DEPARTMENT OF ENVIRONMENTAL QUALITY
LAND QUALITY DIVISION

GUIDELINE NO. 8

HYDROLOGY

COAL AND NON COAL

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TABLE OF CONTENTS

I. INTRODUCTION 1
II. DEFINITIONS 1
III. SURFACE WATER 2
A. Premining Studies (to be included in Appendix D-6 (Hydrology)) 2
1. Precipitation (can be cross-referenced from Appendix D-4 (Climatology)) 2
2. Evapotranspiration (ET) (can be cross-referenced from Appendix D-4 (Climatology)) 3
3. Runoff 3
4. Watershed and Stream Channel Characterization 4
5. Baseline Water Quality 5
6. Water Rights 6
B. Mine Plan 6
1. Design of Temporary Diversions and Culverts 6
2. Impoundments and Sedimentation Ponds 7
3. Monitoring Stations 8
4. Hydrologic Control Map 8
C. Reclamation Plan 8
1. Topography and Watershed Design 8
2. Stream Channel Reconstruction and Permanent Diversion Construction 9
3. Permanent Impoundments 10
4. Reclamation Monitoring 11
IV. GROUNDWATER 11
A. Premining Studies [Appendix D-6 (Hydrology)] 12
1. Geologic Framework 12
2. Aquifer Hydraulic Characteristics 13
3. Potentiometric Surface 15
4. Groundwater Quality 16
5. Water Rights 16
B. Mine Plan 17
1. Impacts of Dewatering or Water Consumption 17
2. Monitoring 19
3. Water Rights 22
C. Reclamation Plan 23
1. Aquifer Reclamation 23
2. Land Surface - Water Table Interactions 23
3. Monitoring 24
V. PROBABLE HYDROLOGIC CONSEQUENCES 24
A. Surface Water Consequences 25
1. Surface Water Quantity 25
2. Surface Water Quality 26
3. Geomorphology (surface water quantity and quality) 26
B. Groundwater Consequences 26
1. Groundwater Quantity 27

2. Groundwater Quality 27
C. Surface Water/groundwater Interactions 27
1. Water Quantity 27
2. Water Quality 28
D. Water Rights 28
E. Important Habitats 28
APPENDIX 1 30
PREMINING WATER QUALITY SAMPLING 30
APPENDIX 2 37
STREAM CHANNEL DESIGN 37
APPENDIX 3 39
TEMPORARY AND PERMANENT IMPOUNDMENTS 39
APPENDIX 4 41
MONITOR WELL INSTALLATION AND MAINTENANCE 41
APPENDIX 5 46
RULES AND REGULATIONS CITATIONS 46
APPENDIX 6 53
PLUGGING AND ABANDONMENT 53
APPENDIX 7 54
MINING PHASE SURFACE AND GROUNDWATER MONITORING AT SURFACE COAL MINES 58
APPENDIX 8 54
WYOMING GROUNDWATER PERFORMANCE STANDARDS WHITE PAPER 57

I. INTRODUCTION

This document is a guideline only. Its contents are not to be interpreted by applicants, operators, or Land Quality Division (LQD) staff as mandatory. If an operator wishes to pursue other alternatives, he or she is encouraged to discuss these alternatives with the LQD staff.

This guideline is not intended to be comprehensive. It clarifies the more important but less specific regulations, and it compliments rather than substitutes for the existing regulations. (See Appendix 5 for appropriate Rules and Regulations.) All headings in the Guideline may not apply to all operators. A table of contents is provided to direct the applicant to the appropriate topic for individual permitting needs. Required hydrology data collected during the annual report period should be presented and analyzed in the annual report submitted by the operator to the LQD. Coal operators are required to follow the Coal Annual Report Format (CARF) for reporting and presentation of all the required hydrology data collected during the annual report period.

II. DEFINITIONS FOR PURPOSES OF THIS GUIDELINE

A. **"Affected Aquifer"** An aquifer whose natural state or physical properties have been, will be, or may be disturbed as a result of mining operations.

B. **"Affected Land"** The area of land from which overburden is removed, or upon which overburden, development waste rock, and/or refuse is deposited; where access roads, haul roads, mineral stockpiles, mill tailings, and impoundment basins have been built; and all other lands whose natural state has been or will be disturbed as a result of the operations.

C. **"Aquifer"** A zone, stratum, or group of strata that stores and transmits water in sufficient quantities for a specific use.

D. **"Aquitard"** A layer of low permeability that can store groundwater and also transmit it slowly from one aquifer to another. May also be called a leaky confining layer.

E. **"Confined Aquifer"** An aquifer that is overlain by a confining layer where the water level in a well completed in that aquifer will rise above the top of the aquifer.

F. **"Diversion"** means a channel, embankment, device, or other man-made structure constructed for the purpose of diverting water from one area to another.

G. "**Ephemeral Stream**" A stream which flows only in direct response to precipitation in the immediate watershed or in response to snow melt, and which has a channel bottom that is always above the prevailing water table.

H. **"Impoundment"** means a closed basin formed naturally or artificially built which is dammed or excavated for the retention of water, slurry or other liquid or semi-liquid material. A permanent impoundment is a structure that will remain after final bond release.

I. "**Intermittent Stream**" A stream or part of a stream that is below the local water table for some part of the year, but is not a perennial stream.

J. **"Master Stream"** A relative term referring to the highest order stream(s) in the permit area and adjacent lands. Master streams should be determined with the LQD staff during permitting.

K. **"Perched Aquifer"** An aquifer which is underlain by an aquitard and which is also underlain by geologic strata which are unsaturated or only partially saturated.

L. "**Perennial Stream**" A stream or part of a stream that flows continuously during all of the calendar year as a result of groundwater discharge or surface runoff.

M. **"Piezometer"** A well constructed in such a manner that the water level in the well will respond to changes in hydraulic head in one aquifer or a portion of one aquifer.

N. **"Potentiometric Surface"** The surface that coincides with the static level of water in an aquifer. The surface is represented by the levels to which water from a given aquifer will rise under its full head.

O. **"Sedimentation pond"** means a sediment control structure designed, constructed, and maintained to slow down or impound precipitation runoff to reduce sediment concentrations in a point source discharge, including dams or excavated depressions. The term does not include straw dikes, riprap, check dams, mulches, collection ditches, toe ditches, vegetative buffers, gabions, contour furrows and other traditional soil conservation techniques and non-point source runoff controls.

P. **"Unconfined Aquifer"** An aquifer in which there are no confining beds between the zone of saturation and the surface. The water level in a well completed in an unconfined aquifer will be coincident with the top of the aquifer. Also known as a water table aquifer.

III. SURFACE WATER

A. Premining Studies (to be included in Appendix D-6 (Hydrology))

1. Precipitation (can be cross-referenced from Appendix D-4 (Climatology))

   Long-term precipitation data may be obtained from the nearest weather station or from the National Oceanic and Atmospheric Administration (NOAA) map (US Department of Commerce, 1973). Operations more than 50 miles from a permanently staffed official weather station may be required to keep precipitation records. These data should include:

   a. Precipitation (inches) for the 2-, 5- 10-, 25-, and 100-year, 6-, and 24-hour storm events; and

b. Average monthly and average annual precipitation in inches.

Any storm event precipitation data collected at the mine site should be presented, and the monitoring station equipment and location should be described. The most useful data would include continuous precipitation for each storm event, presented in intervals of ten (10) minutes or less.

2. Evapotranspiration (ET) (can be cross-referenced from Appendix D-4 (Climatology)). ET data may be required based on the design requirements of impoundments or other water retaining structures.

   a. Actual ET: Where measurements of actual ET are available they should be summarized and referenced.
   b. Potential ET: Potential ET may be estimated from weather station data or from regional maps.

3. Runoff

   a. Water Quantity Measurements

   Surface water quantity measurements should be taken for a minimum of one year prior to application submittal. Permanent continuous recording gages should be established at the up and downstream permit boundaries on all master streams. The monitoring plan should be discussed with the LQD in the early stages of the permitting process and ultimately approved by the LQD.

   The following information should be included in the application:

   (1) Monitoring station description: equipment, measurable flows, type of flow control for high and low discharges (weir, flume, channel control), stage discharge relationship, location of monitoring stations on a map, and other appropriate information;
   (2) Description of monitoring station maintenance procedures, including but not limited to: checks for structural, mechanical, and electrical integrity of equipment; and checks for signs of erosion or debris preventing the proper function of any equipment. Where possible, inspections of equipment should take place within 24 hours after each substantial runoff event and at the beginning of the runoff season (early spring). All problems preventing the proper function of a gaging station should be corrected upon discovery. A written log of inspection and maintenance activities should be available at the mine and summarized in the annual report;
   (3) Daily non-zero runoff volumes (missing data should be estimated), event peak flows, representative hydrographs and flow-duration curves (for perennial streams) for all master streams, whether ephemeral, intermittent or perennial;

(4) The runoff volume and peak flows of 2-yr, 10-yr, and 100-yr frequencies should be estimated near the downstream permit boundary for all master streams. This can be done using a variety of techniques, such as:
   (a) Relationships based on basin and/or channel characteristics (e.g., Craig & Rankl, 1977; Lowham, 1988; Miller, 2003);
   (b) Soil Conservation Service Triangular Hydrograph Method; and
   (c) Estimates using computer models, such as Trihydro, Multsed, SEDCAD+, HEC-1, etc.; and

(5) Estimates of recharge and discharge due to groundwater interactions within the permit area.
   a. Empirical Methods
      The empirical methods above may be used to determine volume and peak flows on all other streams on the permit area.
   b. USGS Data
      Available USGS gaging data, relevant to the permit area, should be summarized for the period of record.

4. Watershed and Stream Channel Characterization

a. Watershed Network

A drainage network map (scale 1 inch = 1000 feet) of the permit and adjacent areas on the topographic base map should be included in the application. The applicant should:

(1) Include all streams with defined channels (the extent of stream channels should be checked in the field and/or with aerial photography);
(2) Distinguish perennial, intermittent, and ephemeral streams;
(3) Show boundaries of contributing watersheds;
(4) Locate stream gages; and
(5) Show areas of alluvium, terraces, playas, groundwater discharge areas, stock ponds, and other hydrologic features.

b. Watershed Delineation

For all basins that will be disturbed by mining activities within the permit area, measure and tabulate:

(1) Watershed area;
(2) Basin relief ratio (Strahler, 1964) or average basin slope (Craig and Rankl, 1977);
(3) Valley and channel slope;
(4) Channel sinuosity; and
(5) Drainage density (mi/mi^2)

c. Stream Characterization

Plot longitudinal profiles and calculate the slopes for channels that drain areas greater than 100 acres and which will be disturbed by mining activities. Locate any bedrock outcrops and headcuts. Describe vegetation on channel bed and banks, texture of channel materials, bank and bed stability, and presence or absence of sediment deposits.

d. Stream Morphology

Survey and plot cross-sections sufficient to characterize the morphology of the stream channels indicated in point "c." above. The suggested cross-section interval is 2000 feet or less. This information is necessary to characterize the premining condition of the stream channels and can be used in the design of reclaimed stream channels, see Section III.C.2.a. of this guideline.

e. Potential Offsite Changes

Describe any offsite conditions that might be expected to affect reclaimed channels in the future (e.g., major headcuts, dams, etc.).

5. Baseline Water Quality

The Water Quality Division's (Chapter 1) stream classifications for all identified streams should be provided in order to establish the current and postmining uses.

On master streams, well-mixed zones should be sampled both upstream and downstream of the lands to be affected. In addition, a reconnaissance sampling program should be conducted to include samples at groundwater discharge points and on channels draining different geologic units. Surface water quality samples should be collected from benchmarked sampling points where flow can be measured or calculated. Baseline water quality constituent, field preservation techniques, quality control measures, and holding times are referenced in Appendix 1 of this guideline.

On intermittent and perennial streams, samples to be analyzed for constituents listed in Appendix 1 should be collected monthly for one year in order to identify seasonal variation. On ephemeral streams, one sample should be taken as early as possible during snowmelt runoff, and one should be taken during a thunderstorm runoff event. The following information should be submitted:

a. Sample collection and preservation methods;
b. Date and time of sample collection;
c. Discharge at time of sampling; and
d. Analytical results

6. Water Rights

a. Within the Permit
A map showing the locations of all surface water rights within the permit area should be submitted.

b. Within one-half mile
The following information should be tabulated for each surface water right within one-half (½) mile of the permit area:
(1) Source;
(2) Permit number;
(3) Location;
(4) Priority date;
(5) Facility name (reservoir, ditch);
(6) Applicant name;
(7) Acre-feet; and
(8) Use (industrial, irrigation, stock, etc.).

B. Mine Plan

1. Design of Temporary Diversions and Culverts

a. Design Flow

(1) Minimum standards require that temporary diversion channels be designed for the 2-yr, 6-hr event or a duration that yields a higher peak flow. However, it is recommended that the design event recurrence interval be chosen based on the structure's expected lifetime and an appropriate probability of failure for the function of the diversion. Recommended design event return periods are:

Life of Diversion	Storm Event Return Period
<3 yrs	10 yr
3-10 yrs	25 yr
11-20 yrs	50 yr
>20 yrs	100 yr

(2) Suggested methods for calculating flood peaks and/or volumes in Wyoming may be found in Section III.A.3.a.(4) of this guideline.

b. Diversion Design Considerations - greater than 20-year life of diversion (but not permanent)

The operator should:

(1) Submit the design methodology, criteria, assumptions, and representative calculations (e.g., Manning's "n", velocity, sheer stress, flow depth, bed or energy grade line slope);

(2) Discuss the erodibility of the channel materials;
(3) Submit representative cross-section(s); and
(4) Submit transition zone design(s).

c. Diversion Design Considerations - less than 20-year life of diversion

For a diversion in place less than 20 years, operators should demonstrate that the design discharge will not exceed an appropriate maximum permissible velocity.

d. Culvert Design

(1) Culverts should pass the design flood peak using the head available at the entrance. Culverts should pass the same peak event described in Section III.B.1.a.(1). The suggested minimum culvert diameter is 18 inches.
(2) Erosion control measures for culverts should be specified.
(3) Where appropriate, trash racks should be placed at or near culvert entrances to prevent clogging.
(4) A culvert maintenance plan should be outlined.

2. Impoundments and Sedimentation Ponds

Runoff from disturbed and reclaimed areas should be controlled either by sediment ponds (see LQD Guideline 13), alternative sediment control measures (see LQD Guideline 15), or a combination of both. Detailed design specifications are required for those structures that are planned to be built during the term of permit. For those impoundments that are planned to be constructed after the term of permit, the applicant only needs to submit the general location and approximate impounding capacity of the structure. For more detail concerning impoundment designs and other considerations, see Appendix 3 of this guideline.

3. Monitoring Stations

a. Wyoming Pollutant Discharge Elimination System (WYPDES)

The WYPDES program, administered by the Department of Environmental Quality, Water Quality Division and overseen by the U.S. Environmental Protection Agency, regulates the discharge of pollutants into surface waters of the State. All discharges into waters of the State are required to be permitted. This includes stormwater discharges. Permits issued under this program establish effluent limitations which specify maximum amounts of pollutants or wastes which may be discharged. Questions concerning permitting, reporting and monitoring requirements for WYPDES permits should be directed to Water Quality Division. The location(s) of all WYPDES discharges and outfalls should be shown on the hydrologic control map. WYPDES sampling requirements may be included as part of the surface water quality and quantity monitoring.

b. Mining Phase Water Quality Monitoring

Surface water quality samples analyzed for Appendix 7 constituents should be:

(1) Collected quarterly from upstream and downstream stations on through-flowing intermittent and perennial streams;

(2) Collected twice annually on ephemeral streams; during a snowmelt runoff event, and a thunderstorm runoff event. With adequate justification, this monitoring frequency may be changed or monitoring may be discontinued after approval from the LQD; and

(3) Collected from all WYPDES discharge points according to the requirements specified by the WQD permit.

