SECTION 38

POST-RECLAMATION SURFACE STABILIZATION AND SEDIMENT CONTROL

TABLE OF CONTENTS

SECTION	SECTION TITLE	PAGE NUMBER

SECTION 38

POST-RECLAMATION SURFACE STABILIZATION AND SEDIMENT CONTROL

LIST OF TABLES

SECTION 38

POST-RECLAMATION SURFACE STABILIZATION AND SEDIMENT CONTROL

LIST OF FIGURES

SECTION 38

POST-RECLAMATION SURFACE STABILIZATION AND SEDIMENT CONTROL

LIST OF REVISIONS DURING PERMIT TERM

REV. NUMBER	REVISION DESCRIPTION	DATE APPROVED

SECTION 38 POST-RECLAMATION SURFACE STABILIZATION AND SEDIMENT CONTROL

38.1 Surface Stabilization and Sediment Control Plan for Reclaimed Lands

BHP Navajo Coal Company (BNCC) recognizes that the final surface configuration (FSC), presented in Section 34 (Post-Reclamation Topography), may be revised during the operational life of Pinabete Mine Plan permit area (permit area). The terms FSC and approximate original contours (AOC) may be used interchangeably within this permit application package (PAP). This section serves as the surface stabilization and sediment control plan for the permit area. It describes the measures used to control erosion and sediment transport on reclaimed lands. The control measures and techniques presented in this plan will be the best technology currently available (BTCA) that has been demonstrated as successful in the arid Southwest. The Surface Mining Control and Reclamation Act (SMCRA) uses the term BTCA for sediment and erosion control practices, while the Clean Water Act (CWA) uses the term best management practices (BMPs). Both terms may be used interchangeably within this PAP. The surface stabilization and sediment control plan relies on sound, scientifically proven, engineering practices that emphasize landform construction and erosion controls that do not rely on the use of water treatment approaches to achieve sediment control goals. The control measures and techniques utilized by BNCC ensure that reclaimed lands will not significantly contribute additional suspended solids to runoff or stream flow outside the permit area beyond what was identified during baseline studies, presented in Section 18 (Water Resources). These measures will also aid in compliance with applicable federal, state, and tribal water quality laws, regulations, and standards as discussed in Section 8 (Compliance with Air and Water Quality Laws and Regulations). See Section 41 (Probable Hydrologic Consequences) for detailed analysis and comparison of pre- and post-mining sediment loads.

The drainages within the permit area flow only as a result of precipitation events and/or as a result of snow melt and thus meet the strict definition of an ephemeral drainage. However, drainages with watersheds greater than 1 square mile are defined as intermittent streams by SMCRA, administered by the Office of Surface Mining Reclamation and Enforcement (OSM), at 30 CFR 701.5.

BNCC has designed the FSC to utilize the fluvial geomorphic reclamation approach (Section 34, Post-Reclamation Topography). However, BNCC acknowledges that circumstances may dictate implementation of traditional reclamation strategies that include designing surface drainages and hill slopes that are dependent on riprap, gradient terraces, or other “hard engineering” approaches to stabilize drainages and control erosion (Section 38.1.4). It is BNCC’s goal to keep the use of these traditional reclamation techniques to a minimum.

38.1.1 Fluvial Geomorphic Surface Stabilization Approach for Reclamation

BNCC will reclaim the lands disturbed by mining operations through the implementation of established fluvial geomorphic principles in hydrologic restorations (Dunne and Leopold 1978; Rosgen 1996), unless other designs are required and specified in the PAP. These principles include:

- stabilizing the drainage area through land shaping to achieve geomorphically appropriate slopes, drainage densities, and channel profiles;
- regulating the water channel velocity by constructing channel slopes, channel meander lengths, and cross-sections according to fluvial geomorphic principles; and
- adjusting reclaimed channel configuration based on bed and bank material (substrate) characteristics, as needed.

Implementation of these principles allows BNCC to design, construct, establish, and restore ephemeral streams to appropriate longitudinal plans and profiles, gradients, and cross-sections, including aquatic habitats (usually a pattern of riffles, pools, and drops rather than uniform depth) that approximate pre-mining stream channel characteristics. This approach allows the longitudinal profile of the stream, the channel, and the floodplain to remain stable in dynamic equilibrium with channel segments that may be upstream or downstream of reclaimed areas. The channel capacity will be at least equal to that of the unmodified ephemeral stream channel immediately upstream and downstream.

Surface water and groundwater quality will be protected by handling earth materials, mine water inflows, and surface water runoff to minimize adverse impacts to surface water and groundwater quality and to prevent the additional contribution of sediment to ephemeral stream flow outside the permit area. This will be accomplished by utilizing the sediment and drainage control plans presented in Section 25 and Section 26, respectively. BNCC has conducted pre-mine (i.e., baseline) water resource studies, presented in Section 18 (Water Resources), to determine the quality and quantity of surface water and to develop the pre-mine hydrology model. These baseline surface water studies and the accompanying surface hydrology model were used to develop operational and post-reclamation hydrology comparisons discussed in Section 41 (Probable Hydrologic Consequences).

As described in Section 41 (Probable Hydrologic Consequences), during mining operations, some surface drainages originating within the permit area may be temporarily impacted to facilitate mining operations. Following mining activities, these drainages will be reconstructed to approximate pre-mining area and flow length, as practicable. Drainage channels and swales will have fairly gradual gradients with a concave upward configuration to minimize the potential for head cutting and significant erosion loss.

38.1.2 Fluvial Geomorphic Approach to Stream Channel Design, Protection, and Mitigation

A fluvial geomorphic approach was undertaken to design the drainage areas and drainage channels within the reclamation areas. The following is a discussion of the approach taken in development of the FSC presented in Section 34 (Post-Reclamation Topography) and is an outline of steps to be taken in the event that future revisions of the FSC are needed. The landforms created with this approach comply with SMCRA, include a variety of slope aspects and drainage meander lengths, are erosionally stable, and have low maintenance requirements. To create these landforms, BNCC collected a variety of information related to the fluvial geomorphology of the pre-mine areas, other associated undisturbed areas, reference watersheds, and regional landforms (Appendix 34.A).

BNCC will conduct surveys of channel profiles and cross-sections for drainages that intersect the mining area, including upstream and downstream of the mining disturbance. The purpose of these surveys is to measure important channel characteristics: bank-full width, meander length, and valley characteristics (e.g., meander belt width, valley slope, and drainage density). These channel characteristics will serve as references and help BNCC to determine the proper design characteristics for the reclamation channel and valley slopes.

The drainage density, defined as channel length per unit of land area (e.g., mile/square mile or feet/acre), will be determined for the survey areas. This value will generally provide a lower limit for the reclamation, because the backfilled material is usually less consolidated than the native material and will tend to require a greater drainage density. The soil types (i.e., substrate) and hillside slopes will also be considered when selecting an appropriate reclamation drainage density. This drainage density will generally be accomplished by establishing first- and second-order minor channels on the valley slopes and by constructing major channels in the valley bottom.

BNCC will estimate the discharge through the reclamation reaches and design channels that are hydrologically appropriate for those flows. These designed channels are not expected to support vegetation within their bank full flow area because of natural annual scouring by runoff. The channels will be appropriate for the valley type and slope, channel substrate, sediment soil particle size, and other relevant parameters. Because the channel designs will incorporate the correct channel geometry, the channels will pass the discharge and sediment load supplied to them with erosion comparable to the surrounding terrain.

In summary, BNCC will:

- survey adjacent areas for hydrologic parameters (e.g., drainage density, channel type, etc.);
- estimate discharge from the reclamation area;
- compare discharge estimates with channel dimensions in the survey area to verify estimates;

- determine the appropriate channel types for the reclamation area slopes and valley bottom using fluvial geomorphic principles;
- design valley wall slopes with the minor channel to the determined drainage density;
- design the appropriate major valley channel; and
- incorporate the channels into the FSC for the valley wall slopes and valley bottom.

