groundwater. (8)

Perching bed—A body of rock or poorly permeable material, generally having the form of a layer, bed, or stratum, that supports a body of perched groundwater. Its permeability is sufficiently low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure. (8)

Percolation—The movement, under hydrostatic pressure, of water through the interstices of a rock or soil. (Does not include movement through large openings, such as caves.) (2)

Perennial stream—A stream, or part of stream, that flows continuously during the year as a result of groundwater discharge or surface runoff. (9)

Permeability (intrinsic)— A measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient. (1)

Permit area—The area of land indicated on the approved map submitted by the operator with his or her application, required to be covered by the operator's performance bond . . . which shall include the area of land upon which the operator proposes to conduct surface coal mining and reclamation operations under the permit, including all disturbed areas, . . . (9)

Permittee—A person holding or required by the Act . . . to hold a permit to conduct surface coal mining (and underground mining) and reclamation operations issued by a State regulatory authority pursuant to a State program, by the Director pursuant to a Federal program, by the Director pursuant to a Federal lands program, . . . (9)

pH—A standard unit for expressing the hydrogen-ion concentration. It is defined as the negative logarithm to the base 10 of the hydrogen-ion concentration in gram-moles per liter. A pH of 7 is neutral, whereas values below 7 are acidic and values above 7 to the theoretical maximum of 14 are alkaline. More precisely, pH meters measure chemical activity rather than concentration of the hydrogen-ions; however, activity is equal to or nearly equal to concentration in dilute solutions. (5)

Phreatic water—A term that originally was applied only to water that occurs in the upper part of the zone of saturation under water-table conditions, but has come to be applied to all water in the zone of saturation. (8)

Phreatophyte—A plant that obtains its water from the zone of saturation or through the capillary fringe and is characterized by a deep root system. (8)

Porosity—The percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected. (8)

Potentiometric map—A map showing the altitude of a potentiometric surface of an aquifer by means of contour lines or other symbols. (8)

Potentiometric surface—An imaginary surface representing the total head of groundwater and defined by the level to which water will rise in a tightly cased well. (8)
—The water table of an unconfined aquifer is a particular potentiometric surface. (1)

Precipitation—All forms of water particles, liquid or solid, that fall from the atmosphere and reach the ground. (8)

Precipitation event—A quantity of water resulting from drizzle, rain, snow, sleet, or hail, in a limited period of time; . . . also includes that quantity of water emanating from snow cover as snow melt in a limited period of time. (9)

Primary porosity—The "porosity" that developed during the final stages of sedimentation or that was present within sedimentary particles at the time of deposition. (8)

Probable hydrologic consequences (PHC) determination—A premining predictive estimate (by the operator) of the hydrologic impacts of the proposed mining operation.
—An analysis of the potential impacts of the proposed mining operation on the quantity and quality of groundwater and surface water under seasonal flow in the permit and adjacent areas.
—A predictive estimate of the potential impacts on the hydrologic balance. (9)

Public-water system—A system for the provision to the public of piped water for human consumption, if such system has at least 15 service connections or regularly serves an average of at least 25 individuals daily at least 60 days out of the year. (9)

Pumpage—The quantity or discharge of water, or other liquid, pumped, such as groundwater. (8)

Pumping level—The water level in a discharging well.

Pumping test—See aquifer test.

Radius of influence—The radial distance from the center of a well bore to the edge of its area of influence. (8)

Rank (coal)—A generalized classification of coals according to degree of metamorphism, or progressive alteration, in the natural series from lignite to anthracite. (11)

Rating curve—See stage-discharge curve.

Recharge—The process involved in the absorption and addition of water to the zone of saturation; also, the amount of water added. (8)

Recharge area—An area in which water is absorbed that eventually reaches the zone of saturation in one or more aquifers. (8)

Recharge capacity—The ability of the soils and underlying materials to allow precipitation and runoff to infiltrate and reach the zone of saturation. (9)

Regolith—A general term for the layer or mantle of fragmental and unconsolidated rock material, whether residual or transported and of highly varied character, that nearly everywhere forms the surface of the land and overlies or covers the bedrock. (8)

Rib—The side wall of an outside entry in a coal mine. (11)

Rider coal—A thin, unmineable coal found closely above a thicker, mineable coal bed. Normally only a few inches thick. (11)