When the WQD is informed of an accidental oil or hazardous materials spill within or near the permit area that could potentially affect the quality of surface water or groundwater, the LQD should be notified with a phone call relating the same information.

c. Mining Phase Water Quantity Monitoring

Surface water flows should be monitored during the life of mining. Flow information should include:

(1) Continuous recorded data from stations on the up and down stream permit boundaries for all master streams;

(2) Flow data from streams that may be significant to downstream water rights.

The applicant should have a plan approved by the LQD to analyze monitoring station data to determine mining impacts on flow peaks, flow volumes, infiltration, and any rating curves.

4. Hydrologic Control Map

A hydrologic control map should be provided locating and identifying diversions, monitoring locations, culverts, ponds, WYPDES discharge points, alternate sediment control structures and their drainage areas. This map should be at the same scale as the mine plan map.

C. Reclamation Plan

1. Topography and Watershed Design

a. Topography Design

The reclaimed topography should be designed to maximize geomorphic stability and topographic diversity. Slopes should generally be shaped to be concave up, because slopes that are convex up generally have an increased potential for severe erosion. Streams should be designed to avoid abrupt changes in slope between undisturbed and reclaimed channels. Topographic diversity can be enhanced by

shortening designed slope lengths, increasing the drainage density and decreasing drainage basin sizes.

The reclaimed topographic map should show drainage basin boundaries and reclaimed channels with reference to cross-sections and longitudinal profiles. The map should be on the same scale and have a contour interval not greater than the pre-disturbance map.

b. Watershed Design

Drainage areas, basin relief ratios, valley and channel slopes, channel sinuosity, and drainage densities for all reclaimed basins should be tabulated. The table should be constructed such that it can be compared to the same data for premining basins (see Section III.A.4.b. of this guideline). Factors affecting premining channel and landscape stability that may be altered in the reclaimed landscape (e.g., bedrock controlled headcuts and differences in material erodibility) should be discussed.

2. Stream Channel Reconstruction and Permanent Diversion Construction

a. Stream Channel Reconstruction

Stream channels should be designed to maximize geomorphic stability. The channel planimetric, longitudinal, and cross-section design should be explained. Cross-sections representative of any variations along the profile should be provided. Detailed thalweg profiles, including at least 500 feet of undisturbed channel on either end of reconstructed reaches, should be submitted.

The following geomorphic measurements and hydraulic variables (for the design discharge) should be calculated or measured for the reclaimed channel and the undisturbed upstream and/or downstream reaches:

GEOMORPHIC	**HYDRAULIC**
Channel Depth	Flow Depth
Channel Top Width	Water Surface Width
Channel Cross-Section Area	Cross-Section Area of Flow
Thalweg Slope	Water Surface Slope
Valley Slope	Manning's and/or Vegetal Retardance
Channel Sinuosity	Channel Hydraulic Radius
Bendway Radius of Curvature	Mean Channel Velocity
	Thalweg Shear Stress

Baseline stream channel data, collected as part of Section III.A.4.c. and d. of this guideline, should also be used to evaluate and/or modify the reclaimed channel design.

b. Permanent Diversion Construction

A plan for field-verifying that each reclaimed channel has been constructed according to specification should be included. The applicant should submit and explain graphical or tabular survey data, and the survey technique used to bring the channel to the approved grade. The survey should be conducted after grading but before topsoil replacement in the stream channel. Several representative cross-sections should be surveyed if signs of instability (e.g., headcutting, bank failure, channel avulsion) are anticipated or discovered during inspections or photo surveys. Inspection reports or photo surveys should be included in the Annual Report.

c. Additional References

For more information concerning reclaimed channel design see Appendix 2 of this guideline.

3. Permanent Impoundments

a. Location

All permanent impoundment locations should complement the anticipated final land use. The permanent impoundments should be located on the postmining topography map. Surface owner consent is also required for all permanent impoundments.

b. Expected Life

The expected life of the impoundment should be estimated based on the loss of water storage capacity due to sedimentation.

c. Water Availability

The applicant should demonstrate that enough water is available to fill the impoundment, the onsite transmissivity is sufficient to supply groundwater to the impoundment (if groundwater is a major contributor to total storage), and the anticipated final water quality is suitable for the postmining use. The demonstration should include items listed in Land Quality Division Coal Rules and Regulations Chapter 4, Section 2.(g). These include:

(1) Aquifer characteristics;

(2) The rate of groundwater recovery after dewatering within the impoundment area;
(3) The final water surface elevation and expected water level fluctuations;
(4) The yearly evaporative rate from the impoundment surface;
(5) The anticipated final water quality of the impoundment and its relationships to the proposed use of the impoundment;
(6) Surface water contributions to the impoundment; and
(7) State Engineer Office approval.

d. Postmine Impoundment Water Quality

4. Reclamation Monitoring

The applicant should continue to monitor surface water following the approved monitoring plan as discussed in Section III.B.3 of this guideline.

IV. GROUNDWATER

The purpose of this introduction is to outline the strategy for designing a groundwater hydrologic monitoring program which will be in place and provide useful information throughout the life of the operation - from premining through Final Bond Release. For more detail concerning groundwater performance standards, see Appendix 8 of this guideline. The information in this introduction applies to all of the groundwater monitoring sections in this guideline. More specific information regarding groundwater monitoring during each stage of the operation can be found in the Premining, Mine Plan and Reclamation Plan sections of this guideline. It is imperative that the reader keep this strategy in mind when designing all stages of the hydrologic monitoring program. The reader should also keep in mind that site-specific hydrogeologic aberrations may require additional information. For this reason, the monitoring strategy should be discussed with the LQD in the early stages of the permitting and revision process and ultimately approved by the LQD.

The goal of premining hydrologic monitoring is to characterize the hydrogeologic system and establish baseline conditions. The goals of during mining and reclamation hydrologic monitoring are to track mine related impacts to the groundwater system and to assure the suitability of the water for current and postmining uses. To efficiently achieve these goals, wells should be located where they will provide useful information for as long as possible. That is, wells should be placed in areas accessible year-round and outside near-term mining areas. The placement of wells for hydrogeologic characterization and tracking of mine related impacts will apply to all potentially affected aquifers including overburden, coal, underburden, clinker and alluvium.

Initial geologic information, obtained through literature searches, exploration drilling and reconnaissance level mapping, should be used to identify the different hydrogeologic environments in and near the permit area. The monitor well network within the permit area should be designed to further characterize these different environments. The designs of this network should also consider the near-term mining sequence so that as many of the wells as

is possible can also be used to track mine related impacts. The monitor well network within the permit area should be incorporated into the design of the long-term monitoring strategy. Sections IV.A.1., 2., and 3. of this guideline discuss the characterization of the local geology and hydrogeology.

The primary goals of the long-term monitoring strategy is to track mine related impacts to, and recoveries of, the groundwater system throughout the mining and the postmining monitoring periods. It is suggested that the long-term monitoring strategy be based on a radial pattern originating at the approximate center of the permit area, with wells located at or near the permit boundary. Water level fluctuations should be used as a first indication of impact and water quality should be used as a second indication. The monitoring network within the permit area should be designed to fit into this pattern as much as possible. Section IV.B.2., of this guideline, discusses the long-term monitoring strategy, including hydrologic monitoring to track mine-induced impacts.

Once baseline has been established, monitoring frequencies will be based on the assumption that water level declines will be a first indication of mine related impacts. Most contaminants, excluding gaseous phase contaminants, cannot move away from a pit, only towards the pit, when water levels indicate the prevailing hydraulic gradient is towards the pit. If water levels demonstrate a hydraulic gradient towards the pit, water quality can be monitored less frequently, after approval from the LQD.

The adoption of this long-term monitoring strategy by existing operations should not necessitate major reworking of the existing monitor well network (i.e., new wells). It is recommended that this strategy be adopted and meshed with the present monitoring network by adjusting monitoring frequencies at existing wells, abandoning unnecessary wells, and/or strategically locating future wells (especially off permit wells). For more detail concerning plugging and abandonment, see Appendix 6 of this guideline.

A. Premining Studies [Appendix D-6 (Hydrology)]

1. Geologic Framework

   Note: much of this information can be referenced from Appendix D-5 (Geology/Soils)

   a. Stratigraphy

      Stratigraphy within the permit area and adjacent areas should be identified and described using lithologic and geophysical logs, geologic maps, and published data. The extent, thickness, and continuity of all aquifers and confining layers should be identified.

   b. Geologic Features

      Geologic features that could influence aquifer properties such as dip, grain size,

faulting, folding and sorting should be described. Any occurrence of clinker, clay or shale should be described and identified on a map.

c. Hydrologic Boundaries

Potential hydrologic boundaries, recharge and discharge areas (including springs, seeps, sinks and wet areas), and significant perched aquifers should be identified on the potentiometric surface map.

d. Cross-Sections

Cross-sections extending through the affected area should identify:

(1) Potentiometric surface(s);
(2) Lithologies;
(3) The mineral to be mined;
(4) Geologic features such as faults, paleochannels, etc.;
(5) Extent of mining;
(6) Aquifers and aquitards;
(7) Areas of aquifer communication;
(8) Hydrologic boundaries;
(9) Recharge and discharge areas; and
(10) Wells used for hydrogeologic interpretations.

e. Supporting Data

Supporting information including: geophysical logs (resistivity, gamma ray, self-potential, density) and/or lithologic logs should be referenced from Appendix D-5 of the permit. A structure contour map of the aquifer and the unit directly below it (top of coal and bottom of coal) should be referenced from Appendix D-5 (Geology/Soils). A map showing cross-section and drill hole locations should be referenced or included.

2. Aquifer Hydraulic Characteristics

Hydrogeologic characterization of the permit area requires prior knowledge of the mining method, extent of disturbance, depth of the pit, duration of the mining, and potential impacts to surrounding water resources and water rights. The characterization program should be designed to: 1) determine the hydraulic characteristics of aquifers that may be affected by mining; 2) determine the quantity and quality of groundwater to be dewatered at various stages of mining; 3) estimate the areal extent of static water level declines in potentially affected aquifers; 4) evaluate potential impacts to water resources due to mining, and 5) estimate groundwater conditions and aquifer characteristics likely to exist after reclamation.

a. Hydrogeologic Characteristics

A narrative summary of hydrogeologic characteristics should include the following:

(1) Number of aquifers and their intercommunication;
(2) Aquifer characteristics and variability;
(3) Direction of flow and significance of recharge and discharge areas to the sites;
(4) Significance of hydrologic boundary conditions;
(5) Potentiometric surface(s);
(6) Water quality;
(7) The effect of any existing adjacent operations on the premining information and data; and
(8) Regional potentiometric surface(s)

b. Aquifer Tests

Aquifer tests should be used to determine transmissivities, hydraulic conductivities, storage coefficients, hydrologic boundaries, leakage, aquifer homogeneity, and isotropy. For example, a multi-well pump test evaluation, as described by Theis (1935), Cooper and Jacob (1946), Boulton (1954), or a test as summarized by Lohman (1979) is suggested. A data log for each aquifer test should be placed in the application to identify both a chronological order of events and decisions that were made during testing. The location and number of aquifer tests should be sufficient to characterize the different hydrogeologic environments present within the potentially affected area. At a **minimum**, at least one aquifer test should be performed for each potentially affected hydrogeologic environment identified during the preliminary geologic investigation. The geohydrologic characterization plan or strategy should be discussed with the LQD during the early stages of the permitting process in order to facilitate LQD approval. In some instances, a temporary discharge permit may be required from WQD.

Within the data log mentioned in the above paragraph, the following information should be submitted for each aquifer or pump test:

(1) All data obtained from the aquifer tests and measurements necessary to evaluate the testing results; and

(2) Methods of analyses:

(a) List the methods of analyses and equations used;
(b) List the assumptions upon which the equations are based;
(c) List how assumptions were met by the physical conditions; and
(d) Present sample calculation.

(3) Graphs which show:

(a) All drawdown and/or recovery data;
(b) Curve or line fits;
(c) Match points, u, W(u);
(d) Boundary and casing storage effects;
(e) Pump breakdown;
(f) Discharge adjustments; and
(g) t_o.

(4) Correction factors and their associated supportive data and the method used for data adjustment

(5) Results of analyses:

(a) Hydraulic conductivity;
(b) Transmissivity; and
(c) Storage coefficient or (apparent) specific yield.

3. Potentiometric Surface

a. All Affected Aquifers

The premining potentiometric surface for all aquifers that may be affected by mining should be defined and located on a 1 inch = 1,000 foot scale map(s) which encompass the affected lands and potentially affected aquifers. Potentiometric surfaces should be extended into all units which are in good hydraulic communication with the aquifer, including clinker, alluvium, etc. This map should also show well locations, groundwater recharge and discharge areas, and other hydrogeologic features.

b. Premining Monitoring

Potentiometric surface elevations should be measured quarterly for one year, except for alluvial wells or aquifers in non-static conditions. For alluvial wells or aquifers in non-static conditions, measurement frequencies shall be agreed to by the LQD and the operator. Continuous monitoring should be considered where hydrographs are needed for assessment of groundwater recharge or discharge zones. This is particularly important for determination of alluvial valley floor (AVF) characteristics (see LQD Guideline 9). Closed-in information pressure readings may be necessary in gassy wells and flowing artesian wells.

c. Well Installation and Maintenance Program

A well installation and maintenance program should be thoroughly outlined (see Appendix 4 of this guideline).

4. Groundwater Quality

   a. Sampling Frequency

      Representative groundwater samples should be taken at a minimum quarterly for one year to characterize potentially affected aquifers. For alluvial wells or aquifers in non-static conditions, sampling frequencies shall be agreed to by the LQD and the operator. Samples should be analyzed for the constituents referenced in Appendix 1 of this guideline. Sample quality assurance procedures should also be followed and are found in Appendix 1.

   b. Sampling Method

      It should be documented that aquifer water and not borehole water is being collected. This can be done by withdrawing at least three casing volumes of water prior to sampling (document pump rate and purging time) <u>or</u> by pumping until pH, conductivity, temperature, and water level readings remain constant (document changes in each constituent against time in tabular form). If recharge cannot match minimal pumping rates in the low permeability aquifers, then a sample can be retrieved by clearing the borehole once and bailing water that subsequently enters the well.

   c. Reporting Results

      The results of water quality analyses should be tabulated in the application. The following information should be reported for each sample:

      (1) Sample site identification;
      (2) Laboratory identification;
      (3) Date sampled;
      (4) Date analyzed;
      (5) Constituents and associated units as outlined in Appendix 1 of this guideline (Note whether such analyses represent field or laboratory measurements.);
      (6) Calculated cation-anion balance
      (7) TDS determined at 180°F vs. TDS calculated from major cation-anion analyses; and
      (8) Analytical method

   d. Description of Alternative Methods

      If methods are used other than those outlined in 40 CFR Part 136, then a brief description of these alternative methods and associated justifications for their use should be included.