Generally, BNCC will control soil erosion through the use of shorter, flatter slopes, as compared to traditional reclamation techniques. The FSC design, presented in Section 34 (Post-Reclamation Topography), will have stable drainages by using fluvial geomorphic principles to create channels that are appropriate for the post-mining slope, aspect, substrate, vegetation, and land use. The backfill and grading plan, presented in Section 34 (Post-Reclamation Topography), will show the valley location for each major drainage. A major drainage is generally defined as a higher-order channel that occupies a valley floor and collects water from lower-order channels draining upland slopes. The backfill and grading plan will show the valley slope and meander belt width that BNCC has determined are necessary for the channel type that will occupy the valley. The backfill and grading plan will depict the drainage density minimum that BNCC has determined necessary for valley wall slopes as “blue lines” on the plan. In summary, the backfill and grading plan will show:

1. The valley location for each major drainage,
2. The valley slope and meander belt width for the channel type that will occupy the valley, and
3. The drainage density minimum for the valley wall slopes represented by for the channel length.

The necessary channel length for each subwatershed area will be shown on the plan, presented in Section 34 (Post-Reclamation Topography), but the location of the subwatershed boundaries and channels is conceptual and may shift slightly during the regrading process. These field fitted locations will be communicated and explained to OSM during regulatory inspections as the construction proceeds. During backfill and grading activities, there may be opportunities to install various types of structures to help control erosion and enhance plant diversity or wildlife habitat. The structures will be placed in opportunistic locations that are best suited for the particular structure. The following includes a list of some of the post-reclamation features BNCC may utilize:

1. Small depressions may be opportunistically constructed in the upland areas and drainages to minimize erosion, conserve soil moisture, create or enhance wildlife habitat, and promote the growth of vegetation. The capacities of the depressions will be less than 1 acre-foot. Small depressions are further described in Section 34 (Post-Reclamation Topography).
2. Rock habitat structures will be distributed in various arrangements, sizes, and locations to provide hiding and nesting sites for mammals and perching sites for raptors. In addition, they may be used to harvest water for improving plant production and controlling erosion (Ramsey and Porterfield

1995). Wildlife habitat structures are discussed further in Section 39 (Fish and Wildlife Enhancement).

3. Water harvesting features, such as surface drainage traps, topdressing reservoirs, and root-zone pitting (Ramsey and Porterfield 1995), may be used throughout the landscape primarily for the purpose of improving plant cover, minimizing erosion, and creating wildlife habitat.
4. Talus may be installed to resemble pre-mine or undisturbed conditions. Talus areas will be used primarily in locations of steep slopes to help stabilize the surface when competent rock materials are available. In addition, talus will provide a secondary benefit for wildlife habitat and possible water harvesting if the terrain allows (Ramsey and Porterfield 1995). The rock materials will range in size from 0.5 foot to greater than 10 feet. The overall structure will vary in size from a possible height of 100 to 150 feet to a length up to 300 feet. If BNCC determines there is a need or opportunity to install a talus, BNCC will consult with the OSM inspector and/or technical staff personnel, before installing.
5. Topographic features will be installed in the FSC as needed to achieve fluvial geomorphic stability. Features such as ridges, mounds or bumps on slopes, and small ephemeral stream valleys will be used to dissect slopes and achieve appropriate drainage densities. These features may often be too small to depict on the 10-feet interval topographic map used to present the FSC.
6. Bluff features may be incorporated into the FSC design to provide cliff type habitats similar to those that existed in the pre-mining topography to replace the bluff/cliffs as potential nesting and perching habitat for many avian species. The ends of the bluff features will be blended into the surrounding topography with slopes that are less than 3 horizontal to 1 vertical (3h:1v). The bluffs will have a safety factor of 1.3 or greater and will not pose a hazard to persons or wildlife in the area. A geotechnical assessment will be performed by BNCC documenting the safety factor, as required by OSM. If BNCC determines there is a need or opportunity to install a bluff feature, BNCC will consult with the OSM inspector and/or technical staff personnel, before installing
7. Permanent impoundments, as referenced in Section 35 (Hydrologic Reclamation Plan), may also be built to increase the potential for long-term water availability, thereby enhancing wildlife habitat and drainage control. These permanent impoundments may also serve to replace water sources as described in Section 35 (Hydrologic Reclamation Plan).

Contemporaneous reclamation and construction of stream channel segments may require the construction of temporary in-line sediment and drainage control ponds. These structures would be constructed along the perimeter of ramp roads or at the confluence point of reconstructed channels where water flow will interfere with continued mining and reclamation activities or compliance with surface water discharge regulations. This may create segments that have a potential for temporary or minor ponding of surface water flows until the remainder of the channel is constructed. The ponded segments along the channel would be expected to fill relatively quickly with alluvial deposits as the channel re-establishes its grade and moves toward dynamic equilibrium within the full channel reach length. Surface water ponding may continue in the in-line sediment and drainage control ponds even after removal, until the channel obtains dynamic equilibrium. Although this condition is not ideal, it should be expected because the sediment and drainage control is required during reclamation activities to prevent the untimely release of water and sediment from within the permit area in compliance with SMCRA and National Pollutant Discharge Elimination System permit requirements.

The vertical tolerances of the FSC are critical to the long-term stability of the landform and it is not practical to consider any substantial departure from the design once construction is complete. The benefits of the FSC far outweigh the potential benefits of mitigating spoil after construction is complete. Traditional spoil mitigation techniques consist of capping unsuitable root-zone material with up to 4 feet of suitable material. This mitigation and the resulting changes in the FSC could be extremely detrimental to the hydrologic design and subsequent erosional stability of the FSC. BNCC will conduct regular spoil sampling and will mitigate the upper 1 foot of unsuitable root-zone areas in accordance with Section 36 (Post-Reclamation Soil). This approach will mitigate root-zone unsuitability, while still allowing BNCC to create an appropriately designed fluvial geomorphic landscape.

The topographic diversity provided by the FSC will promote diversity within the vegetation communities, thereby increasing suitability of the landscape for post-mining grazing land use. Further information on the post-mining land use and post-reclamation vegetation communities is provided in Section 30 (Post-Reclamation Land Use) and Section 37 (Post-Reclamation Vegetation), respectively.

38.1.3 Fluvial Geomorphic Approach to Hill Slope Design, Protection, and Mitigation

The estimated post-mining soil losses for the permit area FSC design have been estimated using the SEDCAD4™ (SEDCAD) modeling program. By estimating the soil loss over the reclamation areas, designs can be evaluated as to whether or not they will maintain the hydrologic balance and provide a suitable surface for the post-mining land. SEDCAD surface flow and sediment yield modeling results for pre- and post-mining watershed conditions are provided in Section 18 (Water Resources) and Section 41 (Probable Hydrologic Consequences), respectively. A comparison of these modeling results indicates little change in surface flows and sediment yield for pre- and post-mining conditions. These modeling results show that the FSC designs for the permit area will maintain the hydrologic balance and provide a suitable surface for post-mining grazing land use. The following performance standards and assumptions were used to develop the FSC designs in the PAP:

1. The FSC is shaped to accommodate the designated post-mining land use of grazing.
2. The FSC is designed so that the overall soil loss values for the post-mining topography are similar in magnitude to the pre-mining soil loss values.

3. The FSC supports the incorporation of wildlife habitat enhancement features into the post-mining topography. These features will be placed or incorporated in opportunistic locations during the regrade process. Examples of diversity structures are:
    a. Rock habitat structures – structures built with rock and ranging from loose piles of durable rock to rocky rims constructed along the contour of slopes.
    b. Escarpments structures – thin exposed areas of end walls or final pits that provide durable rock or rocky ledges, talus slopes, or rock rims similar in configuration to rock habitat structures. Such structures will be less than 15 feet in height, less than 500 feet in length and blended into the surrounding topography with slopes that are less than 3h:1v. Escarpment features are discussed further in Section 39 (Fish and Wildlife Enhancement).
    c. Small depressions, with a capacity less than 1 acre-ft. These structures will create microhabitat niches for both the wildlife and vegetation communities. Small depressions are described further in Section 34 (Post-Reclamation Topography).
4. Slopes with complex profiles are used when appropriate to minimize soil loss.
5. The post-mining drainage density approximates the pre-mining drainage density as appropriate for the watershed size and slope. Complex slopes with varied aspect support the drainage density, although the drainages are swales instead of channels with defined beds and banks.
6. All exposed mineable coal seams are covered with 4 feet of non-combustible material.

The FSC design and resulting backfill and grading plan presented in Section 34 (Post-Reclamation Topography) will have increased topographic diversity that provides for a more diverse plant community and wildlife habitat, and provides geomorphically suitable and stable landforms that are compatible with the post-mine grazing land use.