Rose diagram—A circular or semicircular star-shaped graph indicating values or quantities in several bearing directions, consisting of radiating rays drawn proportional in length to the value or quantity; some examples include a structural diagram for plotting strikes of planar features, or a "histogram" of orientation data. (8)

Runoff—That part of the precipitation that appears in surface streams. It is the same as streamflow unaffected by artificial diversions, storage, or other works of man in or on the stream channels. (2)

Salinity—A term describing water solutions containing dissolved mineral solids. The U. S. Geological Survey has assigned terms for degrees of salinity for waters with the following dissolved-solids concentration ranges: (5)

slightly saline	=	1,000 to 3,000 mg/L (milligrams per liter)
moderately saline	=	3,000 to 10,000 mg/L
very saline	=	10,000 to 35,000 mg/L
briny	=	over 35,000 mg/L

Sandstone—A medium-grained clastic sedimentary rock composed of abundant rounded or angular fragments of sand size (1/16 to 2 mm) set in a fine-grained matrix (silt or clay) and more or less firmly united by a cementing material (commonly silica, iron oxide, or calcium carbonate); the consolidated equivalent of sand, intermediate in texture between conglomerate and shale. (8)

Sandstone channel—A sandstone body that ranges in thickness from several inches to many feet and in length up to several miles and that cuts across structure and bedding of the enclosing rocks. Also called a clastic dike. (11)

Saturated thickness—See zone of saturation.

Secondary porosity—The porosity developed in a rock after its deposition or emplacement through such processes as solution or fracturing. (8)

Seepage measurements—Flow measurements made at various locations along a stream to determine whether or not a stream is losing or gaining water. (15)

Semiperched groundwater—Unconfined groundwater separated by a low-permeability, but saturated, bed from a body of confined water whose hydrostatic level is below the water table. (8)

Shale—A fine-grained detrital sedimentary rock, formed by the consolidation (especially by compression) of clay, silt, or mud. It is characterized by finely laminated structure that imparts a fissility approximately parallel to the bedding, along which the rock breaks readily into thin layers and that is commonly most conspicuous on weathered surfaces, and by an appreciable content of clay minerals and detrital quartz; a thinly laminated or fissile claystone, siltstone, or mudstone. (8)

"Shut-in" well—A tightly cased well is "shut-in" when a valve, or other flow restricting device, is closed preventing discharge of fluids. A well is "shut-in" to measure fluid pressures, which can be related to hydraulic properties of the aquifers tapped by the well.

Slug test—An aquifer testing method where a known solid volume—a slug of water or a sand filled pipe—is instantaneously injected into (or removed from) a well, and the decline of (or recovery of) the water level is measured at closely spaced intervals to determine hydraulic characteristics of the aquifer materials penetrated by the well.

Sole-source aquifer—An aquifer that supplies 50 percent or more of the drinking water of an area, as defined by the U. S. Environmental Protection Agency. (14)

Solute—Any substance derived from the atmosphere, vegetation, soil, or rocks and is dissolved in water.

Specific capacity—The rate of discharge of a well divided by the drawdown of the well; expressed as gallons per minute per foot of drawdown. Specific capacity is roughly proportional to transmissivity. (1)

Specific conductance—A measure of the ability of a water to conduct an electrical current. It is the reciprocal of the electrical resistance in ohms measured between opposite faces of a centimeter cube of an aqueous soluion at a specific temperature. The standard measurement is expressed in microseisms per centimeter at 25 degrees Celsius (°C), abbreviated μS/cm. The old units were micromhos per centimeter at 25 degrees Celsius, abbreviated μmhos/cm at 25°C. Specific conductance is related to the type and concentration of ions in solution and can be used to approximate the dissolved-solids concentration in water. Estimates of the dissolved-solids concentration, in milligrams per liter (mg/L), range from 60 to 85 percent of the specific-conductance value in μS/cm at 25°C. (5)

—For sulfate-type waters, the estimated range of dissolved solids concentration in milligrams per liter is from 90 to 100 percent of the specific-conductance value.