5. Water Rights

a. Map

A map showing the locations of all groundwater rights within the permit area and three miles beyond the permit boundary should be submitted.

b. Report Information

The following information should be tabulated for each groundwater right within the permit area and three miles beyond the permit boundary:

(1) Permit number;
(2) Location;
(3) Priority date;
(4) Facility name;
(5) Applicant;
(6) Total depth;
(7) Depth of water;
(8) Yield;
(9) Statement of well log availability; and
(10) Use (irrigation, stock, domestic, etc.).

c. Discussion of Impacts and Protection

A narrative should be included which discusses the potential and extent of mine related impacts to the quantity and quality of water protected by these water rights.

B. Mine Plan

1. Impacts of Dewatering or Water Consumption

a. Dewatering Methods

(1) The applicant should specify all methods to be used to dewater all affected aquifers, including the locations and typical designs of dewatering wells, and predicted pumping rates.

(2) All methods, calculations, and numerical values used in the dewatering assessment should be provided.

(3) If groundwater is discharged into a stream channel, anticipated discharge flow rate, water quality, and estimated seasonal discharge of the groundwater should be tabulated. The availability and suitability of this water for downstream water users should also be evaluated.

b. Anticipated Water Quality and Quantity

(1) The quantity and quality of groundwater removed at various stages of mining should be described, including wells supplying water for facilities and dust suppression.

(2) Ponds should be designed to treat the volume of water pumped from mine pits and underground workings at any given time. Discharges from well heads may not require treatment, however erosion protection measures for well head discharge points should be described. Anticipated discharge rates to stream channels should be discussed.

(3) The DEQ WQD requires a WYPDES discharge permit for each mine. The WYPDES permit regulates all discharges and discharge points on the mine site.

c. Drawdown Modeling

(1) The purpose of drawdown modeling is to predict mine related impacts to the hydrologic system. The modeling results should be used to assess probable hydrologic consequences and cumulative hydrologic impacts. The level of sophistication used in estimating drawdown should be proportional to the complexities of the hydrogeologic system.

(2) A thorough description of the selected model or prediction technique should be submitted and include:

(a) An introduction of the problem and the approach chosen for modeling (e.g., finite difference);
(b) A written description of all equations;
(c) A list of simplifying assumptions, sinks, sources and boundary conditions;
(d) The solution techniques for the equations (e.g., strongly implicit procedure (SIP), line successive over-relaxation (LSOR) and alternating direction implicit procedure (ADI)) and associated error tolerances;
(e) The grid nodes superimposed on a base map of the same scale as the premining potentiometric map;
(f) The selection of time steps;
(g) A tabulation of data input; and
(h) A sensitivity analysis.

(3) The drawdown predictions should be evaluated for consistency with the most current potentiometric data at each renewal period for coal. If drastic inconsistencies are observed, adjustments will be required for predicting drawdowns for the subsequent term of permit and life-of-mine. Trend analysis of existing life-of-mine potentiometric data may substitute for

recalibration of the original drawdown model given an adequate data base.

2. Monitoring

a. Monitor Well Network

(1) The groundwater monitoring strategy during the early phase of the mining operation should take into consideration the initial pit locations. Information provided from the monitoring network within the permit area will be used to track mine related impacts and evaluate drawdown model predictions. Ideally, wells should be located in a radial pattern centered around the projected near-term pit(s) and in locations which will not be mined through in the early phases of the operation. The monitoring network will track impacts for longer periods of time if the wells are located in this manner. The network should be designed to monitor impacts to the overburden, coal, underburden aquifers, and in any other aquifer which may be impacted. This early term monitor network should be incorporated into the design of the long-term monitor network as soon as possible.

(2) This simple strategy may not be applicable in all mining situations. For example, a mine with multiple operating pits may need to establish a monitoring network around each pit. It may be beneficial to share monitor wells which are located between two pits. These multiple networks should be incorporated into the long-term monitoring network as much as possible. The LQD does not feel that further specification of well locations is beneficial in this guideline because a certain degree of flexibility is needed for site-specific hydrogeologic considerations. The LQD should be consulted in the early stages of the permitting process in order to facilitate approval of the groundwater network.

(3) It is suggested that the life-of-mine monitor well network be installed in a radial pattern originating at the approximate center of the life-of-mine permit area, as shown in Figure 2. The wells should be located along radii spaced approximately 45 degrees apart near the life-of-mine permit boundary. Additional wells will be necessary off the permit as drawdowns extend beyond the mine boundary. A recommended rule of thumb is that new wells should be installed, further from the permit area and along the same radii, when drawdowns exceed ten feet at any of the permit boundary wells.

The LQD recognizes that access to potential monitor sites off the permit area may be restricted by surface or mineral owners. Off permit wells may require special BLM permits.

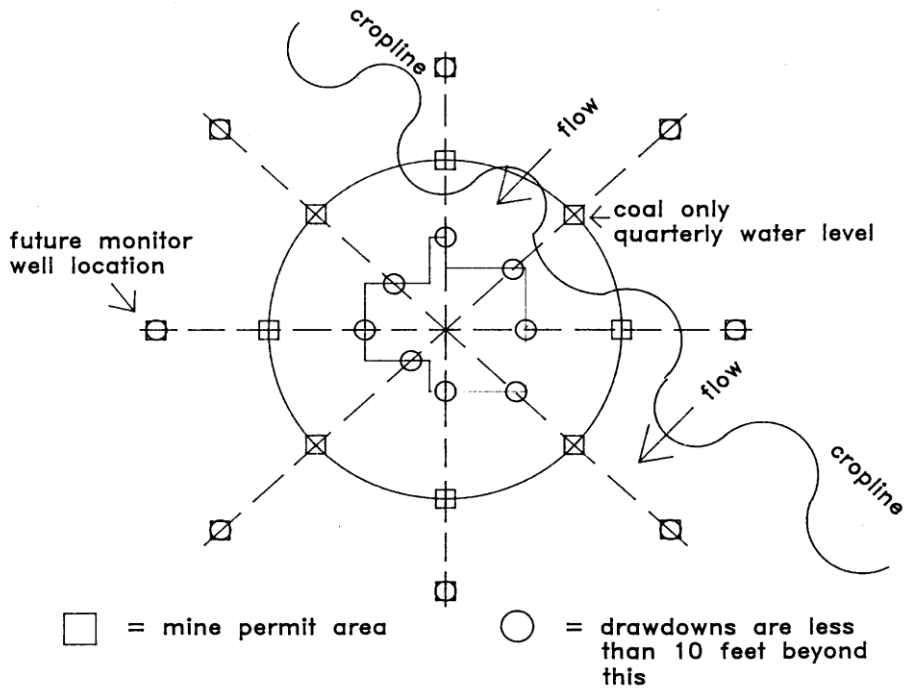
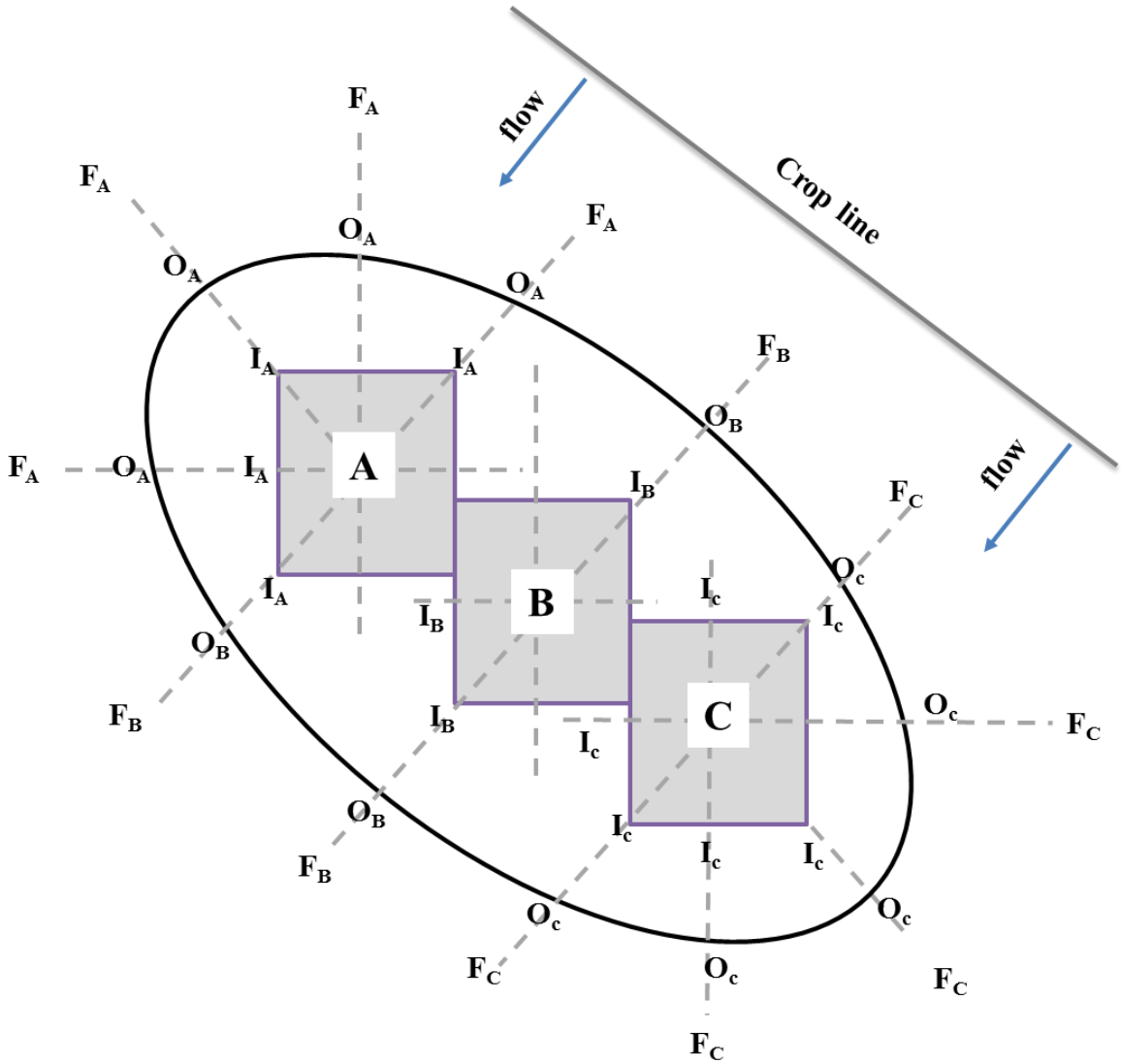


Figure 1: Suggested Groundwater Monitor Well Network

(4) If pump tests and/or other baseline data indicate a direction of greater transmissivity or any other hydraulic discontinuity, one of the radii should be oriented in that direction. Other adaptations will be necessary in order to fit this general pattern to the specific circumstances at each mine. Some of the anticipated modifications are diagramed in Figure 1. The possibility exists for cooperating operators to share monitoring responsibilities and/or monitoring data from common monitor wells thereby reducing the overall number of wells needed in any one region. These agreements must be made between the operators. This life-of-mine network should consider the early term, or on permit area monitoring network, as well as the postmining monitoring network.



I_A, I_B and I_C	Inner ring wells: underburden, coal and overburden: quarterly water levels, annual water quality.
O_A, O_B and O_C	Outer ring wells: coal only: quarterly water levels.
F_A, F_B and F_C	Future wells: to be installed when drawdowns exceed ten feet at outer ring well; will become outer ring.
I_A, O_A and F_A	Approximate location of wells to be monitored by mine A.
I_B, O_B and F_B	Approximate location of wells to be monitored by mine B.
I_C, O_C and F_C	Approximate location of wells to be monitored by mine C.
▬	Line of equal drawdown where drawdown equals ten feet.
▭	Permit area.

Figure 2: Suggested Groundwater Monitor Well Network for Multiple Adjacent Mines

(5) Each master stream channel where the stream enters and exits the permit area should be characterized with at least one monitor well located in the alluvium. Other technologies approved by the LQD may also be used for the characterization of the alluvium in the stream channel. Additional alluvial wells may be requested if the overburden aquifer and the stream appear to be hydraulically connected. LQD Guideline 9 should be referenced for monitoring recommendations for declared AVFs.

b. Water Quantity

(1) Water levels should be obtained quarterly in monitor wells which form the ring closest to the active pit and in which drawdowns have not exceeded ten feet (as shown in Figure 1).
(2) Water levels should be obtained at least semi-annually from all other monitor wells. The frequency of measurements can be reduced after approval from the LQD.
(3) Closed-in formation pressure readings may be necessary in gassy and flowing wells.
(4) Monthly monitoring of alluvial wells may be requested if streamflow losses are anticipated.

c. Water Quality

(1) Water quality in non-backfill wells should be monitored at least on a semi-annual schedule initially and the frequency can be reduced, if water level measurements indicate no possibility for groundwater flow offsite (i.e., closed cone of depression). If potentiometric surface data indicate that groundwater is flowing offsite (i.e., a closed cone of depression is <u>not</u> maintained), water quality should be monitored more frequently. The monitoring frequency and constituents will depend on site-specific factors such as transmissivity, gradient, overall water quality in adjacent aquifers, and proximity of adjudicated water rights. The applicant should consult with the LQD to determine the frequency and constituents of water quality monitoring.
(2) Samples should be analyzed for the constituents referenced in Appendix 7 of this guideline.
(3) Sampling protocol is discussed in Appendix 7 of this guideline.
(4) Well purging techniques are found in Section IV.A.4.b. of this guideline.

3. Water Rights

a. Potential Effects

Potential effects of mining on existing water rights should be assessed. Examples include effects of drawdowns on surface water flows, degradation of water quality from lateral flow through spoils, and depleted water levels in adjudicated wells.

b. Mitigation

If the quality or quantity of adjudicated water supplies are affected, then an alternative source should be identified as part of the mitigation plan.

C. Reclamation Plan

1. Aquifer Reclamation

a. Description of Expected System

A description of the anticipated post-reclamation groundwater system should be provided by the applicant. The discussions and maps used in this description should be supported by data and referenced material and should include:

(1) Final aquifer hydraulic properties (e.g., hydraulic conductivity, storativity, saturated thickness, etc.) including those of backfilled overburden;
(2) Anticipated groundwater quality during and after aquifer restoration;
(3) Anticipated post-reclamation potentiometric surface and estimated time to resaturate; and
(4) Post-reclamation effects on adjacent aquifers, wells, springs, and surface waters.

b. Reclamation Plan

The reclamation plan should be designed to minimize the disturbance to the hydrologic balance. This may be accomplished by including:

(1) An ongoing hydrologic monitoring program of the replaced spoil to determine the best replacement techniques (The initial results may be applied to later reclamation.)
(2) A program to isolate and bury unsuitable material out of the zone of fluctuation of the estimated post-reclamation potentiometric surface (see LQD Guideline No. 1).
(3) A plan to segregate and compact suitable spoil material to minimize the impact to the adjacent aquifer and reconstructed drainages.

c. Subsidence Effects

Any post-reclamation subsidence effects on the hydrologic system should be assessed.

2. Land Surface - Water Table Interactions

a. Anticipated Subirrigated Areas

A reclamation plan that proposes to reclaim to a subirrigated condition should consider the effect of salt accumulation and demonstrate that such reclamation will satisfy the postmining land use.

b. AVF Reclamation Plan

In those areas where a declared AVF has been or will be disturbed, a detailed design for reconstruction of subirrigation characteristics will be necessary. LQD Guideline 9 contains AVF reconstruction information.