The assessment of probable hydrologic consequences in Section 41 demonstrates that erosion and sediment control measures for the reclaimed lands, based on the FSC presented in Section 34 (Post-Reclamation Topography), will prevent additional contributions of suspended solids to stream flow or to runoff outside the permit area. These analyses also demonstrate that the final surface design will not cause, or contribute to, a violation of federal, state, and tribal water quality laws, regulations, and standards. Reconstruction of major and minor ephemeral stream channels will provide a system that is in dynamic equilibrium with both upstream and downstream watersheds with hydrologic function comparable to pre-mine conditions.

38.1.4 Traditional Surface Stabilization Approach for Reclamation

As stated in Section 38.1, BNCC intends to implement the fluvial geomorphic approach to reclamation. However, BNCC acknowledges that situations may develop where this approach is not feasible or applicable. In these cases, BNCC will implement a traditional approach that uses "hard-engineered" structures to achieve surface stabilization and sediment control. In implementing the traditional approach, as with the fluvial geomorphic approach, BNCC will use BTCA measures to meet the reclamation goals and comply with all applicable federal, state, and tribal rules and regulations.

The function of gradient terraces (Figure 38.1-1) is to decrease the length of the hillside slope, thereby reducing sheet and rill erosion, preventing the formation of gullies, and providing a water harvesting mechanism for semi-arid areas. Two terracing schemes may be implemented in the permit area: 1) gradient terraces that utilize an ephemeral or intermittent channel as an outlet (Figure 38.1-2); and 2) gradient terraces that use downdrain structures to transport the runoff down a slope (Figure 38.1-3). No constructed terrace will exceed 7,000 feet in length. The reclaimed landform on which traditional controls may be constructed will likely contain areas of potentially steep and long rolling slopes, which utilize both types of terraces. These areas include, but are not limited to outslopes of reclaimed boxcut spoils, final pit and highwall reclamation, and hill slopes adjacent to ramps and haul roads. The terraces may be placed in watersheds where the post-reclamation sediment yield, using the fluvial geomorphic approach, is higher than the pre-mining sediment yield. Other operational constraints that may dictate the use of traditional reclamation approaches include, but are not limited to:

1. Protection of the health and safety of BNCC employees and the surrounding community;
2. Protection of historical or cultural sites;
3. Maintenance of appropriate buffers around the permit or lease boundary; and
4. Compliance with contemporaneous reclamation requirements.

<u>38.1.4.1 Traditional Surface Stabilization Design Process</u>

The specific steps taken to design gradient terraces will be similar to the following techniques:

1. Define the reclamation area or subwatershed in question.
2. Collect the Revised Universal Soil Loss Equation (RUSLE) and SEDCAD parameters (i.e., subwatershed acres, rainfall factor (R), soil erodibility factor (K), slope length factor (L), slope steepness factor (S), cover management factor (C), support factor (P), curve number, and time of concentration) required for the design. BNCC has developed soil erodibility (K) and cover management (C) factors for the permit area based on soil textures for surface water modeling. These factors for mining operations and post-reclamation operations are presented in Appendix 41.C and Appendix 41.D, respectively.
3. Input watershed information into SEDCAD or a similar hydrologic modeling computer program to determine:
    a. Peak discharge generated from a 10yr-6hr storm event.
    b. Peak discharge generated from a 100yr-6hr storm event.
4. Use SEDCAD to determine the sediment yield for the watershed for the given storm events and compare these values to the pre-mine sediment yields. The yield for the subwatershed can be

above or below these values as long as the overall watershed sediment loading is below the target yield. If the subwatershed yield needs to be reduced, move on to Step 5.

5. Place gradient terraces on slopes to reduce the LS factor and, therefore, the annual sediment yield. Terraces will be placed on the slopes with the highest LS factors first until the appropriate yield is met.
6. Determine the length of the terraces to be designed. Gradient terraces are not to exceed 7,000 feet.
7. Utilize Manning's Equation to determine the velocity of flow during peak discharge of a 10yr-6hr storm event. Alter the channel slope to maintain a velocity less than the limitations for the material in Table 38.1-1 and a Froude number less than 0.9. The average channel slope must not exceed 2%.
8. Utilize Manning's Equation to determine the peak stage in the channel during peak discharge of a 100yr-6hr storm event. From the peak stage data, add the following values to determine the minimum height of the terrace:
    a. Peak stage resulting from a 100yr-6hr storm event;
    b. Five years of sediment storage capacity; and
    c. Depth maintaining a minimum of 1-foot freeboard, depending on the terrace length.

BNCC has developed Table 38.1-2 and Table 38.1-3 for utilizing traditional reclamation techniques at Navajo Mine to show the typical dimensions of each slope category, terrace length, and associated velocities (BNCC 1999). All terraces and v-ditches, if needed, will be designed on a site-specific basis, therefore, Table 38.1-2 and Table 38.1-3 are used to show representative information.

38.1.4.2 Traditional Surface Stabilization Field Layout Process

The gradient terrace system plan recorded on the design area topographic map will be transferred onto the land using horizontal and vertical controls. When the final topographic surface has been established, BNCC will physically layout the terrace system on the ground. This process will begin with the establishment of the key terrace location.

The key terrace is laid out first, and usually requires adjustment by the field engineer. It is typically placed in the middle of an anticipated group of parallel terraces. Therefore, it is representative of the entire layout and average conditions. From the key terrace, the remaining terrace locations are located and staked. The proper location of the key terrace is essential in the terrace system layout. If the first attempt at field locating the key terrace does not give the required results, the key line will be relocated until the layout meets the terrace design objectives. On long slopes, slopes with significant variation in slope grade or where a large number of terraces are required, it will be impossible to make all terraces parallel. The best layout for this area will involve dividing the slopes and area of protection into groups, then selecting the location for a key terrace in each group.

Staking of the key terrace will begin in the middle of the terrace length or in the area requiring the most erosion protection. This location will be determined by the field engineer, based on experience and general knowledge of the terrace system being developed. The final location of all terraces will be reviewed by a New Mexico Registered Professional Engineer, assuring that the objective of the terrace system is being met. This review process will take place prior to the start of the construction process.

38.1.4.3 Traditional Surface Stabilization Construction Process

Two types of gradient terraces may be utilized if deemed necessary: 1) flat bottom terraces; and 2) v-ditch terraces. All gradient terraces will either be constructed by reshaping the slope area to incorporate the terrace into the hillside, or the terrace will be constructed as a berm extending up from the regraded surface. Because they will be constructed of material that meets the suitability criteria defined in Section 36 (Post-Reclamation Soil), mitigation and sampling of terraces will not be performed.

The construction of flat bottom terraces will incorporate either of the following practices:

1. Incorporating the flat bottom terrace and berm into the hill slope with a combination of dozer and scraper reshaping activities.
2. Utilizing scrapers to cut the flat bottom terrace into the hill slope and constructing the corresponding berm.

The construction of v-ditch type terraces will involve constructing a berm that extends up from the regrade surface at a 2h:1v to 3h:1v slope, utilizing the natural grade as the opposite side slope.

The berm portion of the terraces will maintain a relatively low profile, typically less than 4 feet, and will be compacted by normal routing or equipment wheel-rolling over the berm. All fill material will have adequate moisture to achieve reasonable compaction. Where topdressing material has been spread prior to the construction of the terraces, topdressing material will be removed, and then replaced on the terrace embankments following construction. All gradient terraces will maintain a channel lining of spoil material.

38.1.4.4 Traditional Surface Stabilization Drop Structures

Drop structures may be utilized in three different applications within the reclamation process:

1. along steep slope areas where terraces are constructed and relief is required to transport runoff into a reclamation channel (Figure 38.1-3);
2. where drainage ways from either reclaimed areas or non-disturbed areas upstream of reclaimed areas require drop structures to minimize the erosional effects of surface runoff into the reclaimed channels (similar in appearance to Figure 38.1-3); and

3. facilitate the required elevation drop within a reclamation channel where the channel requires a gentler grade to minimize velocities.

The design of steep conveyance structures is a critical step in developing a stable drainage network on a surface mine site. Steep slope conditions (slope > 10%) are typical in areas of highwall and outslope reclamation areas. The success or failure of these conveyances, typically intermittent or ephemeral drainages, determines the sediment load delivered to the downstream environment. Therefore, steep slope conveyances must be adequately designed to ensure the long-term success of the drainage network.