Specific discharge—The rate of discharge of groundwater per unit area of porous media measured at right angles to the direction of flow. (1)

Specific storage—The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. (1)

Specific yield—The yield, or storage coefficient, of an unconfined aquifer defined as the ratio of the volume of water which saturated rock or soil will yield by gravity to the total volume of the saturated rock or soil. (1)

Spoil—The overburden or noncoal material removed in gaining access to the coal or mineral material in surface mining. (9)

Spring—A place where groundwater flows from a rock or soil upon the land or into a body of surface water. (3)

Stage-discharge curve (rating curve)—A graph showing the relation between the gage height, usually plotted as ordinate, and the amount of water flowing in a channel, expressed as volume per unit of time, plotted as abscissa. (2)

Static water level—The water level in a well which is in equilibrium with the groundwater flow conditions of the aquifer at the well; that is, when no water is being, or recently has been, taken from the aquifer either by pumping or by free flow. It is generally expressed as the distance from the ground surface (or from measuring a point near the ground surface) to the water level in the well; also, static head. (12)

Steady flow—Occurs when, at any point, the magnitude and direction of the specific discharge are constant in time. (1)

Storage—In groundwater hydrology, storage refers to water naturally detained in a groundwater reservoir, to artificial impoundment of water in groundwater reservoirs, and to the water so impounded. (7)

Storage coefficient—See storativity.

Storativity—The hydraulic property of an aquifer that measures the volume of water an aquifer releases from or takes into storage per unit of surface area of the aquifer per unit change in head. (1)
—The storage capacity of an aquifer as described by the terms specific yield, effective porosity, coefficient of storage, and storage coefficient. (15)

Strata—Plural of stratum. (8)

Stratigraphic classification—The arbitrary but systematic arrangement, zonation, or partitioning of the sequence of rock strata of the earth's crust into units with reference to any or all of the many different characters, properties, or attributes that the strata may possess. (8)

Stratigraphic column—See geologic column.

Stratigraphic map—A map that shows the areal distribution, configuration, or aspect of a stratigraphic unit or surface. (8)

Stratigraphic section—See geologic column.

Stratigraphic sequence—A chronological succession of sedimentary rocks from older below to younger above, essentially without interruption. (8)

Stratigraphy—The science of rock strata. It is concerned not only with the original succession and age relations of rock strata but also with their form, distribution, lithologic composition, fossil content, geophysical and geochemical properties and other characteristics and attributes of rocks as strata; also their interpretation in terms of environment or mode of origin, and geologic history. (8)

Stratum—A tabular or sheetlike body or layer of sedimentary rock, visually separate from other layers above and below; a bed. (8)

Stream—A general term for a body of flowing water. (2)

Stream basin—See drainage basin.

Stream gaging—The process and art of measuring the depths, areas, velocities, and rates of flow in natural or artificial channels. (2)

Stream-gaging station—A location on a stream at which a record of stream discharge is obtained. Within the U.S. Geological Survey, this term is used only for those stream sites where a continuous record of discharge is obtained. (2)

Stream regimen—The system or order characteristics of a stream; . . . its habits with respect to velocity and volume, form of and changes in channel, capacity to transport sediment, and amount of material supplied for transportation.
—Term also applied to a stream which has reached equilibrium between erosion and deposition. (2)

Strike (structural geology)—The direction (bearing) or trend taken by a structural surface, such as a bedding plane or fault plane as it intersects the horizontal. (8)

Structure (geologic)—The general disposition, attitude, arrangement, or relative positions of rock units within an area; the sum total of the structural features within an area, reflecting past deformational processes such as faulting, folding, and igneous intrusion. (8)

Structure contour—A contour line on a map that indicates the altitude of a structural surface, such as on the base or top of a formation, a formation boundary or a fault. (8)

Structure-contour map—A map that indicates the subsurface configuration by means of structure contour lines. (8)

Structure section—A vertical section that shows the observed geologic structure on a vertical or near-vertical surface, or, more commonly, one that shows the inferred geologic structure as it would appear on a vertical plane cutting through part of the earth's crust. (8)

Subsidence—The sudden sinking or gradual downward settling of the earth's surface with little or no horizontal motion. (8)
—A sinking of part of the earth's surface, such as may result from soil compaction, collapse of underground mines, or removal of groundwater, oil or gas. (15)

Subsidence crack—A crack or joint in the rock formed or widened as a result of subsidence. (15)