3. Monitoring

a. Postmining Network

The postmining monitoring network should include the undisturbed monitor wells remaining from the mining phase of the operation as well as a system of backfill monitor wells. The backfill wells should be located as far down gradient as possible within the backfill and at a density adequate to characterize the backfill aquifer as approved by the LQD.

b. Monitoring Frequency

Water levels in each backfill monitor well should be obtained quarterly until final bond release. Once a reasonable trend in the water levels has been established, the frequency of measurements can be reduced after approval from the LQD.

c. Water Quality

Water quality in each backfill monitor well should be analyzed quarterly for the constituents listed in Appendix 7 of this guideline. Once a reasonable trend in the water quality has been established, reductions in sampling frequency and constituents will be considered by the LQD staff.

d. Sampling Procedures

(1) Sampling protocol, quality assurance, and quality control are discussed in Appendix 1 and Appendix 7 of this guideline.
(2) Well purging techniques are found in Section IV.A.4.b. of this guideline.
(3) Well installation and maintenance for backfill monitor wells are discussed in Appendix 4 of this guideline.

V. PROBABLE HYDROLOGIC CONSEQUENCES

The applicant should prepare a narrative describing the probable hydrologic consequences (PHC) of the mining and reclamation operations. The PHC section should demonstrate that

the mining operation has been designed to prevent material damage to the hydrologic balance as required by the Wyoming Environmental Quality Act, W.S. § 35-11-406(n)(iii). In the PHC section, the applicant should predict the areal extent, magnitude, and duration of the impacts to specific components of the surface water and groundwater systems and to these systems as a whole. Potential or anticipated impacts to the premining hydrologic balance should be determined for both during the life of the mine and after final reclamation has been completed. The applicant should also describe preventive and remedial measures taken to minimize hydrologic impacts.

The PHC section should contain a brief discussion of the probable hydrologic impact of any adjacent operations on the hydrologic balance within the proposed permit area.

The PHC section in the initial permit application should synthesize into one discussion the hydrologic information from the Premining, Mine Plan and Reclamation Plan sections of the permit application. In subsequent renewals the PHC section should also include a comparison of measured data to the hydrologic predictions. If the comparisons indicate revisions are necessary, the revised predictions should be included in the updated PHC section.

A. Surface Water Consequences

The applicant should determine and discuss the probable consequences from the mining operation on the surface water hydrologic balance of watersheds which may be impacted. In the discussion, the predicted and/or measured parameters outlined below should be compared to premining, postmining and during mining (if applicable) conditions for each affected watershed. The size of the watershed unit to be considered in the PHC is subject to discretion and should be discussed with the LQD. However, the analysis should focus on the size watershed which most dramatically illustrates the effects of mining

1. Surface Water Quantity

   a. Streamflow Characteristics

      The discussion for streamflow characteristics should include:

      (1) Base flow;
      (2) Soil infiltration capacity;
      (3) Event peak runoff rate;
      (4) Flood recurrence interval;
      (5) Total event runoff volume; and
      (6) Total annual water yield.

   b. Ponded Water Bodies (all sources of ponded water)

      This discussion should include:

(1) Summary of surface areas and volumes; and
(2) Discussion of spatial distribution.

2. Surface Water Quality

Discussion for this section should include the instantaneous concentrations of important constituents listed in Appendix 7 of this guideline.

3. Geomorphology (surface water quantity and quality)

a. Watershed Geomorphology

A discussion of the watershed geomorphology should include:

(1) Topographic diversity;
(2) Drainage density; and
(3) Watershed geometry
  (a) Drainage area;
  (b) Slope gradient; and
  (c) Slope length.
(4) Watershed erosional stability
  (a) Percent vegetation cover; and
  (b) Soil erodibility

b. Stream Channel Geomorphology

The following parameters should be included to define the stream channel geomorphology:

(1) Channel geometry
  (a) Cross-section dimensions;
  (b) Slope and channel profile; and
  (c) Sinuosity and planimetric shape.

(2) Channel erosional stability
  (a) Channel material erodibility;
  (b) Natural bedrock grade control;
  (c) Channel vegetation;
  (d) Hydraulic characteristics during peak discharge; and
  (e) Channel geometry.

B. Groundwater Consequences

For groundwater, the PHC should describe how the mining operation will affect the suitability of the water for the current and postmining uses for each specific aquifer and the groundwater system as a whole in the following areas:

1. Groundwater Quantity

   The areal extent, magnitude, and duration of static water level declines expected in potentially affected aquifers should be predicted. This should include a description of the drawdown model results, the extent of the five-foot drawdown contour, and, in permit renewals, measures verification of the drawdown predictions.

   The final predicted postmining groundwater flow should be compared to the premining groundwater flow and discussed with respect to the potential for impacts to the local and regional groundwater system. The comparison and discussion should include those hydraulic properties listed in Section IV.C.1.a. (items 1, 3 and 4) of this guideline for aquifers both premining and postmining, the backfill aquifer, and any other potentially affected aquifers.

2. Groundwater Quality

   The projected postmining groundwater quality should be estimated. A detailed description of potential changes in water quality from flow through backfill should be included. Any potential changes to water quality in adjacent aquifers should be discussed with respect to the potential for offsite material damage.

C. Surface Water/Groundwater Interactions

The applicant should discuss changes in the interaction between the surface water and groundwater systems from the premining through the postmining phases of the operation. The discussion should include, but not be limited to, the following:

1. Water Quantity

   a. Drawdown and Pit Water Discharge

      Describe how drawdown and pit water discharge may affect baseflow in streams.

   b. Infiltration Rate

      Describe how potential changes to the infiltration rate in reconstructed stream channels and diversion channels may affect groundwater recharge and stream baseflow. The changes in surface infiltration rates should be discussed with reference to changes in slope and soil structure.

   c. Postmining Potentiometric Surfaces

      Describe how the intersection of the postmining topographic and potentiometric surfaces may affect the location and size of groundwater-fed water bodies.

2. Water Quality

   a. Streams and Ponded Water Bodies

      Describe the extent to which backfill groundwater and pit discharge may affect the quality of streams and ponded water bodies.

   b. Potentiometric Surfaces

      Describe how the intersection of the postmining topographic and potentiometric surfaces may affect the location and size of groundwater-fed water bodies.

D. Water Rights

The applicant should evaluate the potential contamination, interruption or diminution of surface water and groundwater within and adjacent to the permit area that may affect legal water rights. This evaluation should be based on the predictions made in response to items A, B, and C of this section of this guideline.

E. Important Habitats

The applicant should identify and address the specific probable hydrologic consequences that may positively or negatively impact important habitats with emphasis on wetland areas.

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Strahler, A.N., 1964. Quantitative Geomorphology of Drainage Basins and Channel Networks, in, Handbook of Applied Hydrology, Ven Te Chow, ed., McGraw Hill, Inc., pp. 4-39 to 4-76.

Theis, C.V., 1935. The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Groundwater Storage, in, Transactions, American Geophysical Union, v.2, pp. 519-524.

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APPENDIX 1

PREMINING WATER QUALITY SAMPLING

I. INTRODUCTION

Water quality constituents that should be included in connection with premining (baseline) water quality sampling are listed below. Site-specific conditions, mining operations, and the purposes of collecting water quality data may warrant modifications to this list. An explanation for such modifications should be provided with the monitoring program submitted to the LQD.

II. FIELD MEASUREMENTS[1]

pH (report to nearest 0.1 standard units)
temperature (°C)
conductivity, umhos/cm corrected to 25°C
water level, reported to the nearest 0.1 foot AMSL (above mean sea level) (ground water only)
number of casing volumes purged prior to sampling (ground water only)
instantaneous discharge, ft^3/second (surface water only)

III. QUALITY ASSURANCE/QUALITY CONTROL

Quality control during sampling should be implemented to detect any data errors that may result from improper sampling or analytical methods, poor sample preservation, or collection of nonrepresentative samples. The following quality control samples should be collected, analyzed and reported for every twenty (20) samples or once every sample collection round, whichever is less, to help verify that the sample collection system is producing reliable information.

A. Duplicate Samples. At randomly selected stations duplicate samples are collected by filling two separate bottle sets from any one station and preserving, storing and shipping the sets in an identical manner. This provides a check of precision.

B. Sample Preservation Blanks. Field blanks are essentially low standards produced in the field. The same quantity of appropriate preservative should be added to sample bottles filled with distilled water. Field blanks check for analytical recognition of zero values, any positive bias from contaminated sample bottles or preservatives, and any contamination from atmospheric sources (e.g., airborne dust).

C. Analytical Data. Analytical data should include cation-anion balances and TDS determined at 180°F vs. TDS calculated from major cation-anion analyses.

IV. WATER QUALITY CONSTITUENTS AND SAMPLE PREPARATION[1]

Listed below are parameters for which each water quality sample should be analyzed. Samples should be kept on ice (4°C) and stored in the dark until analysis. The operator is responsible for applying all sample preparation, handling and preservation procedures required for the analytical method used.

Constituents (reported in mg/l unless noted)	Analytical Method	Max Holding Time[2]	Rational for Analysis
Ammonia Nitrogen as N	EPA 350.1	28 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Nitrate + Nitrite as N	EPA 353.2	28 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Bicarbonate	EPA 310.1/310.2	14 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Boron	EPA 212.3/200.7	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Carbonate	EPA 310.1/310.2	14 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Fluoride	EPA 340.1/340.2/340.3	28 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Sulfate	EPA 375.1/375.2	28 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv))
Total Dissolved[3] Solids (TDS) @ 180°F	EPA 160.1/SM2540C	7 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv))
Dissolved Arsenic	EPA 206.3/200.9/200.8	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv))

Dissolved Cadmium	EPA 200.9/200.7/200.8	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch 2, Sec 4(a)(xi),(xii),(xiv))
Dissolved Calcium	EPA 200.7/215.1/215.2	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch 2, Sec 4(a)(xi),(xii),(xiv))
Dissolved Chloride	EPA 300.0	28 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch 2, Sec. 4(a)(xi),(xii),(xiv))
Dissolved Chromium	EPA 200.9/200.7/200.8	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch 2, Sec. 4(a)(xi),(xii),(xiv))
Total and Dissolved Iron	EPA 236.1/200.9/200.7/200.8	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch.2, Sec. 4(a)(xi),(xii),(xiv)
Dissolved Magnesium	EPA 200.7/242.1	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Total Manganese	EPA 200.9/200.7/200.8/243.1/243.2	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch.2, Sec. 4(a)(xi),(xii),(xiv)
Dissolved Molybdenum	EPA 200.7/200.8	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Dissolved Potassium	EPA 200.7/258.1	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Dissolved Selenium	EPA 270.3/200.9/200.8	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Dissolved Sodium	EPA 200.7/273.1	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Dissolved Zinc	EPA 200.9/200.7/200.8	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)

V. SUPPLEMENTAL ANALYSIS

Listed below are additional constituents for which water quality samples may be analyzed depending on site-specific or mining process specific conditions. Samples should be kept on ice (4°C) and stored in the dark until analysis.

A. Uranium Mines

For all open pit and in-situ mines, applicants should utilize the list of constituents described in Table 2, Reference Document 10 within WDEQ/LQD – Guideline 4. Tailings pond water quality analyses at these operations should include Thorium and Beryllium in addition to the constituents described in Table 2.

B. In-situ Coal Gasification

Constituents (reported in ug/l unless noted)	Analytical Method	Max Holding Time	Rational for Analysis
Cyanide (mg/l)	EPA 335.2/335.3/335.4	14 days	W.S. §§ 35-11-103(f)(iii)&428(a)(ii)&(iii) LQD Coal R&R, Ch. 18, Sec. 3(b)(v)&(d)(i)
Base/Neutral and Acid Extractable Semi-Volatile Organic Compounds	EPA 625/8270	14 days	
Volatile Organic Acids	EPA 8260/1624	7 days	

C. Trona Mines, Underground and In Situ

Constituents (reported in mg/l unless noted)	Analytical Method	Max Holding Time	Rational for Analysis
Total Phosphorous	EPA 200.7/365.1/3565.2/365.3/365.4	28 days	Underground LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) In Situ W.S. §§ 35-11-103(f)(iii)&428(a)(ii)&(iii) LQD Non-Coal R&R, Ch. 11, Sec. 3(a)(xv)

D. Surface Water

Constituents (reported in mg/l unless noted)	Analytical Method	Max Holding Time	Rational for Analysis
Dissolved Oxygen	EPA 360.1/360.2	8 hours	LQD Coal R&R, Ch. 4, Sec. 2(i) WQD R&R, Ch. 1, Sec. 24
Total Suspended Solids (TSS) as mg/l Residue@103-105°C	EPA 160.2	7 days	30CFR§780.21, LQD R&R, Ch. 4 (a)(xi)(D)(II), WQD R&R, Ch. 1, Sec. 16
Turbidity (NTU)	EPA 180.1	48 hours	LQD Coal R&R, Ch. 4, Sec. 2(i) WQD R&R, Ch. 1, Sec. 23

E. Additional Trace Metals

Constituents (reported in ug/l unless noted)	Analytical Method	Max Holding Time	Rational for Analysis
Dissolved Aluminum	EPA 200.7/200.8/200.9/202.1/202.2	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Dissolved Barium	EPA 200.7/200.8/208.1/208.2	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Dissolved Copper	EPA 200.7/200.8/200.9/220.1/220.2	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Dissolved Lead	EPA 200.7/200.8/200.9/239.1/239.2	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Dissolved Mercury	EPA 200.7/200.8/245.1/245.2	28 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)
Dissolved Nickel	EPA 200.10/200.12/1638/1639/1640	180 days	LQD Non-Coal R&R, Ch. 2, Sec. 2(a)&(b) LQD Coal R&R, Ch. 2, Sec. 4(a)(xi),(xii),(xiv)

VI. FIELD SAMPLING SHEETS

For each well sampled for water quality, a field sampling sheet should be prepared. The field sampling sheet should contain the following items:

A. Identification of the well;

B. Well depth;

C. Static water level depth and measurement techniques;

D. Well yield (if measured);

E. Purge volume, pumping rate and volume per casing volume;

F. Time well purged;

G. Collection methods (bail or pump);

H. Field observations (such as well condition, sample color, sample smell, sound);

I. Name of collector; and

J. Climatic conditions, including air temperature.

FOOTNOTES

1. All measurements should follow EPA approved methods of analysis according to 40 CFR 136, as amended "Guidelines Establishing Test Procedures for the Analysis of "Pollutants" under the Clean Water Act.

2. The holding times listed are the maximum times that samples may be held before analysis and still considered valid. All samples must be kept cool (4°C) and in the dark regardless of holding time.

3. The term "dissolved" is defined as those constituents which pass through 0.456 micro membrane filter.

REFERENCES

American Public Health Association. 1985. Standard methods for the examination of water and wastewater. 16th Edition. Published jointly by: American Public Health Association, American Water Works Association, and Water Pollution Control Federation. Available from: American Public Health Association, 1015 Fifteenth Street NW, Washington, DC 20005.

Code of Federal Regulation, Title 40 Part 136. Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act. Environmental Protection Agency. U.S. Government Printing Office. Washington.