Drop structures will be designed to protect the steep slope segments at terrace outlets, transition segments upstream and downstream of the steep slope segment, and transition areas within reclamation channels. Each drop structure will be evaluated to determine the need for riprap based on the velocities experienced within the structure, and riprap will be sized according to the following section. Channel drop structures will be designed around the corresponding event required for the affected channel. The riprap size specification is provided by the median diameter for the rock riprap (e.g., D50) required. The resulting gradation of the riprap and filter will be determined as detailed in Table 38.1-4. Riprap within structures draining less than 640 acres will be designed to remain stable during a 10yr-6hr precipitation event. Structures draining more than 640 acres will have riprap designed to remain stable during a 25yr-6hr storm event. Channel dimensions of all downdrains and drop structures will be designed to contain a 100yr-6hr storm event.

The SEDCAD channel utilities (Simons 1982), or similar software, will be used to size the riprap for drop structures. The structures will be designed to safely pass the peak flow from the 100yr-6hr precipitation event. Table 38.1-4 has been developed to show the typical dimensions and riprap sizes for the drop structures with respect to the various discharge rates.

Within the context of traditional reclamation approaches, BNCC may utilize riprap for steep slope channel protection and mild slope channel protection. Riprap will be appropriately sized for the application. An integral part of designing proper protection for a slope is the degree of safety to be factored into the equation. Structures that require riprap will be designed with a minimum safety factor of 1.3 for the required storm frequency as outlined in Table 38.1-5.

38.1.5 Traditional Surface Stabilization Approach to Channel Design

It might be necessary for BNCC to design and construct ephemeral stream channels using the traditional surface stabilization approach. Pre-mining ephemeral and intermittent streams within the permit area exhibit irregular channel configurations and unstable conditions both upstream and downstream of the permit area. Some of these channels are relatively steep and the profile has variable slopes. In some cases, the slopes of these native channels are too steep to be used for the design of stable permanent diversions. Over-steepened portions of the native channels have been observed within and adjacent to the permit area. After reclamation, over-steepened segments will remain downstream of the area disturbed by mining. These steep reaches, together with the longer channel slopes required for acceptable design velocities in the reclaimed channels, produce convex channel profiles where reclaimed channels tie in with the natural channels downstream of mining. Where uniform or concave profiles cannot be established, engineered structures will be used to maintain stability along all convex segments in a channel profile. This type of configuration provides a hydrologic system that maintains dynamic equilibrium in the channel aggradation and degradation. Rock riprap drop structures are designed to stabilize these convex sections and to protect the reclaimed channel from head cuts moving upstream into the reclaimed channel. Convex channel profiles also occur along the permit boundary where the reclaimed topography ties in with upstream undisturbed lands. Steep and often convex slopes may be required in this transition zone to reduce flow velocities to acceptable levels.

SEDCAD and HEC-RAS, or similar software, will be utilized to facilitate the design of reclamation channels. SEDCAD is used to determine design peak flows and to design simple channels and drop structures. HEC-RAS is used to design compound channels and transition segments. The major reclaimed channels may be designed as compound channels using the HEC-RAS or similar program. This design emulates certain natural stream systems by incorporating an inner pilot channel with an outer floodplain. The channel and floodplain condition is not typical of the streams within the disturbed mining area. The objective of the reclamation channel and floodplain design is to develop a design that is in dynamic equilibrium with the receiving flows and sediment yields.

Design calculations for compound channels are conducted assuming: 1) a poorly vegetated or fractured shale inner channel condition with a Manning roughness coefficient of 0.030; or 2) a vegetated outer channel or floodplain with a Manning roughness coefficient of 0.045. The bank full capacity for the inner channel will be designed to exceed the peak flow corresponding with the 2yr-6hr rainfall but to be less than the peak flow corresponding with the 10yr-6hr event.

Smaller tributaries are designed as a drainage swale using the SEDCAD utility program for trapezoidal channels, which is based on the Manning equation for uniform flow. Because a drainage swale is likely to support some vegetation cover, the depth and velocity actually encountered is expected to be between the limits established by the unvegetated condition and the vegetated condition associated with Retardance Class B.

38.2 Rill and Gully Control Plan

With successful design and implementation of the surface stabilization and sediment control approaches described in Section 38.1, BNCC does not anticipate the widespread development of rills and gullies. Nevertheless, the goal of successful rill and gully control is to prevent adverse affects on post-mining land use and water quality. If rills and/or gullies are identified on reclaimed areas of the permit area, the cause of their formation will be determined. The identified cause will determine the basis for any remedial action to be taken. It is important to note that the presence of rills and gullies is not necessarily an indication that active or significant erosion is occurring within a specific area. Rills and gullies should be analyzed within the context of their formation, to include size, location, density, mechanism, and initiating precipitation event(s).

The cause of rill and gully formation will be remedied and the rills and gullies may be repaired. Rills and gullies that form in areas that have been regraded, topdressed, and seeded will be repaired if they: 1) disrupt the approved post-mining land use; 2) disrupt the reestablishment of vegetative cover; or 3) cause or contribute to a violation of water quality standards applicable to the reclaimed area and receiving streams. Repair actions may include filling, regrading, or channel construction. The area will be stabilized as described in Section 38.1.

Rills and gullies for which the cause has been remedied may not be repaired by BNCC if repair would be detrimental to the overall reclamation effort in the areas where they have occurred, they are no longer active after the cause has been remedied, they will not interfere with the achievement of vegetation and water quality bond release standards, and they are stable at bond release as judged by the following criteria:

1. Rounding of channel sides;
2. Discontinuance of channel expansion or extension;
3. Establishment of extensive permanent vegetation on the sides and bottom of the channel;
4. Lack of unanchored clumps of soil and vegetation that has fallen from channel sides;
5. Discontinuance of down-channel deposition of eroded materials in exceedance of comparable pre-mine levels;
6. Establishment of a permanent vegetative cover on areas of erosional deposition; and
7. Accumulation of litter and/organic matter in the channel.

If incorrect design basis is identified as the cause of the rills and gullies, appropriate adjustments will be made to the design basis for surface stabilization described in this section to reduce or eliminate the development of future rills and gullies. To the extent practicable, corrections may be made to reclaimed landforms to prevent future development of rills and gullies.

38.3 Permanent Sedimentation Ponds

BNCC does not plan to leave any permanent sedimentation ponds after reclamation and bond release is complete. Therefore, this section is not applicable.

Post-reclamation permanent impoundments for drainage control or replacement of water rights are presented in Section 35 (Hydrologic Reclamation Plan).

38.4 Post-reclamation Surface Stabilization Data Collection and Analysis

38.4.1 Fluvial Geomorphic Reclamation Data Collection and Analysis

Field data were collected during the summer of 2007 for input into the Natural Regrade with Geofluv software. Data were collected within Area 4 South to determine the appropriate ridge to head of channel length, A-channel length, etc. for the constructed uplands within the permit area. Surveys were also conducted for each major ephemeral drainage that enters and exits Area 4 South to determine channel dimension, slope, and elevation. This information was used to determine tie-in parameters for the designed channels and hill slopes. Flows were determined for each major ephemeral channel using the Soil Conservation Service's Rational Method, depending on watershed size. Specifically, the Rational Method was used for determining channel flows from constructed uplands within the permit area that did not receive headwaters.

38.4.2 SEDCAD and RUSLE Modeling Data Collection and Analysis

SEDCAD modeling was used to determine the peak flows, sedimentology, and design storms in the major ephemeral channels for the pre-mine, operational, and post-reclamation models (Appendix 18.B, Appendix 41.C, and Appendix 41.D, respectively). The methods and procedures for determining the SEDCAD and RUSLE model inputs are described in detail in these appendices.