Substantially disturbed—For the purposes of coal exploration, to impact significantly upon land, air, or water resources by such activities as blasting, mechanical excavation, drilling or altering coal or water exploratory holes or wells, construction of roads and other access routes, and the placement of structures, excavated earth, or other debris on the surface of the land. (9)

Surface mining activities—Those surface coal mining and reclamation operations incident to the extraction of coal from the earth by removing the materials over a coal seam, before recovering the coal, by auger coal mining, or by recovery of coal from a deposit that is not in its original geologic location. (9)

Surface water—Water on land surface, such as stream and lakes (as opposed to groundwater). (2)

Syncline—A fold in which the core contains the stratigraphically younger rocks; it is generally concave upward. (8)

Suspended material—See particulate material. (4)

Suspended residue—The material retained by a filter. (4)

Total material—The quantity of a given material present in an unfiltered water sample, regardless of the form or occurrence of the material. (4)

Total recoverable material—The total quantity of all dissolved forms of a given material plus that which is brought into solution and into an analytically determinable form, usually by means of an acid-digestion pretreatment or an acid-oxidation-digestion pretreatment of the sample. The exact conditions of the digestion pretreatment must be specified. (4)

Toxic forming materials—Earth materials or bedrock mine waste which are acted upon by air, water, weathering, or microbiological processes and are likely to produce chemical or physical conditions in soils or water that are detrimental to biota or users of water. (9)

Toxic mine drainage—Water that is discharged from active or abandoned mines or other areas affected by coal exploration or surface coal mining and reclamation operations, which contains a substance that through chemical action or physical effects is likely to kill, injure, or impair biota commonly present in the area that might be exposed to it. (9)

Trace element—Any constituent, other than organic, of water that generally occurs in concentrations of less than one milligram per liter. (10)

Transgressive sediments—Sediments deposited during the advance or encroachment of water over a land area or during the subsidence of the land. (8)

Transmissivity—The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. (1)

Transpiration—The process by which water absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface. (8)

Unconfined aquifer—See water-table aquifer.

Unconfined groundwater—Groundwater that has a free water table and is not overlain by a confining bed . . . (8)

Unconformity—(a) A substantial break or gap in the geologic record where a rock is overlain by another that is not next in stratigraphic succession. . . . (b) The structural relationship between rock strata in contact, characterized by a lack of continuity in deposition and corresponding to a period of non-deposition, weathering, or especially erosion . . . prior to the deposition of the younger beds, and often (but not always) marked by absence of parallelism between the strata; . . . (8)

Unconsolidated materials—(a) Sediment that is loosely arranged or unstratified, or whose particles are not cemented together, occurring either at the surface or at depth. (b) Soil material that is in a loosely aggregated form. (8)

Underburden—The barren rock material underlying a mineral deposit; opposite of overburden; underclay is a special type of underburden.

Underclay—A layer of fine-grained detrital material, usually clay, lying immediately beneath a coal bed or forming the floor of a coal seam. (8)

Underground mining activities—A combination of (a) surface operations incident to underground extraction of coal or in situ processing. . . . (b) underground operations such as underground construction, operation, and reclamation of shafts, adits, underground support facilities, in situ processing, and underground mining, hauling, storage, and blasting. (9)

Undifferentiated—Not separated into different formations of rock types.

Uniform flow—Specific discharge, at every point in the aquifer, that has the same magnitude and direction at any given instant in time. (1)

Unsaturated zone—The thickness of material between the land surface and the water table. (1)

Unsteady flow—Flow that results if the magnitude or direction of the specific discharge changes with time. (1)

Washout (mining)—A mass of shale, siltstone, or sandstone filling a channel in a coal seam that was cut into the coal swamp during the time of deposition. (8)

—A channel cut into or through a coal seam at some time during or after the formation of the seam, and generally filled in later by sand that later lithified into sandstone. (11)

Water-budget—See Hydrologic Budget.

Water table—The upper surface of a zone of saturation, where the body of groundwater is not confined by an overlying impermeable zone. (9)

Water-table aquifer—An aquifer having a water surface at which the water pressure is atmospheric. (1) (see unconfined groundwater)

Well yield—The quantity of water pumped, or withdrawn, from a well per unit of time; for example, the number of gallons per minute. (7)

Zone of saturation—A thickness of rock or soil material in which all the interstices are filled with water under pressure greater than atmospheric. The upper surface of the zone of saturation is the water table. (7)

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