EPA. 1983. Methods for Chemical Analysis of Water and Wastes. EPA - 600/4-79-020. Available from: Center for Environmental Research Information (CERI), EPA, Mail Drop G-70, Cincinnati, Ohio 45268.

EPA. 1982. Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater. EPA-600/4-82-057. Available from: Center for Environmental Research Information (CERI), EPA, Mail Drop G-70, Cincinnati, Ohio 45268.

APPENDIX 2

STREAM CHANNEL DESIGN

A design specification should be submitted to the LQD for every stream channel that will be constructed within the permit area. The operator and the LQD should determine the necessary design detail for each particular channel. The design detail should first be based on the drainage area upstream of the channel to be constructed. A larger drainage area would in general require a larger structure and a more detailed design specification. A second consideration is the steepness of the stream channel to be constructed. Steep stream channels, which may require artificial liners, will require more design detail. A third consideration is the function of the particular stream channel. For example, a small temporary diversion ditch would require less design detail than would a permanently reconstructed intermittent stream channel.

Every unique reach of a stream channel should have its own design specification. Unique channel reaches should be defined by significant changes in the channel slope, drainage area, or physical characteristics of the channel material. Also, channel transition zones, or where the reconstructed/constructed channels are graded into and out of native channels, require a separate design specification. The LQD may also need design specifications for important channel bendways.

The operator should calculate and justify the stream channel design discharge and its estimated recurrence interval and duration. The operator should calculate the design discharge based on an empirical technique or on a computer rainfall-runoff model applicable to Wyoming's hydrologic conditions. For larger stream channels, the operator should compare methods to determine the range of potential design discharges.

Each stream channel design specification should be accompanied with a demonstration that it will not erode substantially during the design peak discharge event. The operator should use maximum permissible velocity, maximum permissible shear streams, stream power, equilibrium slope, sediment balance or another well-established method to demonstrate that the channel will not erode substantially during the design peak runoff event. As a last resort, the operator may need to use riprap on the stream channel bed and/or banks to reduce erosion.

The operator should demonstrate that each channel is geomorphically compatible with its adjoining stream channel network. Abrupt changes in slope, cross-section dimensions, design discharge velocity, vegetation and material erodibility should be avoided between the native and designed channel. The operator should discuss how the particular channel design specification accounts for such changes. Complex stream channels, that incorporate inner "pilot" channels capable of conveying the 2-year peak discharge, are encouraged when they increase geomorphic compatibility with the native stream channel. The LQD realizes that some stream channel bed and bank erosion is to be expected, but the channel slope and cross-sectional dimensions should not change substantially during the design discharge event. Channel network rejuvenation upstream or excessive sediment aggradation downstream of a reconstructed stream channel is unacceptable. Likewise, unusually rapid lateral migration of a stream channel is also unacceptable.

The operator is responsible for demonstrating that the channel has been properly constructed in the field. To make this demonstration, reclaimed stream channels should be surveyed to ensure that the slope and cross-section dimensions were properly emplaced. This survey information should be represented in the annual report. Regular LQD inspections will be conducted in lieu of detailed surveys to verify that, for example, small temporary diversion channels have been adequately constructed.

The operator should present a specific timetable for returning flow to reclaimed stream channels. Flow should be returned once subsidence has largely ceased and the vegetation is sufficiently established. Flows may be incrementally returned into reclaimed stream channels to enhance vegetation growth and consolidate channel sediments.

The following references contain several of the most widely accepted and comprehensive sources for channel design.

REFERENCES

Barfield, B.J., Warner, R.C., and C.T. Haan, 1985. Applied Hydrology and Sedimentology for Disturbed Areas. Oklahoma Technical Press, Stillwater, Oklahoma, p. 603.

Chow, Ven Te, 1959. Open Channel Hydraulics. McGraw-Hill New York, Toronto, Londs, p. 680.

Corps of Engineers, Department of the Army, 1970. Hydraulic Design of Flood Control Channels - Engineering Manual No. 1110-Z-1601. Washington, D.C. - U.S. Government Printing Office.

Fortier, S. and F.S. Scobey, 1926. Permissible Canal Velocities Transactions American Society of Civil Engineers, v.89, pp. 940-984.

Simons, D.B., and Senturk, F., 1977. Sediment Transport Technology. Water Resource Publications, Fort Collins, CO, p. 807.

Simons, Li & Associates, 1982a. Engineering Analysis of Fluvial Systems. Published by Simons, Li & Associates.

Simons, Li & Associates, 1982b. Design Manual for Water Diversions on Surface Mine Operations. Prepared for Office of Surface Mining, U.S. Department of the Interior, Contract No. J5101050 (OSM Technical Report TR-82-2).

U.S. Department of Agriculture, Soil Conservation Service, 1977. Design of Open Channels. Technical Release No. 25. Engineering Division, U.S. Government Printing Office, Washington, D.C.

U.S. Department of Agriculture, Agricultural Research Service, 1987. Stability Design of Grass-lined Open Channels. Agriculture Handbook Number 667. U.S. Government Printing Office, Washington, D.C.

U.S. Department of Transportation, Federal Highway Administration, 1961. Design Charts for Open Channel Flow. Hydraulic Design Series No. 3, U.S. Government Printing Office, Washington, D.C.

APPENDIX 3

TEMPORARY AND PERMANENT IMPOUNDMENTS

Key points regarding impoundment construction are outlined below. The reader should refer to Guidelines 13 and 17 for more complete information pertaining to sedimentation ponds and other types of impoundments, as well as citations to appropriate rules and regulations. The primary requirements for temporary and permanent impoundments are found in Chapter 4, Section 2(g) of the Land Quality Division Coal Rules and Regulations (LQDRR). Requirements for permanent impoundments are also found in the same rules in Chapter 2, Section 2(a)(v)(A)(III); Chapter 4, Section 2(g)(ii) and in W.S. § 35-11-407 of the Environmental Quality Act.

I. PERMITTING

Permits must be obtained from agencies which regulate the construction of embankments. The size of the embankment will determine which agencies must issue permits.

A. The Wyoming State Engineer's Office (SEO) must always be contacted regardless of the size of the embankment.

B. For embankments greater than 20 acre-feet in capacity or 20 feet in height, the following information is required:

   1. An application must be filed with the Mine Safety Health Administration (MSHA). The operator should initiate the process by phoning MSHA and obtaining a project identification number.
   2. A stability analysis of the embankment should be completed. The operator should contact the reviewing agencies (such as SEO and MSHA) to identify currently applicable analyses and procedures.
   3. Dam height is defined differently by various agencies. For example, the SEO currently defines it as the height from the downstream toe of the embankment to the crest of the dam. For temporary impoundments LQD and MSHA define it as the upstream toe of the dam to the crest of the emergency spillway. The dam height for permanent impoundments is defined as the downstream toe of the embankment to the top of the embankment. The operator should become familiar with the most recent definitions and ensure that they are compatible.

C. For small temporary sediment ponds, the SEO application may contain several ponds on a single application as long as the aggregate volume does not exceed 20 acre-feet.

D. Permit applications and accompanying maps must be certified by a professional engineer registered in the State of Wyoming. The certification should include the P.E. seal and a statement about the design.

E. For permanent impoundments, the operator must obtain written consent of the surface land owner. Additional requirements may be necessary if the impoundment is an MSHA pond.

II. SPILLWAY SIZING

A. The spillway sizing is dependent upon the size and life of the impoundment and the downstream level of risk. The Dam Safety Section of the Wyoming State Engineer's Office should be contacted to identify the appropriate design event. However, temporary impoundments must be designed for at least a 25-year, 6-hour event and permanent impoundments must be designed for at least a 100-year, 6-hour event to meet the LQDRR.

B. For grass lined spillways, the velocity and depth of flow should be determined for both active vegetation growth (springtime) and dormant vegetation growth (fall). This analysis will evaluate the adequacy of spillway depth for high vegetal retardance (spring conditions) and the velocity of flow through the spillway for low vegetal retardance (fall conditions).

III. RIPRAP AS EROSION PROTECTION

When utilizing riprap as an erosion control feature, the operator must adequately size the riprap. Sizing of the riprap is important in order to prevent the maximum flow from carrying the riprap downstream. Information regarding size, shape, and gradation of riprap can be found in the following references:

A. Draft Staff Technical Position, Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailings Sites. U.S. Nuclear Regulatory Commission, August, 1989.

B. Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase I/ Colorado State University, Fort Collins, CO, 82523, May, 1987.

C. Applied Hydrology and Sedimentology for Disturbed Areas. Barfield, Warner and Haan, 1985.

The operator should contact the WDEQ-LQD for additional references.

IV. MONITORING/INSPECTION REQUIREMENTS OF EMBANKMENTS

Various agencies have specific monitoring requirements associated with embankments, including WDEQ-LQD, the SEO and MSHA. The operator should contact the appropriate agencies to identify the most current monitoring requirements.

APPENDIX 4

MONITOR WELL INSTALLATION AND MAINTENANCE

I. INTRODUCTION

Proper monitor well installation is critical to the recovery of accurate groundwater level and water quality information at the mine sites. Routine maintenance is also necessary to keep the wells in good working condition. The following discussion offers suggestions on how to properly install and maintain wells under a variety of conditions. The references listed at the end of this appendix should be consulted for more detailed information on monitor well design, installation and maintenance.

II. DESIGN CONSIDERATIONS

Design considerations should include:

A. The purpose of the monitoring program.

B. Geology, aquifer physical characteristics (e.g., hydraulic conductivity), aquifer interrelationships and potentiometric elevation.

C. The anticipated depth and screened interval of the well. A well should be constructed of materials designed to withstand the load to which it will be subjected.

D. Characteristics of known or anticipated contaminants (e.g., chemistry, density, viscosity, reactivity, concentration).

E. Man-induced changes in hydraulic conditions.

F. Regulatory requirements from other agencies (e.g., State Engineer's Office if applicable, U.S. Environmental Protection Agency).

III. RECOMMENDED WELL CONSTRUCTION

A. Casing

Suggested casing materials for wells include PVC, plastic coated steel, stainless steel or fiberglass/plastic combinations. Galvanized steel should not be used. It is recommended that well head be closed with a locking cap.

B. Well Diameter

A minimum casing diameter (inside) of four inches is recommended. This should allow sufficient room for pumping mechanisms to travel downhole. The annular space should

be large enough to allow a minimum grout of two inches around the largest outside casing diameter.

C. Screening and Packing

For wells used in aquifer testing (excluding well efficiency tests) a sized, prefabricated screen should be used. Machine slotted casing is acceptable for water quality and water level monitor wells. The perforations/screen should be sized for surrounding geologic conditions or the type of filter pack being used. The screen length should be maximized to monitor as much of the aquifer thickness as possible without allowing for cross-connection between aquifers. It is also recommended that each well contain an open space or sump below the screened interval. The screened slot size should be chosen to hold greater than 85% of the filter pack materials.

Two types of filter packs commonly used include: 1) naturally packed wells in which the formation has collapsed around the screened interval during well development and 2) artificially packed wells where a filter pack is introduced into the hole. Use of an artificial filter pack is recommended when the screened interval spans geologic units of varying grain size, or the effective grain size of a formation is less than .01 inch diameter and the uniformity coefficient is less than three (3). The filter pack materials should be made of chemically inert silica sands and should not be emplaced by gravity or free fall methods unless the well is very shallow or periodic depth tagging is used to ensure complete emplacement. The annular space above the filter pack must be sealed to prevent cross-contamination. Typically, it is recommended that the filter pack would extend two to five feet above the top of the screen. Techniques used to determine filter pack size and screen/slot selection are thoroughly outlined by (Driscoll, 1986) in Chapter 13. Figure 3 of this guideline shows the basic design components of a groundwater monitoring well.

D. Annular and Surface Seals

Acceptable materials used to create annular seals include bentonite, neat cement or combinations of the two materials. Because bentonite requires water to hydrate and create a seal, it should not be used in unsaturated zones. As with filter packs, materials used in annular seals should not be emplaced by gravity or free fall methods.

A five-foot granular bentonite packer should be placed on top of the filter pack, prior to emplacement of the annular seal. The packer should be allowed to saturate before constructing the seal. Once saturated, the seal should be emplaced by grouting or cementing the borehole to the surface.

A concrete surface seal should be placed at the surface of all wells. This seal may be installed directly on top of, or be an extension of, the annular seal. It should extend vertically to a depth below the zone where seasonal frost heaving may occur and extend one to two feet around the well head. The concrete should be sloped away from the borehole.

E. Well Efficiency Tests

Efficiency tests should be performed on all new wells during development. The results of these tests will be used as a baseline value against which future efficiency tests should be compared.

An elaborate well efficiency test is not required for the baseline value. Drawdown-recovery tests, slug (or bail) tests, specific capacity tests, etc. may be used. A 50 percent drop in efficiency from the baseline value is an indication that the integrity of the well is suspect and the well needs maintenance or redevelopment.

F. The following well completion information should be reported:

1. Field identification number and the Wyoming State Engineer's Office permit number if applicable.
2. Location, date drilled, and aquifer represented.
3. Ground elevation and elevation of the measuring point.
4. Drill bit and casing diameter.
5. Packer base depth and elevation.
6. Casing depth and total depth.
7. Perforation, screened, or open interval depth and elevation.
8. Total hydraulic head elevation (i.e., closed-in formation pressure if well is gassy or flowing; otherwise, static water level).
9. Method of measuring formation pressure.
10. Gravel pack - yes or no.
11. Casing material.
12. Well development techniques.