Personnel

Persons or organizations responsible for data collection, analysis, and preparation of this permit application package section:

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Table 38.1-1 Fortier's and Scobey's Limiting Velocities for Straight Channels After Aging

Material[1]	Water transporting: For clean water velocity (fps)	Water transporting: Colloidal silts velocity (fps)
Fine sand colloidal	1.50	2.50
Sandy loam non-colloidal	1.75	2.50
Silt loam non-colloidal	2.00	3.00
Ordinary firm loam	2.50	3.50
Alluvial silts non-colloidal	2.00	3.50
Alluvial silts colloidal	3.75	5.00
Shales and hardpan	6.00	6.00
Rock riprap	12.00	12.00
Wire-enclosed riprap	15.00	15.00
Grouted riprap	20.00	20.00
Fabricform/concrete	>20.00	>20.00

[1] From Lane 1955

fps – feet per second

Table 38.1-2 Typical Flat Bottom Gradient Terrace Summary (12-feet Bottom Width, 3h:1v Side Slopes)[1]

Slope category / Hydrologic & Sediment Values		Terrace length (ft)	Channel width (ft)	Min. terrace (ft)[4]	Terrace spacing (ft)[3]	Watershed (ac)	5-yr sediment (cyd)	Sediment storage (ft)[5]	TC (hr)	100-yr 6-hr storm Q (cfs)	100-yr 6-hr storm Velocity (fps)	100-yr 6-hr storm Depth (ft)	100-yr 6-hr storm Fr. #	10-yr 6-hr storm Q (cfs)	10-yr 6-hr storm Velocity (fps)	10-yr 6-hr storm Depth (ft)	10-yr 6-hr storm Fr. #
Slope category =	10	1000	12	1.89	800	18.37	269	0.535	0.154	9.28	2.01	0.36	0.62	2.93	1.30	0.18	0.55
Curve number (CN) =	83	2000	12	2.03	800	36.73	539	0.535	0.239	16.24	2.46	0.50	0.65	5.08	1.64	0.26	0.59
Rainfall-runoff erosivity factor (R) =	20	3000	12	2.11	800	55.10	808	0.535	0.325	21.47	2.69	0.58	0.66	6.65	1.80	0.30	0.60
Control management/ support practice factor (CP) =	0.364	4000	12	2.17	800	73.46	1,078	0.535	0.410	25.88	2.85	0.64	0.67	7.96	1.87	0.32	0.61
Soil erodibility factor (K)=	0.160	5000	12	2.23	800	91.83	1,347	0.535	0.496	29.56	3.00	0.70	0.68	9.03	2.01	0.36	0.62
[2] Slope length and steepnes factor (LS) =	3.174	6000	12	2.27	800	110.19	1,617	0.535	0.581	32.68	3.10	0.74	0.69	9.96	2.08	0.38	0.62
Sediment yield (t/ac) =	3.70	7000	12	2.31	800	128.56	1,886	0.535	0.667	35.40	3.20	0.78	0.69	10.82	2.15	0.40	0.63
Slope category =	11	1000	12	1.68	580	13.31	184	0.378	0.131	6.72	1.80	0.30	0.60	2.13	1.16	0.15	0.54
CN =	83	2000	12	1.80	580	26.63	367	0.378	0.214	12.25	2.21	0.42	0.63	3.84	1.44	0.21	0.57
R =	20	3000	12	1.88	580	39.94	551	0.378	0.297	16.16	2.46	0.50	0.65	5.00	1.60	0.25	0.58
CP =	0.364	4000	12	1.93	580	53.26	735	0.378	0.380	19.38	2.60	0.55	0.66	5.98	1.72	0.28	0.59
K =	0.160	5000	12	1.98	580	66.57	918	0.378	0.463	22.14	2.74	0.60	0.67	6.78	1.80	0.30	0.60
[2] LS =	2.984	6000	12	2.01	580	79.89	1,102	0.378	0.546	24.47	2.82	0.63	0.67	7.46	1.83	0.31	0.60
Sediment yield (t/ac) =	3.48	7000	12	2.04	580	93.20	1,286	0.378	0.629	26.46	2.90	0.66	0.68	8.06	1.91	0.33	0.61
Slope category =	12	1000	12	1.59	450	10.33	137	0.288	0.115	6.97	1.80	0.30	0.60	2.54	1.21	0.16	0.54
CN =	83	2000	12	1.66	450	20.66	275	0.288	0.194	9.85	2.05	0.37	0.62	3.10	1.35	0.19	0.56
R =	20	3000	12	1.72	450	30.99	412	0.288	0.274	12.96	2.24	0.43	0.63	4.03	1.48	0.22	0.57
CP =	0.364	4000	12	1.77	450	41.32	550	0.288	0.353	15.55	2.40	0.48	0.64	4.80	1.56	0.24	0.58
K =	0.160	5000	12	1.81	450	51.65	687	0.288	0.433	17.74	2.52	0.52	0.65	5.45	1.64	0.26	0.59
[2] LS =	2.878	6000	12	1.84	450	61.98	825	0.288	0.512	19.63	2.60	0.55	0.66	6.00	1.72	0.28	0.59
Sedimeny yield (t/ac) =	3.35	7000	12	1.87	450	72.31	962	0.288	0.591	21.25	2.69	0.58	0.66	6.48	1.76	0.29	0.60
Slope category =	13	1000	12	1.48	350	8.03	101	0.215	0.103	5.41	1.64	0.26	0.59	1.98	1.11	0.14	0.53
CN =	83	2000	12	1.54	350	16.07	202	0.215	0.179	7.91	1.87	0.32	0.61	2.50	1.26	0.17	0.55
R =	20	3000	12	1.60	350	24.10	302	0.215	0.255	10.37	2.08	0.38	0.62	3.24	1.35	0.19	0.56
CP =	0.364	4000	12	1.64	350	32.14	403	0.215	0.331	12.43	2.21	0.42	0.63	3.85	1.44	0.21	0.57
K =	0.160	5000	12	1.68	350	40.17	504	0.215	0.407	14.20	2.34	0.46	0.64	4.37	1.52	0.23	0.58
[2] LS =	2.713	6000	12	1.71	350	48.21	605	0.215	0.483	15.72	2.43	0.49	0.65	4.81	1.56	0.24	0.58
Sediment yield (t/ac) =	3.16	7000	12	1.73	350	56.24	705	0.215	0.559	17.02	2.49	0.51	0.65	5.19	1.60	0.25	0.58
Slope category =	14	1000	12	1.43	300	6.89	88	0.188	0.094	4.65	1.56	0.24	0.58	1.70	1.06	0.13	0.53
CN =	83	2000	12	1.49	300	13.77	175	0.188	0.166	6.95	1.80	0.30	0.60	2.20	1.16	0.15	0.54
R =	20	3000	12	1.55	300	20.66	263	0.188	0.238	9.15	2.01	0.36	0.62	2.86	1.30	0.18	0.55
CP =	0.364	4000	12	1.58	300	27.55	35	0.188	0.310	10.95	2.11	0.39	0.62	3.39	1.39	0.20	0.56
K =	0.160	5000	12	1.62	300	34.44	438	0.188	0.382	12..50	2.24	0.43	0.63	3.86	1.44	0.21	0.57
[2] LS =	2.751	6000	12	1.64	300	41.32	525	0.188	0.455	13.85	2.31	0.45	0.64	4.25	1.52	0.23	0.58
Sediment yield (t/ac) =	3.20	7000	12	1.66	300	48.21	613	0.188	0.527	15.04	2.37	0.47	0.64	4.59	1.56	0.24	0.58
Slope category =	15	1000	12	1.36	250	5.74	71	0.153	0.088	3.87	1.44	0.21	0.57	1.41	1.00	0.12	0.52
CN =	83	2000	12	1.42	250	11.48	141	0.153	0.158	5.80	1.68	0.27	0.59	1.83	1.11	0.14	0.53
R =	20	3000	12	1.47	250	17.22	212	0.153	0.229	7.74	1.87	0.32	0.61	2.42	1.21	0.16	0.54
CP =	0.364	4000	12	1.51	250	22.96	282	0.153	0.299	9.26	2.01	0.36	0.62	2.87	1.30	0.18	0.55
K =	0.160	5000	12	1.54	250	28.70	353	0.153	0.369	10.58	2.11	0.39	0.62	3.27	1.35	0.19	0.56
[2] LS =	2.660	6000	12	1.56	250	34.44	423	0.153	0.440	11.74	2.18	0.41	0.63	3.60	1.39	0.20	0.56
Sediment yield (t/ac) =	3.10	7000	12	1.58	250	40.17	494	0.153	0.510	12.75	2.24	0.43	0.63	3.89	1.44	0.21	0.57

Notes: (1) Values as appear in Table "I" in Reclamation Surface Stabilization Handbook (BNCC 1999)   t/ac- tons per acre

Table 38.1-2 (Continued)