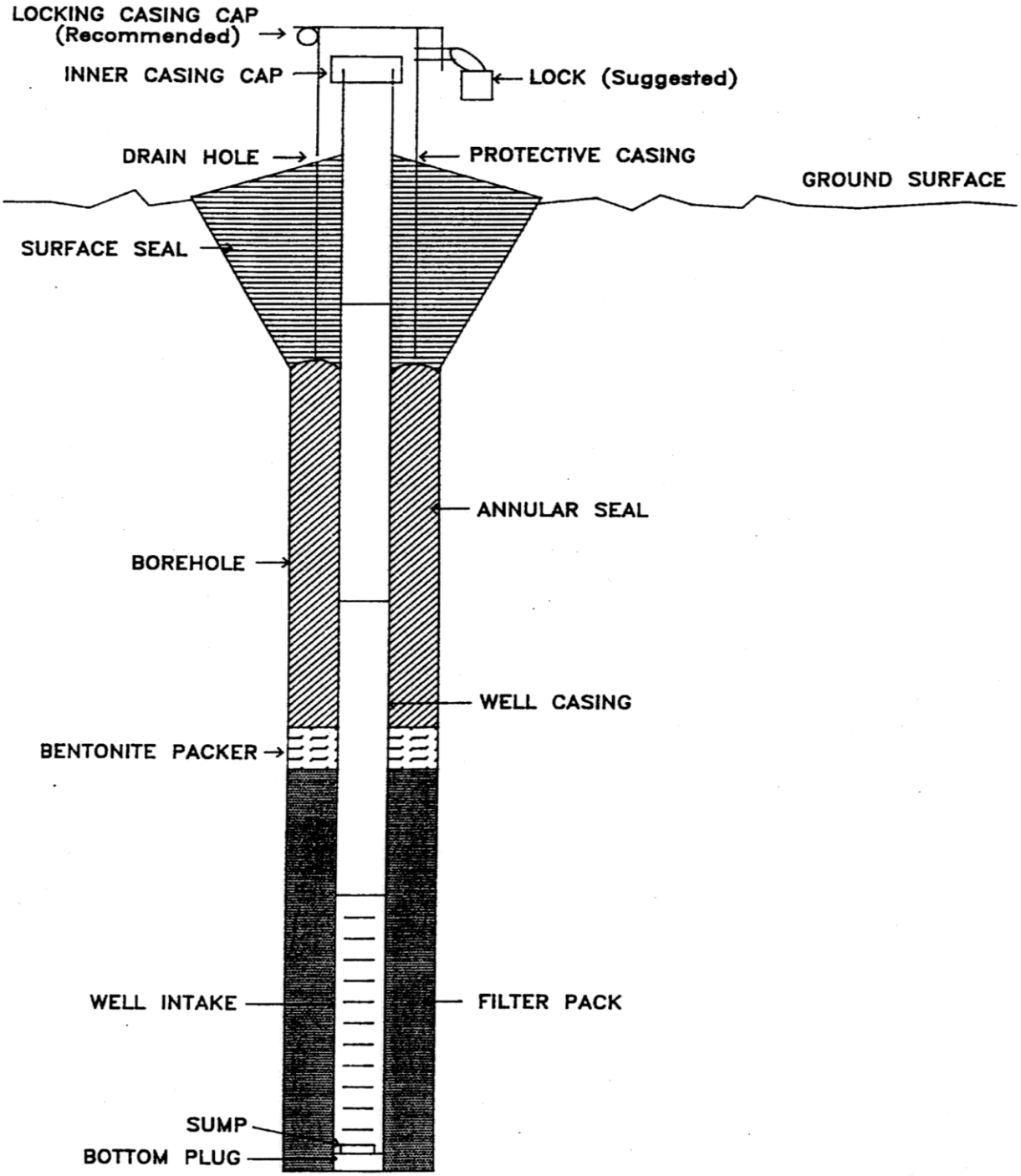


Figure 3: Basic Design Components of a Ground Water Monitoring Well

IV. WELL INSPECTION AND MAINTENANCE PLAN

All operational monitor wells should be inspected once a year for completion problems. Well plugging, cracked or sheared casing, iron bacteria, chemical incrustation and corrosion can cause deterioration of well performance. The following steps should be undertaken during annual well inspection:

A. Measurement of total depth compared with original completion depth to determine whether the well has silted up or the casing has failed.

B. Check surface seal and casing integrity which includes shaking the well to check for seal integrity, inspecting the seal for cracks and animal burrows, and checking ventilation/drain holes for plugging.

C. Listen for trickling, bubbling or gas venting sounds.

D. Check historic data for abnormal water level trends.

E. Conduct well efficiency tests on wells suspected of blocked perforations or screens.

The date and results of the above mentioned maintenance check should be included in each annual report.

REFERENCES

Aller, L., et al., 1989 Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells, National Water Well Association, Dublin, Ohio, p. 398.

Driscoll, F.G., 1986 Groundwater and Wells, 2nd ed., Johnson Filtration Systems Inc., St. Paul, Minnesota, p. 1089.

APPENDIX 5

RULES AND REGULATIONS CITATIONS

I. PREMINING CITATIONS

A. Surface Water

CITATION	KEYWORD
Noncoal Chapter 2 Section 2.(a)(i)(C) Coal Chapter 2 Section 4.(a)(iii)	precipitation data
Noncoal Chapter 2 Section 2.(a)(i)(G)(I) Coal Chapter 2 Section 4.(a)(xi)(A)	list and describe surface waters
Noncoal Chapter 2 Section 2.(a)(i)(G)(II) Coal Chapter 2 Section 4.(a)(xi)(B)	drainage area description
Noncoal Chapter 2 Section 2.(a)(i)(I) Coal Chapter 2 Section 4.(a)(xiii)	water rights
Coal Chapter 2 Section 4.(a)(ix)(D)	premining topography slope measurements
Coal Chapter 2 Section 4.(a)(ix)(E)	water supply intake; receiving waters
Coal Chapter 2 Section 4.(a)(ix)(H)	elevation and location premining monitoring
Coal Chapter 2 Section 4.(a)(xi)	complete information on surface water
Coal Chapter 2 Section 4.(a)(xi)(C)	baseline monitoring
Coal Chapter 2 Section 4.(a)(xi)(D)	water quality data
Coal Chapter 2 Section 4.(a)(xiv)	description for PHC assessment
Coal Chapter 2 Section 4.(a)(xvi)	location of reservoirs
Coal Chapter 19 Section 2.(a)(i)	cumulative hydrologic impact studies

B. Groundwater

CITATION	KEYWORD
Noncoal Chapter 2 Section 2.(a)(i)(H) Coal Chapter 2 Section 4.(a)(viii)(A)	groundwater survey
Noncoal Chapter 2 Section 2.(a)(i)(I) Coal Chapter 2 Section 4.(a)(xiii)	water rights
Coal Chapter 2 Section 4.(a)(vii),(xii)	aquifer description
Coal Chapter 2 Section 4.(a)(xii)	groundwater location
Coal Chapter 2 Section 4.(a)(xii)	monitor station information

Coal Chapter 2 Section 4.(a)(xii)	complete information on groundwater
Coal Chapter 2 Section 4.(a)(xiv)	groundwater description for PHC
Coal Chapter 2 Section 4.(a)(xv)	alluvial valley floors
Coal Chapter 2 Section 4.(a)(xii)(B)	location of wells
Coal Chapter 2 Section 4.(a)(xv)(B)	survey of springs, seeps
Coal Chapter 19 Section 2.(a)(i)	studies of cumulative impact

II. MINE PLAN CITATIONS

A. Surface Water

CITATION	KEYWORD
Noncoal Chapter 2 Section 2.(b)(iii)(D) Coal Chapter 2 Section 5.(a)(i)(D)(IV)	description diversion systems
Noncoal Chapter 2 Section 2.(b)(iii)(F) Coal Chapter 2 Section 6.(b)(vii)	plan for tailing impoundments
Coal Chapter 2 Section 2.(a)(v)(A)(I)	WQD application information
Coal Chapter 2 Section 2.(a)(v)(A)(III)	SEO reservoir application
Coal Chapter 2 Section 5.(a)(i)(D)(I)	location of water treatment and monitoring location
Coal Chapter 2 Section 5.(a)(i)(D)(IV)	location of hydrologic control methods
Coal Chapter 2 Section 5.(a)(i)(D)	term of permit hydrology narrative
Coal Chapter 2 Section 5.(a)(viii)	adverse impact minimization
Coal Chapter 2 Section 5.(a)(ix)	protection plan
Coal Chapter 2 Section 5.(a)(ix)(A)	control/treatment plan
Coal Chapter 2 Section 5.(a)(ix)(B)	sediment removal plan
Coal Chapter 2 Section 5.(a)(ix)(C)	recharge capacity restoration plan
Coal Chapter 2 Section 5.(a)(ix)(D)(I)	monitoring plan
Coal Chapter 2 Section 5.(a)(ix)(E)	alternate sources plan
Coal Chapter 2 Section 5.(a)(x)	PHC determination
Coal Chapter 2 Section 5.(a)(xi)	mining impact and alternative sources
Coal Chapter 2 Section 5.(a)(xii)	coal processing waste bank, hydrologic impact
Noncoal Chapter 3 Section 2.(c)(iv)(B) Coal Chapter 4 Section 2.(c)(xi)(B)	overburden, spoil, stockpile placement
Noncoal Chapter 3 Section 2.(c)(iv)(B) Coal Chapter 4 Section 2.(c)(xi)(G)	permanent spoil piles, contouring, and drainage

Noncoal Chapter 3 Section 2.(c)(iv)(D) Coal Chapter 4 Section 2.(c)(xi)(D)	pollution through leach, stockpiles
Noncoal Chapter 3 Section 2.(e)(i-iv) Coal Chapter 4 Section 2.(e)(iv)(A-D)	diversion systems ephemeral (streams and unchannelized water)
Noncoal Chapter 3 Section 2.(e)(iv) Coal Chapter 4 Section 2.(e)(iv)(D)	permanent diversions
Noncoal Chapter 3 Section 2.(f)(i-vii) Coal Chapter 4 Section 2.(e)(v)(A-H)	diversions, intermittent and perennial streams
Noncoal Chapter 3 Section 2.(g)(i-iv) Coal Chapter 4 Section 2.(g)(ii)(A-D)	permanent impoundments
Noncoal Chapter 3 Section 2.(h)(i-ii) Coal Chapter 4 Section 2.(g)(viii)(A-B)	tailings impoundments
Noncoal Chapter 3 Section 2.(i)(i-iv) Coal Chapter 4 Section 2.(j)	hydrology, and roads, and railroads
Noncoal Chapter 3 Section 2.(i)(vi) Coal Chapter 4 Section 2.(j)(ii)	drainage structures maintained
Noncoal Chapter 3 Section 2.(i)(vii)	hydrology and other transport systems
Noncoal Chapter 3 Section 2.(k)(ii)(A)(IV)	interim stabilization and water quality
Noncoal Chapter 3 Section 2.(k)(ii)(C)	continue monitoring through mine stabilization
Coal Chapter 4 Section 2.(c)(xi)(G)(I)	location of excess spoil piles
Coal Chapter 4 Section 2.(c)(xi)(G)(III)(1)(a)	control pollution from excess spoil piles
Coal Chapter 4 Section 2.(c)(xi) (G)(III)(1)(a)	spoil pile contouring to allow surface drainage
Coal Chapter 4 Section 2.(c)(xi)(G)(III)(6)	cover spoil to prevent water pollution
Coal Chapter 4 Section 2.(c)(xi) (G)(IV)(1)(c)	installation of final surface drainage
Coal Chapter 4 Section 2.(c)(xii)(A)	coal mine waste cannot be used in construction
Coal Chapter 4 Section 2.(c)(xii)(C)(II-III)	coal mine waste - drainage
Coal Chapter 4 Section 2.(c)(xii)(D)(I-V)	coal mine waste - dams
Coal Chapter 4 Section 2.(c)(xiii)(A)	acid material pollution
Coal Chapter 4 Section 2.(c)(xiii)(B)	flood plain protection - acid material
Coal Chapter 4 Section 2.(e)(i) and (iv)	temporary diversion design
Coal Chapter 4 Section 2.(e)(i)(A)	diversion-hydrologic balance
Coal Chapter 4 Section 2.(e)(i)(C)	diversions compatible with natural drainage system
Coal Chapter 4 Section 2.(e)(ii)	control of drainage or discharge
Coal Chapter 4 Section 2.(e)(ii)(A)	discharges must minimize disturbance of hydrologic balance
Coal Chapter 4 Section 2.(f)(i-vii)	sediment reservoir requirements
Coal Chapter 4 Section 2.(g)(i-iv)	temporary impoundments - design, construction, inspection
Coal Chapter 4 Section 2.(i)(ii)	monitoring of "hydrology balance"

Coal Chapter 4 Section 2.(j)(ii)	roads
Coal Chapter 4 Section 2.(j)(vii)(C)(II)	stream fords and road drainage
Coal Chapter 4 Section 2.(r)(i)(C)	habitat protection and mitigation
Coal Chapter 4 Section 2.(r)(ii)	buffer zone
Coal Chapter 4 Section 2.(r)(ii)(A)(I)	mining within 100 feet of stream will not affect water quality or quantity
Coal Chapter 4 Section 2.(r)(ii)(A)(II)	performance standards for permanent diversions
Coal Chapter 4 Section 2.(t)	control water pollution near abandoned underground mine
Coal Chapter 4 Section 2.(w)	hydrologic balance; material damage

B. Groundwater

CITATION	KEYWORD
Noncoal Chapter 2 Section 2.(b)(iii)(D) Coal Chapter 2 Section 5.(a)(ix)(D)(II)	monitoring information
Coal Chapter 2 Section 2.(a)(v)(A)(I,III)	SEO and WQD application information
Coal Chapter 2 Section 5.(a)(i)(D)(IV)	hydrologic control methods
Coal Chapter 2 Section 5.(a)(ix)	groundwater protection plan
Coal Chapter 2 Section 5.(a)(ix)(A)	control/treatment plan
Coal Chapter 2 Section 5.(a)(ix)(C)	recharge capacity restoration
Coal Chapter 2 Section 5.(a)(ix)(D)(II)	monitoring plan
Coal Chapter 2 Section 5.(a)(ix)(E)	alternate water source plan
Coal Chapter 2 Section 5.(a)(x)	PHC determination
Coal Chapter 2 Section 5.(a)(xi)	mining impact/alternative
Coal Chapter 2 Section 5.(a)(xii)	coal processing waste bank
Noncoal Chapter 3 Section 2.(b)(i)(B) Coal Chapter 4 Section 2.(c)(xi)(G)(III)(6)	prevent diminution of groundwater through drainage
Noncoal Chapter 3 Section 2.(c)(iv)(D) Coal Chapter 4 Section 2.(c)(xi)(G)(III)(1)(a)	water pollution from leaching
Noncoal Chapter 3 Section 2.(e)(i)(D) Coal Chapter 4 Section 2.(iv)(A)(IV)	protect water rights
Noncoal Chapter 3 Section 2.(g)(iii) Coal Chapter 4 Section 2.(g)(ii)(C)	mineral seams as water contaminants
Noncoal Chapter 3 Section 2.(k)(ii)(A)(IV)	interim mine stabilization to prevent subsurface water pollution
Noncoal Chapter 3 Section 2.(k)(ii)(C)	continue monitoring through mine stabilization

Noncoal Chapter 3 Section 2.(l)(ii)(B) Coal Chapter 4 Section 2.(l)(ii)(B)	unanticipated significant flow of groundwater
Coal Chapter 4 Section 2.(b)(ii)	backfilling to minimize water pollution
Coal Chapter 4 Section 2.(c)(xi)(G)(I)(1)(b)	excess spoil location - springs and seeps
Coal Chapter 4 Section 2.(c)(xi)(G)(I)	excess spoil location to prevent water pollution
Coal Chapter 4 Section 2.(c)(xi)(G)(III)(2)	spoil pile design to allow subsurface drainage
Coal Chapter 4 Section 2.(c)(xi) (G)(III)(6)	cover excess spoil prevent pollution
Coal Chapter 4 Section 2.(c) (G)(III)(6)	cover toxic material to prevent water pollution
Coal Chapter 4 Section 2.(e)(ii)(B)(I-III)	drainage from acid-forming and toxic forming materials
Coal Chapter 4 Section 2.(h)	protection of groundwater recharge capacity
Coal Chapter 4 Section 2.(i)	monitoring of groundwater
Coal Chapter 4 Section 2.(i)(i)	groundwater monitoring plan
Coal Chapter 4 Section 2.(p)	returning process water and groundwater monitoring
Coal Chapter 4 Section 2.(t)	control water pollution near abandoned underground mine
Coal Chapter 4 Section 2.(w)	hydrologic balance and material damage

III. RECLAMATION CITATIONS

A. Surface Water

CITATION	KEYWORD
Noncoal Chapter 2 Section 2.(b)(iii)(B)(III) Coal Chapter 2 Section 2.(b)(iv)(B)(III)	permanent impoundments
Noncoal Chapter 2 Section 2.(b)(iii)(D) Coal Chapter 2 Section 2.(b)(iv)(D)	description of permanent diversions; monitoring
Noncoal Chapter 2 Section 2.(b)(iii)(E) Coal Chapter 2 Section 2.(b)(iv)(E)	permanent impoundments
Coal Chapter 2 Section 5.(a)(ix)	surface water protection
Coal Chapter 2 Section 5.(a)(ix)(D)(I)(1)	postmining land use
Noncoal Chapter 3 Section 2.(a)(iii) Coal Chapter 4 Section 2.(a)(iii)	water impoundments as land use
Noncoal Chapter 3 Section 2.(b)(i)(B) Coal Chapter 4 Section 2.(b)(iii)	through drainage
Noncoal Chapter 3 Section 2.(b)(i)(D) Coal Chapter 4 Section 2.(b)(viii)	creation of impoundments
Noncoal Chapter 3 Section 2.(b)(ii)(A)	preserve original drainage

Noncoal Chapter 3 Section 2.(b)(ii)(B) Coal Chapter 4 Section 2.(c)(xi)(G)(III)(5)	erosion protection for terraces
Noncoal Chapter 3 Section 2.(b)(ii)(C) Coal Chapter 4 Section 2.(b)(viii)	permanent impoundments
Noncoal Chapter 3 Section 2.(b)(iii)(B)	permanent impoundments
Noncoal Chapter 3 Section 2.(c)(iv)(B)(II) Coal Chapter 4 Section 2.(c)(xi)(B)	placement of stockpiles
Noncoal Chapter 3 Section 2.(c)(iv)(B)(II) Coal Chapter 4 Section 2.(c)(xi)(G)(I-IV)	drainage system for stockpiles
Noncoal Chapter 3 Section 2.(c)(iv)(D) Coal Chapter 4 Section 2.(c)(xi)(D)	water pollution from stockpiles
Noncoal Chapter 3 Section 2.(d)(vii-viii) Coal Chapter 4 Section 2.(d)(i)(G),(K),(M)(IV),(M)(V)	irrigation
Coal Chapter 4 Section 2.(e)(i)(E)(II)	restore stream characteristics
Noncoal Chapter 3 Section 2.(e)(iv) Coal Chapter 4 Section 2.(e)(iv)(D)	permanent diversions - requirements
Noncoal Chapter 3 Section 2.(f)(i-vii) Coal Chapter 4 Section 2.(e)(v)	permanent diversion - design criteria
Noncoal Chapter 3 Section 2.(g)(i-iv) Coal Chapter 4 Section 2.(g)(ii)(A-D)	permanent impoundments
Coal Chapter 4 Section 2.(b)(i-viii)	backfilling, grading, contouring
Coal Chapter 4 Section 2.(b)(ii)	pollution and backfilling
Coal Chapter 4 Section 2.(b)(iii)	AOC
Coal Chapter 4 Section 2.(b)(v)	postmining slopes, stable drainage reconstructions
Coal Chapter 4 Section 2.(b)(viii)	permanent impoundments
Coal Chapter 4 Section 2.(c)(i)(A-F)	topsoil replacement
Coal Chapter 4 Section 2.(c)(v)(B)	topsoil placement for water infiltration
Coal Chapter 4 Section 2.(c)(vi)	rill and gully repair
Coal Chapter 4 Section 2.(c)(xi)(G)	location of excess spoil piles, drainages
Coal Chapter 4 Section 2.(c)(xi)(G)(III)(1)(a)	control pollution from excess spoil piles
Coal Chapter 4 Section 2.(c)(xi) (G)(III)(2)	spoil piles design to allow subsurface drainage
Coal Chapter 4 Section 2.(c)(xi)(G)(III)(3)	no impoundments on excess spoil piles
Coal Chapter 4 Section 2.(c)(xi) (G)(III)(4)	slope protection erosion of excess spoil piles
Coal Chapter 4 Section 2.(c)(xi) (G)(III)(6)	cover spoil to prevent water pollution
Coal Chapter 4 Section 2.(c)(xi) (G)(IV)(1)(c)	installation of final surface drainage
Coal Chapter 4 Section 2.(c)(xiii)(A)	acid material pollution
Coal Chapter 4 Section 2.(c)(xiii)(B)	flood plain protection from acid material

Coal Chapter 4 Section 2.(e)(i-iii)	diversions and drainage control
Coal Chapter 4 Section 2.(g)(i-iv)	permanent impoundments
Coal Chapter 4 Section 2.(i)(ii)	monitoring for hydrologic balance
Coal Chapter 4 Section 2.(r)(ii)(A)(II)	performance standards for permanent diversions
Coal Chapter 4 Section 2.(w)	hydrologic balance material damage

B. Groundwater

CITATION	KEYWORD
Noncoal Chapter 2 Section 2.(b)(iii)(D) Coal Chapter 2 Section 5.(a)(ix)(D)(II)	groundwater monitoring
Noncoal Chapter 3 Section 2.(b)(i)(B) Coal Chapter 4 Section 2.(b)(iii)	through drainage to prevent diminution of groundwater
Noncoal Chapter 3 Section 2.(g)(iii) Coal Chapter 4 Section 2.(g)(ii)(C)	mineral seams as water contaminants
Coal Chapter 4 Section 2.(b)(ii)	backfilling to prevent water pollution
Coal Chapter 4 Section 2.(c)(v)(B)	topsoil placement for water filtration
Coal Chapter 4 Section 2.(c)(vii)	fertilizer to prevent pollution of groundwater
Coal Chapter 4 Section 2.(c)(xi)(G)(I)	excess spoil location
Coal Chapter 4 Section 2.(c)(xi) (G)(III)(1)(a)	excess spoil location to prevent pollution
Coal Chapter 4 Section 2.(c)(xi) (G)(III)(2)	spoil pile design to allow subsurface drainage
Coal Chapter 4 Section 2.(c)(xi) (G)(III)(6)	cover spoil to prevent water pollution
Coal Chapter 4 Section 2.(c)(xiii)(A-B)	cover toxic material to prevent water pollution
Coal Chapter 4 Section 2.(h)(i-iii)	protection of groundwater recharge capacity
Coal Chapter 4 Section 2.(i)	monitor groundwater until final bond release
Coal Chapter 4 Section 2.(i)(i)	groundwater monitoring plan
Coal Chapter 4 Section 2.(w)	hydrologic balance and material damage

APPENDIX 6

PLUGGING AND ABANDONMENT

Wells must be properly abandoned to prevent adverse changes in water quality or quantity and to prevent a hazard to people, livestock, wildlife and machinery. The Water Quality Division (WQD), State Engineers Office (SEO), and Land Quality Division (LQD) Rules and Regulations describes acceptable well abandonment procedures. Please see the references listed below to determine the appropriate plugging and abandonment procedures. Consult with LQD to determine the appropriate plugging and abandonment procedures.

In general WQD, SEO and LQD requirements consist of placement of impermeable material (material with a permeability of 10^{-7} cm/sec or less), such as neat cement, sand-cement grout, concrete, or bentonite clay, (use of drilling muds is not acceptable) in the same interval as confining units and in screened or perforated zones (see LQD, Noncoal, Chapter 8, Section 2). Material containing drilling muds or organic matter are not acceptable. In some instances it is preferable to fill the entire hole from bottom to top with impermeable material.

In all wells the upper 30 feet are filled with impermeable material, as defined above. Typically the casing is cut off approximately 2 feet below ground surface and the upper 2 feet is filled to the surface with suitable material. A permanent tag showing the well name and any other pertinent information should be affixed to the top of the plug.

References:

State Engineers Office, Regulations and Instructions Part III, Water Well Minimum Construction Standards, Chapter 4, Well Completion and Maintenance, Section 4, Water Well Plugging and Abandonment.

Wyoming Department of Environmental Quality, Water Quality Division, Rules and Regulations, Chapter 26, Well Construction Standards, Section 11, Plugging and Abandonment.

Wyoming Department of Environmental Quality, Land Quality Division, Noncoal, Rules and Regulations, Chapter 8, Noncoal Exploration by Drilling, Section 2, General Drill Hole Abandonment Requirements.

APPENDIX 7

MINING PHASE SURFACE AND GROUNDWATER MONITORING AT SURFACE COAL MINES

A. Surface Water

Note: Upon completion of the permitting phase and following establishment of baseline surface water characteristics, surface coal mining operations are permitted (via a formal permit change) to transition to a "mining phase" surface water monitoring program similar to the following:

Constituents (reported in mg/l unless noted)	Analytical Method	Holding Time	Rational for Analysis
Ammonia Nitrogen as N	EPA 350.1	28 days	LQD R&R, Ch. 4, Sec. 2(i) WQD R&R, Ch. 1, Sec. 21(a)
Turbidity (NTUs)	EPA 180.1	48 hours	LQD R&R, Ch. 4, Sec. 2(i) WQD R&R, Ch. 1, Sec. 23
Field Conductivity (micromhs/cm)	EPA 120.1	Analyze Immediately	Good comparison with TDS
Dissolved Oxygen	EPA 360.1	Analyze Immediately	LQD R&R, Ch. 4, Sec. 2(i) WQD R&R, Ch. 1, Sec. 24
Field Water Temperature (degrees Celsius)	EPA 170.1	Analyze Immediately	LQD R&R, Ch. 4, Sec. 2(i) WQD R&R, Ch. 1, Sec. 25
Field Water pH (standard units)	EPA 150.1	Analyze Immediately	30CFR§780.21, LQD R&R, Ch.2(a)(vi)(L)(IV), WQD R&R, Ch.1, Sec. 26
Oil and Grease	EPA 413.1	28 days	LQD R&R, Ch. 4, Sec. 2(i) WQD R&R, Ch. 1, Sec. 29
Total Dissolved Solids (TDS) @ 180°F	EPA 160.1/SM2540C	7 days	30CFR§780.21, LQD R&R, Ch.2(a)(vi)(L)(IV), WQD R&R, Ch.1, Sec. 31
Total Suspended Solids	EPA 160.2	7 days	30CFR§780.21, LQD R&R, Ch.2(a)(vi)(L)(IV), WQD R&R, Ch. 1,Sec. 16
Dissolved Chloride	EPA 300.0	28 days	LQD R&R, Ch. 4, Sec. 2(i) WQD R&R, Ch. 1, Sec. 31
Dissolved Arsenic	EPA 206.3/200.9/200.8	180 days	LQD R&R, Ch. 4, Sec. 2(i) WQD R&R, Ch. 1, Appendix B

Dissolved Cadmium	EPA 200.9/200.7/200.8	180 days	LQD R&R, Ch. 4, Sec. 2(i) WQD R&R, Ch. 1, Appendix B
Dissolved Chromium	EPA 200.9/200.7/200.8	180 days	LQD R&R, Ch. 4, Sec. 2(i) WQD R&R, Ch. 1, Appendix B
Total and Dissolved Iron	EPA 236.1/200.9/200.7/200.8	180 days	30CFR§780.21, LQD R&R, Ch.2(a)(vi)(L)(IV), WQD R&R, Ch. 1, Appendix B
Total Manganese	EPA 200.9/200.7/200.8/243.1/243.2	180 days	30CFR§780.21, LQD R&R, Ch.2(a)(vi)(L)(IV), WQD R&R, Ch. 1, Appendix B
Dissolved Selenium	EPA 270.3/200.9/200.8	180 days	LQD R&R, Ch. 4, Sec. 2(i) WQD R&R, Ch. 1, Appendix B
Dissolved Zinc	EPA 200.9/200.7/200.8	180 days	LQD R&R, Ch. 4, Sec. 2(i) WQD R&R, Ch. 1, Appendix B

This table simply provides a recommendation of test constituents for mining phase surface water quality monitoring which should ensure mining:

- minimizes disturbance to the hydrologic balance in the permit and adjacent areas
- prevents material damage to the hydrologic balance outside the permit area
- minimizes impacts to all surface waters affected so they remain suitable for all uses for which they were suitable prior to mining (i.e., WQD Chapter 1).
- protects the water rights of other users

A few constituents may need to be added to recommended constituents based on site-specific conditions such as important water resources, alluvial valley floors (AVF), wetlands, mine facilities or domestic water supplies.

Instantaneous discharge (ft^3/second) must also be determined and recorded at each surface water sample point.

B. Groundwater

All wells should be analyzed for the constituents outlined in Appendix 1, Table 1 of this guideline until the operator can demonstrate to the satisfaction of LQD that a reduced constituents list is acceptable. The sampling results and analysis should demonstrate:

- minimal disturbance to the hydrologic balance in the permit and adjacent areas

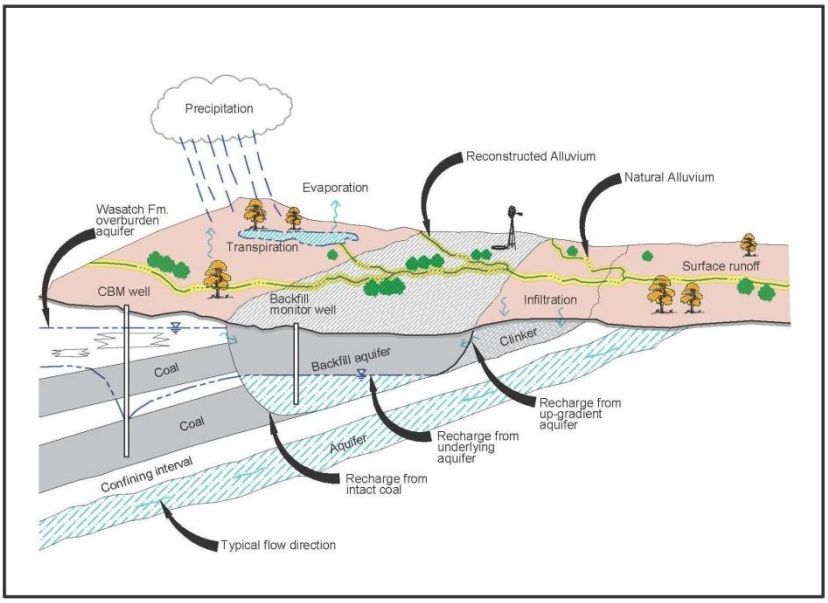
- prevention of material damage to the hydrologic balance outside the permit area
- minimal impacts to all aquifers affected so they remain suitable to support approved postmining land uses (i.e., WQD Class III livestock use).
- protection of the water rights of other users

For each well sampled for water quality, a field sampling sheet should be prepared. The field sampling sheet should contain the following items:

1. Identification of the well;
2. Well depth;
3. Static water level depth and measurement techniques;
4. Well yield (if measured);
5. Purge volume, pumping rate and volume per casing volume;
6. Time well purged;
7. Collection methods (bail or pump);
8. Field observations (such as well condition, sample color, sample smell, sound);
9. Name of collector; and
10. Climatic conditions, including air temperature.

Appendix 8

Wyoming
Groundwater Performance Standards
White Paper



Land Quality Division Industry/

Agency Coal Working Group and WWC Engineering

November 2013

The contents of this White Paper were thoroughly discussed and agreed to by members of the Coal Work Group, and represent the groups combined best efforts to capture and simplify this complex issue.

Nancy Nutbrock *Date*

Administrator, Land Quality Division

Department of Environmental Quality

WYOMING GROUNDWATER PERFORMANCE STANDARDS WHITE PAPER

Purpose and Need

Chapter 4 Section 2 (h) and (i) of WDEQ/LQD Rules and Regulations (Environmental Performance Standards) provide reclamation performance standards for coal mine operations in mined areas. The Chapter 4 Section 2 (h) performance standards pertaining to groundwater require restoration of the recharge capacity of reclaimed land to a condition which:

- Supports the approved postmining land use which typically includes livestock grazing, wildlife use, pasture and cropland;
- Minimizes disturbances to the prevailing hydrologic balance[1] in the permit area and in adjacent areas; and
- Provides a rate of recharge that approximates the premining recharge rate.