Slope category / Hydrologic & Sediment Values	Terrace length (ft)	Channel width (ft)	Min. terrace (ft)(4)	Terrace spacing (ft)(3)	Watershed (ac)	5-yr sediment (cyd)	Sediment storage (ft)(5)	TC (hr)	100-yr 6-hr storm Q (cfs)	Velocity (fps)	Depth (ft)	Fr. #	10-yr 6-hr storm Q (cfs)	Velocity (fps)	Depth (ft)	Fr. #

(2) Surface runoff will become channelized in one-half the distance between terraces
(3) values per Phillip Reinholtz memo dated 20 Aug 1990 (on file at BNCC's Navajo Mine office)
(4) Terrace height includes sediment storage + 10-yr 6-hr flow depth + 1.0-ft freeboard
(5) Sediment density is 1.26 tons per cubic yard

TC- time of concentration
cfs- cubic fet per second
cyd- cubic yard
fps- feet per second
Fr. #- Froude number

Table 38.1-3 Typical V-Ditch Gradient Terrace Summary (Side Slopes 3v:1v and 7h:1v)[1]

Slope category / Hydrologic & Sediment Values		Terrace length (ft)	Channel width (ft)	Min. terrace (ft)[4]	Terrace spacing (ft)[3]	Watershed (ac.)	5-yr sediment (cyd)	Sediment storage (ft)[5]	TC (hr)	100-yr 6-hr storm Q (cfs)	100-yr 6-hr storm Velocity (fps)	100-yr 6-hr storm Depth (ft)	100-yr 6-hr storm Fr. #	10-yr 6-hr storm Q (cfs)	10-yr 6-hr storm Velocity (fps)	10-yr 6-hr storm Depth (ft)	10-yr 6-hr storm Fr. #
Slope category =	10	1000	0	3.89	800	18.37	269	2.010	0.154	9.28	2.40	0.88	0.65	2.93	1.80	0.57	0.60
Curve number (CN) =	83	2000	0	4.10	800	36.73	539	2.010	0.024	16.24	2.77	1.09	0.67	5.08	2.06	0.70	0.62
Rainfall-runoff erosivity factor (R) =	20	3000	0	4.22	800	55.10	808	2.010	0.325	21.47	2.97	1.21	0.68	6.65	2.22	0.78	0.63
Control management/ support practice factor (CP) =	0.364	4000	0	4.30	800	73.46	1,078	2.010	0.410	25.88	3.10	1.29	0.69	7.96	2.31	0.83	0.64
Soil erodibility factor (K)=	0.160	5000	0	4.37	800	91.83	1,347	2.010	0.496	29.56	3.21	1.36	0.69	9.03	2.38	0.87	0.64
[2] Slope length and steepnes factor (LS) =	3.174	6000	0	4.42	800	110.19	1,617	2.010	0.581	32.68	3.29	1.41	0.70	9.96	2.46	0.91	0.65
Sediment yield (t/ac) =	3.70	7000	0	4.47	800	128.56	1,886	2.010	0.667	35.40	3.37	1.46	0.70	10.82	2.51	0.94	0.65
Slope category =	11	1000	0	3.44	580	13.31	184	1.660	0.131	6.72	2.22	0.78	0.63	2.13	1.67	0.51	0.59
CN =	83	2000	0	3.64	580	26.63	367	1.660	0.214	12.25	2.58	0.98	0.66	3.84	1.92	0.63	0.61
R =	20	3000	0	3.75	580	39.94	551	1.660	0.297	16.16	2.77	1.09	0.67	5.00	2.06	0.70	0.62
CP =	0.364	4000	0	3.82	580	53.26	735	1.660	0.380	19.38	2.89	1.16	0.68	5.98	2.16	0.75	0.63
K =	0.160	5000	0	3.88	580	66.57	918	1.660	0.463	22.14	2.99	1.22	0.68	6.78	2.22	0.78	0.63
[2] LS =	2.984	6000	0	3.93	580	79.89	1,102	1.660	0.546	24.47	3.07	1.27	0.69	7.46	2.27	0.81	0.64
Sed iment yield (t/ac) =	3.48	7000	0	3.97	580	93.20	1,286	1.660	0.629	26.46	3.13	1.31	0.69	8.06	2.33	0.84	0.64
Slope category =	12	1000	0	3.23	450	10.33	137	1.436	0.115	6.97	2.23	0.79	0.63	2.54	1.73	0.54	0.59
CN =	83	2000	0	3.34	450	20.66	275	1.436	0.194	9.85	2.44	0.90	0.65	3.10	1.84	0.59	0.60
R =	20	3000	0	3.44	450	30.99	412	1.436	0.274	12.96	2.61	1.00	0.66	4.03	1.94	0.64	0.61
CP =	0.364	4000	0	3.51	450	41.32	550	1.436	0.353	15.55	2.74	1.07	0.67	4.80	2.04	0.69	0.62
K =	0.160	5000	0	3.56	450	51.65	687	1.436	0.433	17.74	2.82	1.12	0.67	5.45	2.10	0.72	0.62
[2] LS =	2.878	6000	0	3.61	450	61.98	825	1.436	0.512	19.63	2.90	1.17	0.68	6.00	2.16	0.75	0.63
Sediment yield (t/ac) =	3.35	7000	0	3.64	450	72.31	962	1.436	0.591	21.25	2.95	1.20	0.68	6.48	2.20	0.77	0.63
Slope category =	13	1000	0	2.95	350	8.03	101	1.229	0.103	5.41	2.10	0.72	0.62	1.98	1.63	0.49	0.59
CN =	83	2000	0	3.06	350	16.07	202	1.229	0.179	7.91	2.31	0.83	0.64	2.50	1.73	0.54	0.59
R =	20	3000	0	3.15	350	24.10	302	1.229	0.255	10.37	2.47	0.92	0.65	3.24	1.84	0.59	0.60
CP =	0.364	4000	0	3.21	350	32.14	403	1.229	0.331	12.43	2.58	0.98	0.66	3.85	1.92	0.63	0.61
K =	0.160	5000	0	3.27	350	40.17	504	1.229	0.407	14.20	2.68	1.04	0.66	4.37	1.98	0.66	0.62
[2] LS =	2.713	6000	0	3.30	350	48.21	605	1.229	0.483	15.72	2.74	1.07	0.67	4.81	2.04	0.69	0.62
Sediment yield (t/ac) =	3.16	7000	0	3.34	350	56.24	705	1.229	0.559	17.02	2.80	1.11	0.67	5.19	2.08	0.71	0.62
Slope category =	14	1000	0	2.83	300	6.89	88	1.146	0.094	4.65	2.02	0.68	0.62	1.70	1.58	0.47	0.58
CN =	83	2000	0	2.94	300	13.77	175	1.146	0.166	6.95	2.23	0.79	0.63	2.20	1.69	0.52	0.59
R =	20	3000	0	3.03	300	20.60	263	1.146	0.238	9.15	2.40	0.88	0.65	2.86	1.80	0.57	0.60
CP =	0.364	4000	0	3.09	300	27.55	350	1.146	0.310	10.95	2.51	0.94	0.65	3.39	1.86	0.60	0.61
K =	0.160	5000	0	3.14	300	34.44	438	1.146	0.382	12.50	2.60	0.99	0.66	3.86	1.92	0.63	0.62
[2] LS =	2.751	6000	0	3.18	300	41.32	525	1.146	0.455	13.85	2.67	1.03	0.66	4.25	1.98	0.66	0.62
Sediment yield (t/ac) =	3.20	7000	0	3.21	300	48.21	613	1.146	0.527	15.04	2.72	1.06	0.67	4.59	2.02	0.68	0.62
Slope category =	15	1000	0	2.67	250	5.74	71	1.029	0.088	3.87	1.94	0.64	0.61	1.41	1.51	0.44	0.60
CN =	83	2000	0	2.77	250	11.48	141	1.029	0.158	5.80	2.14	0.74	0.63	1.83	1.60	0.48	0.58
R =	20	3000	0	2.85	250	17.22	212	1.029	0.229	7.74	2.29	0.82	0.64	2.42	1.71	0.53	0.59
CP =	0.364	4000	0	2.91	250	22.96	282	1.029	0.299	9.26	2.40	0.88	0.65	2.87	1.80	0.57	0.60
K =	0.160	5000	0	2.96	250	28.70	353	1.029	0.369	10.58	2.49	0.93	0.65	3.27	1.86	0.60	0.61
[2] LS =	2.660	6000	0	2.99	250	34.44	423	1.029	0.440	11.74	2.54	0.96	0.65	3.60	1.90	0.62	0.61
Sediment yield (t/ac) =	3.10	7000	0	3.02	250	40.17	494	1.029	0.510	12.75	2.60	0.99	0.66	3.89	1.94	0.64	0.61

Table 38.1-3 (Continued)

Slope category	Terrace	Channel	Min.	Terrace		5-yr	Sediment		100-yr 6-hr storm				10-yr 6-hr storm			
	length	width	terrace	spacing	Watershed	sediment	storage	TC	Q	Velocity	Depth	Fr. #	Q	Velocity	Depth	Fr. #
Hydrologic & Sediment Values	(ft)	(ft)	(ft)(4)	(ft)(3)	(ac.)	(cyd)	(ft)(5)	(hr)	(cfs)	(fps)	(ft)		(cfs)	(fps)	(ft)	

Notes: (1) Values as appear in Table "J" in Rec. Surface Stabilization Handbook (BNCC 1999)
(2) Surface runoff will become channelized in one-half the distance between terraces
(3) values per Phillip Reinholtz memo dated 20 Aug 1990 (on file at BNCC's Navajo Mine office)
(4) Terrace height includes sediment storage + 10-yr 6-hr flow depth + 1.0-ft freeboard
(5) Sediment density is 1.26 tons per cubic yard

t/ac- tons per acre
TC- time of concentration
cfs- cubic fet per second
cyd- cubic yard
fps- feet per second
Fr. #- Froude number

Table 38.1-4 Typical Drop Structure Riprap Size

Channel slope (%)/ peak flows (cfs)		Bottom width (ft)	Flow depth (ft)	Side slopes (z)	Manning's n	Channel velocity	Apron length (ft)	Riprap specification (1)					
								Bottom (ft)			Bank (ft)		
								Dmax	D50	D10	Dmax	D50	D10
10%	50	12	0.38	2.0	0.034	6.83	15.0	0.63	0.50	0.17	0.63	0.50	0.17
	100	12	0.65	2.0	0.037	8.86	15.0	0.94	0.75	0.25	0.94	0.75	0.25
	150	12	0.86	2.0	0.039	10.00	15.0	1.25	1.00	0.33	1.25	1.00	0.33
	200	12	1.04	2.0	0.040	10.73	15.0	1.56	1.25	0.42	1.56	1.25	0.42
	250	12	1.18	2.0	0.041	11.26	15.0	1.88	1.50	0.50	1.88	1.50	0.50
11%	50	12	0.37	2.0	0.035	6.96	15.0	0.63	0.50	0.17	0.63	0.50	0.17
	100	12	0.63	2.0	0.037	9.05	15.0	0.94	0.75	0.25	0.94	0.75	0.25
	150	12	0.84	2.0	0.039	10.22	15.0	1.25	1.00	0.33	1.25	1.00	0.33
	200	12	1.01	2.0	0.041	10.99	15.0	1.56	1.25	0.42	1.56	1.25	0.42
	250	12	1.15	2.0	0.042	11.54	15.0	1.88	1.50	0.50	1.88	1.50	0.50
12%	50	12	0.36	2.0	0.035	7.07	15.0	0.63	0.50	0.17	0.63	0.50	0.17
	100	12	0.61	2.0	0.038	9.20	15.0	0.94	0.75	0.25	0.94	0.75	0.25
	150	12	0.82	2.0	0.040	10.41	15.0	1.25	1.00	0.33	1.25	1.00	0.33
	200	12	0.98	2.0	0.041	11.21	15.0	1.56	1.25	0.42	1.56	1.25	0.42
	250	12	1.12	2.0	0.042	11.78	15.0	1.88	1.50	0.50	1.88	1.50	0.50
13%	50	12	0.35	2.0	0.036	7.15	15.0	0.94	0.75	0.25	0.94	0.75	0.25
	100	12	0.60	2.0	0.038	9.32	15.0	1.25	1.00	0.33	1.25	1.00	0.33
	150	12	0.79	2.0	0.040	10.56	15.0	1.56	1.25	0.42	1.56	1.25	0.42
	200	12	0.96	2.0	0.041	11.39	15.0	1.88	1.50	0.50	1.88	1.50	0.50
	250	12	1.09	2.0	0.042	11.98	15.0	2.19	1.75	0.58	2.19	1.75	0.58
14%	50	12	0.34	2.0	0.036	7.22	15.0	0.94	0.75	0.25	0.94	0.75	0.25
	100	12	0.58	2.0	0.038	9.41	15.0	1.25	1.00	0.33	1.25	1.00	0.33
	150	12	0.77	2.0	0.040	10.68	15.0	1.56	1.25	0.42	1.56	1.25	0.42
	200	12	0.93	2.0	0.042	11.54	15.0	1.88	1.50	0.50	1.88	1.50	0.50
	250	12	1.06	2.0	0.043	12.15	15.0	2.19	1.75	0.58	2.19	1.75	0.58
15%	50	12	0.33	2.0	0.036	7.26	15.0	0.94	0.75	0.25	0.94	0.75	0.25
	100	12	0.56	2.0	0.039	9.48	15.0	1.25	1.00	0.33	1.25	1.00	0.33
	150	12	0.75	2.0	0.041	10.77	15.0	1.56	1.25	0.42	1.56	1.25	0.42
	200	12	0.90	2.0	0.042	11.65	15.0	1.88	1.50	0.50	1.88	1.50	0.50
	250	12	1.03	2.0	0.043	12.28	15.0	2.19	1.75	0.58	2.19	1.75	0.58

Notes (1) Riprap size generated by SEDCAD™ - version 4.0
cfs - cubic feet per second
fps - feet per second

Table 38.1-5 Minimum Design Storm Frequencies

Conveyance structure type	Minimum frequency
Terraces (velocity limitations)	10yr-6hr
Terraces (capacities)	100yr-6r
Ephemeral downdrains (<640ac)	
Velocity limitation (riprap sizing)	10yr-6hr
Capacities	100yr-6hr
Drop structures (intermittent)	
Velocity limitation	25yr-6hr
Capacities	100yr-6hr
Intermittent downdrains (>640ac.)	
Velocity limitation (riprap sizing)	25yr-6hr
Capacities	100yr-6hr