Chapter 4 Section 2 (i) requires a groundwater monitoring program to determine:

- Infiltration rates, subsurface flows, and storage characteristics of the reclaimed land and adjacent areas; and

[1] Reference to the hydrologic balance invokes Chapter 1, Section 2 (bp) which defines hydrologic balance as "the relationship between the quality and quantity of inflow to, outflow from, and storage in a hydrologic unit such as a drainage basin, aquifer, soil zone, lake or reservoir. It encompasses the quantity and quality relationships between precipitation, runoff, evaporation, and the change in ground and surface water storage." Therefore, water quality in this regulatory context is a component of the hydrologic balance addressed in postmine groundwater recovery analysis.

The LQD Industry/Agency working group (Coal Working Group) has concluded that evaluations of groundwater performance compared to criteria outlined in Chapter 4 can be made on an-ongoing basis in the annual report process. With this change in focus there will no longer be a need to conduct a separate groundwater verification for a Phase 3 bond release request.

WWC Engineering prepared this paper third-party assessment of the current postmine groundwater monitoring programs being conducted by the Wyoming coal industry to determine whether the ongoing data collection and analysis methods are sufficient to demonstrate compliance with the Chapter 4 Section 2 groundwater performance standards, and evolved through subsequent review and comment from both LQD staff and operators.

Scope of Work

This study's focus is on areas of coal removal and groundwater recovery in backfilled areas, which is common to all surface mining operations. Those portions of mine areas containing mine facilities (e.g. repair shops, loadout facilities, shipping areas, fuel storage areas and office buildings) and coal preparation plant areas (e.g. storage and stockpile areas, settling basins and impoundments) were not addressed. These areas are usually located where coal is not present and groundwater level recovery is not monitored. These areas can be, however, the subject of regulatory action pertaining to leaks and spills of fuel, antifreeze, solvents and other products. Cleanup activities addressing spills, although under the purview of LQD, are generally not addressed in bond calculations and therefore would typically be considered individually, as not all operations will be addressing environmental cleanups during bond release.

Description of the Monitoring Programs

All permits have or will have backfill monitoring wells on a density of approximately one backfill well per square mile. Additionally, postmining groundwater monitoring programs include wells completed in undisturbed aquifer units. Exceptions to the one backfill well per square mile standard usually consist of more than one well per section in reclaimed alluvial valley floors and areas of special regulatory attention (see Murphree, (2005)). Backfill monitoring wells are typically installed after vegetation has been established and are screened across a large portion of the backfill material. All operations have installed backfill wells which are routinely measured for static water levels and sampled for quality. Additionally, each operator has committed to conduct aquifer tests on backfill wells when sufficient saturation has occurred and most operators have conducted aquifer tests on one or more backfill wells.

Previous Studies

The studies cited below are not a comprehensive list of all work conducted on the topic of groundwater recovery in mined areas, but a listing of work reviewed in the preparation of this paper.

Early work on the influences of mining on the hydrogeologic system was conducted by Van Voast et al. (1977) and Van Voast and Reiten (1988). Both papers were published by the Montana Bureau of Mines and Geology and discussed the Montana portion of the PRB using information collected in the vicinity of Colstrip and Decker. Van Voast and Reiten (1988) indicate that, in addition to infiltrating precipitation, backfill resaturation is also driven by lateral flow from adjacent undisturbed aquifers and in some instances, vertical flow from deeper aquifers.

Hoy et al. (2003), compared water level and quality trends in coal mine backfill aquifers from ten mines located on the eastern margin of the PRB. The mines included in the study were divided into a northern group of seven mines (Buckskin, Dry Fork, Eagle Butte, Fort Union, KFx, Rawhide and Wyodak) and a southern group of three mines (Jacobs Ranch, Black Thunder and North Rochelle). The study evaluated the influence of the backfill aquifer's depositional and hydrologic characteristics on fluctuations in these trends. Hoy et al. hypothesized that site specific factors such as backfill placement methods, hydraulic conductivities, proximity and communication with adjacent aquifers, etc. all affect recharge rate. However, the report notes significant difficulties associated with quantifying the effects of these aquifer properties on recharge trends caused by ongoing anthropogenic stresses (e.g. CBM development). The authors concluded that backfill aquifers can meet the WDEQ/WQD livestock water quality standards, which was proposed as a performance standard by Martin, et al. (1988) in one of the early cumulative hydrologic impact analyses conducted on the Wyoming coal industry.

Murphree (2005) evaluated the findings of numerous studies on backfill water quality conducted at the Caballo Mine and compared the updated backfill water quality results with premining water quality and geology for the same locations. Although Murphree's study focused primarily on the quality of backfill groundwater, valuable insight to the recharge mechanism is also provided. As do Van Voast and Reiten (1988), Murphree suggests that recharge occurs from adjacent undisturbed aquifers and from deeper units. Murphree's findings also indicate that the backfill areas can be quite heterogeneous, with large variations in lithology. The backfill texture affects the rate of resaturation, with areas dominated by sand showing more rapid recovery than those containing a large percentage of clay.

Mining in the southern portion of Wyoming predates the Surface Mining Control and Reclamation Act (SMCRA) of 1977 and continues to this day. There is long history of coal mining in the southern portion of Wyoming, beginning in the 1860s with the Union Pacific Railroad. Numerous underground mines were located in the vicinity of Hanna and Rock Springs and were in operation until the 1950s when locomotives converted to diesel fuel. Surface mining continued in these areas after closure of the underground mines. Currently, the Abandoned Mine Land Division of the WDEQ conducts extensive groundwater monitoring of the Rock Springs area and also monitors groundwater and surface water in the vicinity of Hanna. The purpose of these monitoring programs is to assess mining-related impacts.

In the Rock Springs area, coal was removed primarily from the Mesa Verde Group of Late Cretaceous age. In the Hanna area, the primary mining target was the Hanna Formation of Paleocene Age. Bartos, et al. (2006) reported that most wells completed in the Hanna Formation, are for stock use or monitoring near coal mines. Bartos et al. (2006) advised that groundwater from the Hanna Formation is generally suitable for livestock use, based on 34 analyses.

Conceptual Model

Based on the 30 years of data collection since installation of the first backfill monitoring wells in the early 1980s, the general consensus in the mining industry is that the backfill receives recharge from three sources:

- Infiltration from precipitation and ponded surface water and streams when they flow – during snowmelt they can run for days or weeks,
- Lateral flow from adjacent aquifers, and
- Vertical leakage from aquifers beneath the pit floor that may have been in communication with the coal prior to mining or due to the mining process are now in communication with areas of coal removal.

Although the sources of backfill resaturation have been identified, the relative contribution of each source to backfill recovery has not been quantified and would be very location dependent. In general, the data indicate that water levels in areas consisting of sandy backfill recover more quickly than those completed in backfill that is clay-rich; backfill immediately adjacent to unmined areas typically recovers more quickly than areas distant from the mining limits, and areas near surface water impoundments constructed in the backfill also show accelerated recovery. Figure 1 is a sketch of the conceptual hydrogeologic regime in mined areas showing the various sources of recharge to the backfill.

Prior to mining, three aquifers typically exist in the Wyoming coal fields. From the surface down, these aquifers include: alluvium (limited extent, water table conditions and can be hydraulically connected with the overburden), overburden (heterogeneous mix of sandstone lenses in a claystone matrix, highly variable aquifer properties, mixed water table to confined conditions, recharged by infiltration) and coal (regional aquifer, confined except near outcrop areas, recharged at the outcrop, particularly in areas of clinker, and from overlying aquifers).

Postmining the resaturated backfill contains the blended potentiometry of the overburden and coal. In many areas, postmining alluvial aquifers are constructed with clay liners and are perched on the reclaimed surface. Surface impoundments located on the reclaimed surface also exist, which have been noted to enhance the rate of recovery in the backfill aquifer.

Compliance with Chapter 4, Section 2

Although details vary, the postmining groundwater monitoring programs of the various permittees contain these common components:

- One existing or planned backfill monitoring wells located approximately every square mile,
- A varying number of completed backfill wells along with bedrock and alluvial monitoring wells at various levels of saturation, which are measured for static water level quarterly and sampled at least annually for quality, and
- Commitments to conduct pumping tests on selected backfill wells.

As stated previously, the rules and regulations in Chapter 4 Section 2 focus on the postmine recharge capacity. Historically, the premine baseline studies did not include a direct measurement of the recharge rate. Recharge is a parameter that may be more effectively considered qualitatively than quantitatively due to the difficulty in direct measurement, particularly over wide extents such as permit areas. Anderson and Woessner (1992), in their popular textbook on groundwater modeling, state that "No one has yet devised a universally applicable method for estimating groundwater recharge. Numerous methods have been proposed but most have met with limited success". In groundwater modeling, recharge is typically adjusted to achieve model calibration. Due to the inability to measure recharge, the lack of hard data gives the modeler freedom to adjust recharge more than other parameters such as permeability and storage coefficient, which are measured directly through pumping tests. Because of these difficulties and inherent inaccuracies, postmining recharge capacity is best demonstrated through the upward trending water levels in the backfill aquifer.

A demonstration that the groundwater recharge capacity to the backfill is sufficient to support the postmining land use (wildlife and livestock grazing) in compliance with Chapter 4, Section 2, (h) and (i) can be included in annual reports by showing that there is water of sufficient quantity and quality, on average, to support wildlife use and livestock grazing in reclaimed areas. The regulations do not prohibit use of alternative water sources if there is not sufficient water quality or quantity from the backfill wells in a reclaimed area. Alternate sources may include, but are not limited to, surface water and groundwater from aquifers undisturbed by mining activities.

The demonstration of minimization of impacts to the hydrologic balance is accomplished during the permitting process as part of the evaluation of the probable cumulative hydrologic (PHC) impacts. This is required prior to permit issuance by the regulatory authority in compliance with Wyoming statutes. Monitoring is then conducted to verify PHC predictions. If monitoring results are contrary to PHC predictions then the PHC may be updated through the permit revision process. In reclaimed areas, measuring water levels and sampling for quality in monitoring wells

included in the postmining monitoring network and reporting these measurements in annual reports also tracks the impacts to the hydrologic balance through the life of mine.

Evaluation of the recharge rate can be made through a qualitative assessment of the water level recovery in the postmining monitoring network; re-establishment of the recharge capacity is implied through recovering water levels. Site specific factors such as spoil volume, porosity and rate of resaturation over time must be known or assumed in order to estimate recharge rate.

Compliance with the remaining portions of Chapter 4 Section 2 (i) is demonstrated through the existing postmining groundwater monitoring network. Subsurface flow in the backfill aquifer is quantified using potentiometric and pumping test data. Additionally, multi-well pumping tests have been used to measure storage characteristics of the backfill aquifer.

Though determination of infiltration is a requirement of Chapter 4, Section 2 (i), of the permit documents reviewed for this paper, only one baseline infiltration analysis is presented (measurement of infiltration is not a regulatory requirement for baseline studies, nor are infiltration studies discussed in Guideline 8). Reynolds (2012) compared infiltration rates between native and reclaimed areas at the Wyodak and Antelope mines and found that the rate of infiltration on reclaimed areas increased with time, and the infiltration rates at areas reclaimed 20-25 years earlier are similar to infiltration rates on native areas. It is the thought of the Coal Working Group that when postmine vegetative cover is comparable to premine vegetative cover, the postmine infiltration rate is similar to the premining infiltration rate.

Reclaimed alluvial valley floors and restored wetlands, both important postmining features, are designed to utilize infiltration of surface water, primarily in the form of runoff, to re-establish hydrologic functions. Establishment of the postmining hydrologic function within these areas is verified through monitoring data collected by the postmining monitoring network.

Measurement of infiltration is technically difficult and results can be affected by a number of variables including the way a particular method or instrument is used, by alterations in the soil conditions as a function of land management, and also due to the manipulation of the soil before and during the measurement (Pla, 2013). Field infiltration measurement methodology consists of infiltrometer tests that measure the area covered by the test equipment, which is several square feet or square yards at most. Infiltration rates are site specific, susceptible to local topsoil characteristics and compaction history and may not be representative of the backfill as a whole. From an agronomic perspective, the relative health of vegetative growth on reclaimed areas can be an indicator of the infiltration capacity. Further, because potential evapotranspiration (ET) exceeds precipitation (Lenfest, 1987), vertical infiltration past the root zone in reclaimed areas may be negligible and of little significance with respect to groundwater recharge. Therefore, measurement of the infiltration capacity in reclaimed areas may be of little use in demonstrating achievement of the postmining land use as it is a very minor component of recharge unless the backfill is shallow and the water table close to the surface.

Tables 1 and 2 provide the groundwater performance standards presented in Chapter 4, Section 2 and the methods used to evaluate performance.

Table 1. Chapter 4 Section 2 (h) groundwater reclamation performance standards and methods of evaluation.

Recharge Capacity Which:	**Evaluation Method**
Supports the postmining land use	Evaluated by measuring water levels, sampling for quality in the postmining groundwater monitoring network and presenting the water level trends and analytical results in annual reports. In areas where groundwater quality and quantity are not trending toward baseline and/or WDEQ/WQD Chapter 8 groundwater uses, alternate water sources (e.g. surface water and groundwater from aquifers intact after mining) can be used to meet postmine land use requirements.
Minimizes disturbances to the prevailing hydrologic balance	Evaluated in the permit review process through permit issuance and compliance, and through groundwater quality analysis of sampled postmining monitoring wells.
Provides a rate of recharge that approximates the premining recharge	Assessed through measurement of the rate of recovery in postmining groundwater monitoring wells (i.e. change in storage over time).

Table 2. Chapter 4 Section 2 (i) Items determined through postmining groundwater monitoring programs.

Groundwater Monitoring Program to Determine:	**Evaluation Method**
Infiltration rates	Indirectly evaluated through vegetative health (i.e. vegetation establishment implies favorable infiltration).
Subsurface flows	By monitoring groundwater levels and through pumping tests.
Storage characteristics	Through pumping tests. Calculations of saturated backfill vs. time can be used to estimate the recharge rate from all sources.
Effects of reclamation on the recharge capacity of reclaimed land	Through recovering water levels in groundwater monitoring wells.

Conclusions/Path Forward

Measurement of groundwater levels and sampling for groundwater quality have been and will be used to demonstrate that groundwater in reclaimed areas is capable of supporting postmining land uses. Backfill groundwater quality can be compared to existing baseline measurement to demonstrate that disturbance to the hydrologic balance is minimized. To date, the average groundwater quality in reclaimed areas meets postmining land use standards (Class III groundwater). Areas that do not appear to be on trend to meet postmining land use due to limited quantity or poor quality can be mitigated through utilization of alternative sources including, but not limited to, surface water captured in postmine stock reservoirs or groundwater from alternative sources such as wells completed in undisturbed aquifers.

It is the intent of the Coal Working Group to use this paper as a reference in future bond release activities. This paper memorializes LQD's policy decision to use groundwater performance standards required by Chapter 4 Section 2 (h) and (i). The performance standards will be evaluated in annual reports. Bond release will be achieved by demonstrating that the postmining land use can be met. References to this white paper will be added to Guidelines 20 and 25 and the Coal Annual Report Format (CARF).

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