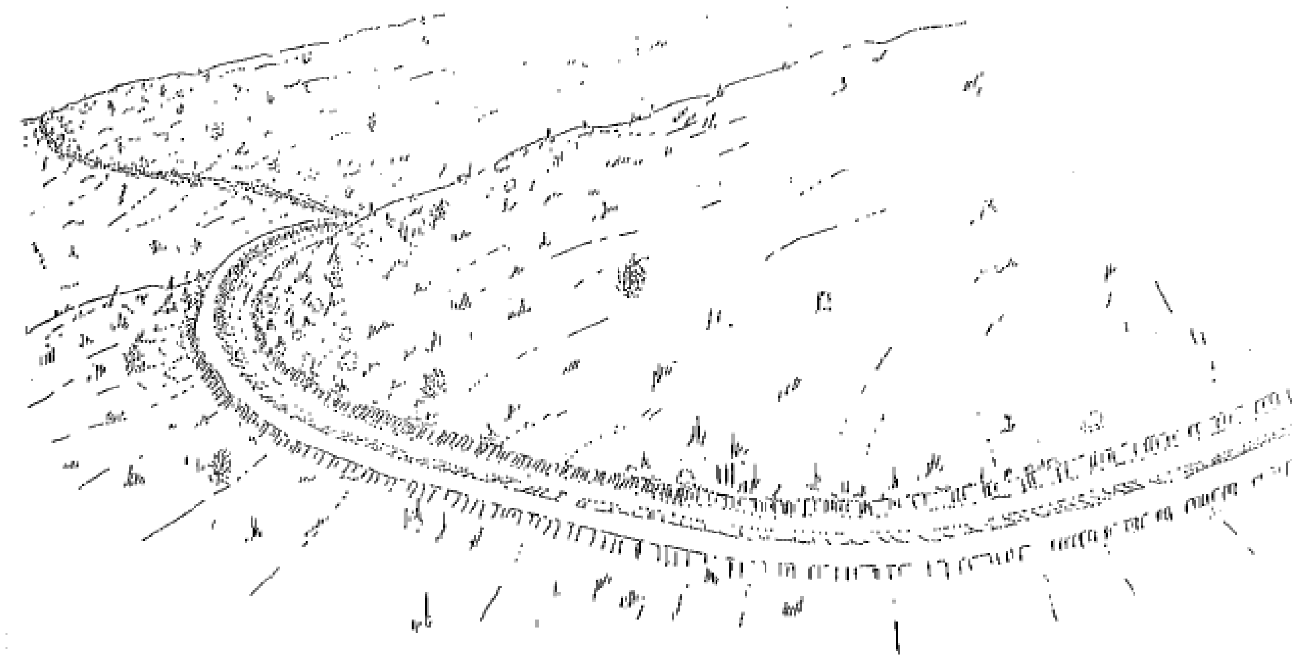

Figure 38.1-1 Typical Gradient Terrace

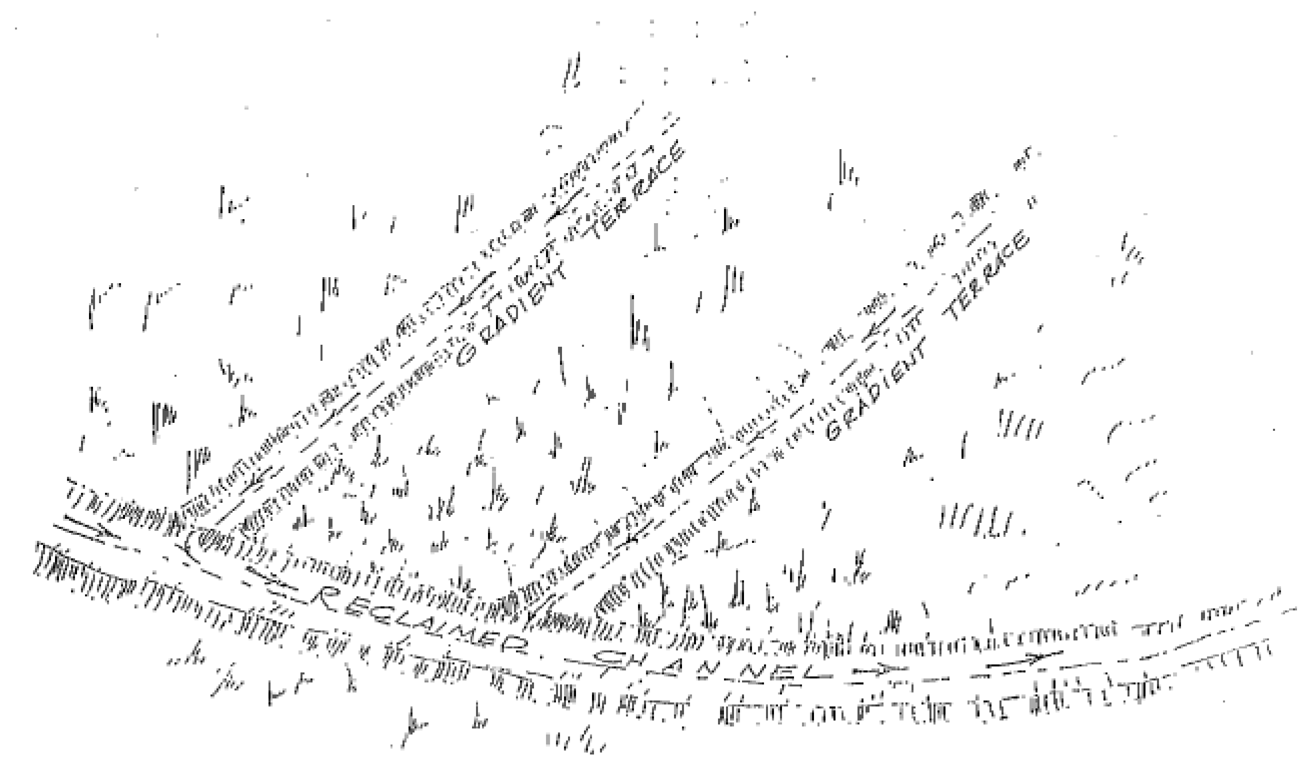

Figure 38.1-2 Typical Gradient Terrace Connecting with Reclaimed Channel

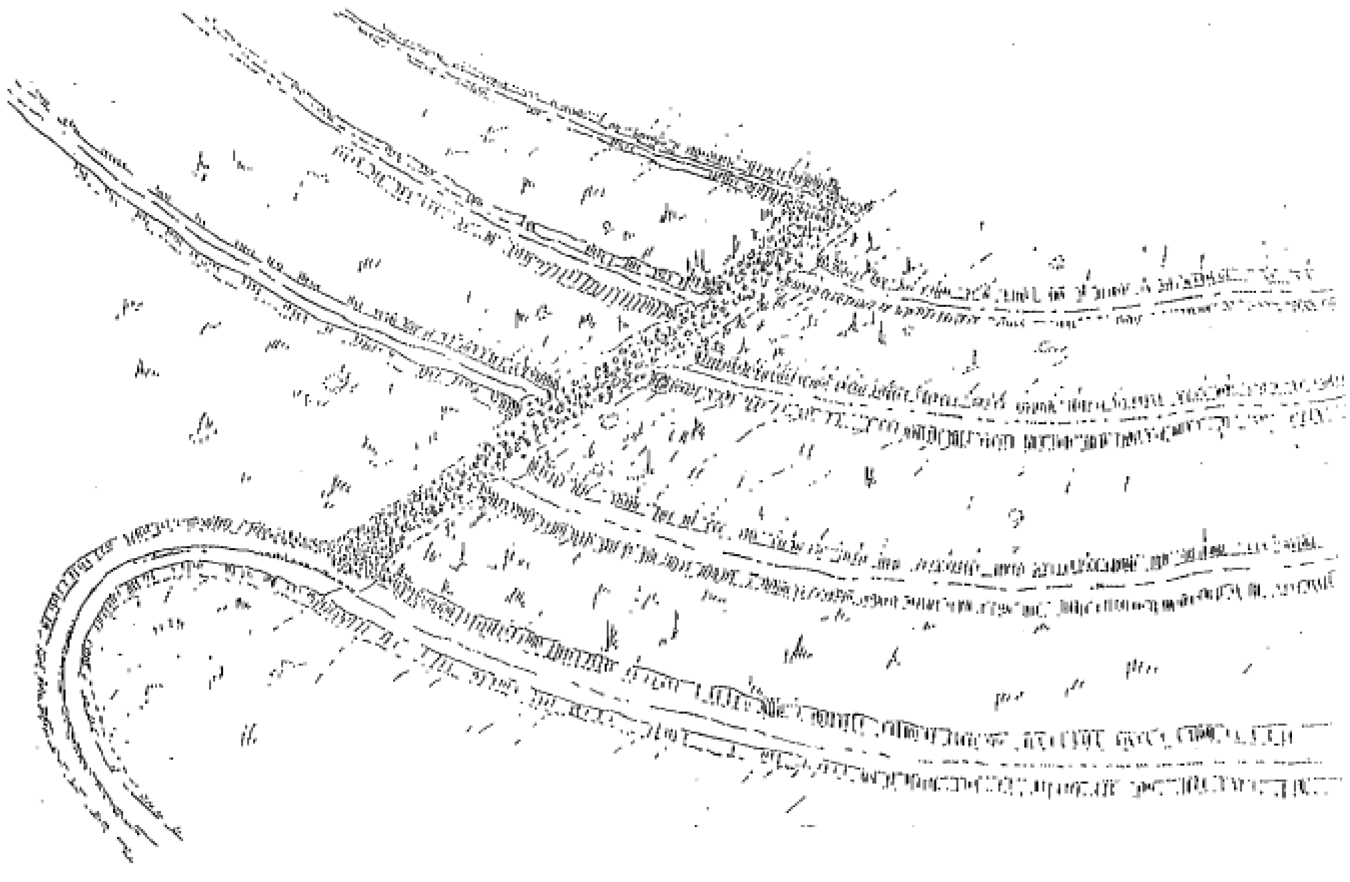

Figure 38.1-3 Confluence of a Series of Typical Gradient Terraces with a Drop Structure Connecting to a Reclaimed Channel