CHAPTER 26

SURFACE STABILIZATION PLAN

MAR 2012
APPROVED

CHAPTER 26

INDEX

	Page
Introduction	1
Regional Environmental and Geomorphologic Setting	1
Surface Stabilization Plan	3
Introduction	3
Implementation of the Surface Stabilization Plan	9
Sedimentation Ponds and Other Sediment Control Measures	13
Preliminary Watershed Design	14
Topographic Manipulation	14
Permanent Water Conveyance Features	18
Gradient Terraces or Swales	18
Reclamation Meandering Downdrain Channels	20
Main Reclamation Channels	21
Drop Structures	23
Temporary Features Used in Support of Topographic Manipulation and Conveyance Structures	23
Check Dams and Erosion Resistant Liners	24
Sediment Traps	24
Minesoil Reconstruction	24
Surface Mechanical Treatments	25
Establishment of Effective Permanent Vegetation Cover	26
Surface Protection Measures	27
Linear Detention and Filtering Structures	29
Maintenance, Management, and Postmining Land Use	30
Jurisdictional Applicability	31
Rill and Gully Plan	32
Sediment Control Plan	33
Literature Cited	36

CHAPTER 26

INDEX (Cont.)

LIST OF FIGURES

		Page
Figure 1	Surface Stabilization Plan Summary	10

LIST OF ATTACHMENTS

Attachment A - Reclamation Scale Geomorphology

Attachment B - Terrace Spacing

Attachment C - Reclamation Surface Stabilization Design Process

Attachment D - Sediment Control Plan

Attachment E - J-16 White Grass Hills Drainage Plan Including Terraces & Downdrains

MAR 2012
APPROVED

CHAPTER 26

SURFACE STABILIZATION PLAN

Introduction

Chapter 26 presents the detailed plan for establishing a reclaimed landscape that will provide effective surface stabilization and long term erosion control with minimal maintenance. The plan is presented in three major segments: background on the environmental and geomorphologic setting and evaluation of current applied reclamation practices relating to surface stability; the proposed surface stabilization program along with applicable geomorphic criteria; and procedures, design criteria, and other documentation in support of the plan. The plan establishes the basis for PWCC's operational decisions for reclamation. The basis takes into account site parameters, material properties, characteristics of the mining operation, reclamation procedures, and Best Technology Currently Available (BTCA) practices that are proven or most applicable for the Kayenta Complex. The basis also includes detailed criteria for design and implementation of the various stabilization measures and measures for insuring the implemented stabilization plan remains functional and effective with minimal maintenance. The surface stabilization plan, accompanying documentation and supporting information, and appropriate sections of the Permit Application Package (PAP), when reviewed in total, clearly demonstrate a stable and sustainable reclaimed landform will be established.

Regional Environmental and Geomorphologic Setting

A brief review of the more important processes that influence regional land surface stability are provided in this section. This review is necessary because the Black Mesa region has high erosion potential. Past and present reclamation practices related to surface stabilization have, to a large degree, been dictated by local erosional and stability processes. The surface stabilization plan evolved through monitoring the response of both undisturbed and reclaimed lands to the processes that affect surface stability, a more thorough understanding of the processes themselves, and applying this knowledge to select the appropriate design and construction techniques and reclamation BTCA practices needed to insure sustained surface stability.

MAR 2012 APPROVED

Chapter 15 (Hydrologic Description) contains detailed information on the regional and local hydrology of Black Mesa. It includes descriptions of the geologic and hydrologic features and processes that determine basin responses to the semi-arid climate. The relationships among the various independent and dependent variables which characterize drainage basin geomorphology on Black Mesa are complex and typical of arid and semi-arid conditions. Native drainage basin morphologies are characterized by high drainage densities, areas of bedrock control, moderate to steep upland hillslopes that feature shallow, highly erosive soils, and prominently entrenched channels in the higher order streams. These drainage basin characteristics are indicative of the typical Black Mesa watershed responses to the high energy rainfall events over time. The climate of Black Mesa is arid to semi-arid, and typically produces from 8 to 12 inches of precipitation annually (Chapter 11). Most rainfall occurs as intense summer thunderstorms that produce high kinetic energies. Thunderstorms result in large amounts of soil detachment and subsequent entrainment of soil particles by overland runoff. Both overland and channelized runoff produced by the thunderstorms rapidly develops supercritical flow regimes, which increases the erosive potential of the runoff due to high tractive forces.

Other supporting information including sediment transport based on monitoring data, geomorphic characteristics of an adjacent un-mined watershed, and numeric targets or ranges (sideboards) for select geomorphic characteristics to be used for designing and constructing reclaimed watersheds at Kayenta Mine are provided in Attachment A to this Chapter (Reclamation Scale Geomorphology).

Soil resources within the Kayenta Complex are quantified and described in Chapter 8 and Appendix A in Chapter 8. The majority of these soils possess physical characteristics which make them moderately to highly susceptible to sheet erosion (high "K" factors). Their potential for producing surface water runoff (hydrologic group) is variable, ranging from low to high. In the native landscape, these soils are generally shallow and the existing degree of erosion is moderate to severe depending in part on slope position and rock outcrops or bedrock control. Deeper soils occur in the third and fourth order washes and adjacent terraces and footslopes where colluvial and alluvial materials have been deposited. These constraints must be considered to achieve the proposed postmining land uses, and to comply with regulatory requirements intended to conserve the available soil resource by utilizing it in the reclamation process.

MAR 2012
APPROVED

The degree of erosion that has been documented in the native landscapes is further influenced by the amount (cover) and kind (structure) of vegetation that occurs on these soils (see Chapter 9 for a complete description of the premining vegetation). In their present condition, the sagebrush shrubland and pinyon juniper vegetation communities have hydrologic cover with a low degree of effectiveness for protecting the soil against erosion because woody vegetation is dominant with a low level of ground cover. Historic land use practices and overgrazing have been a significant factor in further reducing the level of effective hydrologic cover. Chapter 14 contains a complete description of the premining land uses and documents the current condition and trend of the rangeland resources on the leasehold. These constraints are considered in reclamation and postmine land use planning.

Surface Stabilization Plan

Introduction. The following surface stabilization plan ensures all permanent program reclaimed lands are effectively stabilized, protected to minimize or control erosion, and meet water quality standards for receiving streams. Furthermore, the plan provides the means for sustaining landform stability, productivity, and postmining land uses over time under the prevailing environmental and geomorphic processes characteristic of the Black Mesa region. Baseline data collection and ongoing monitoring programs have resulted in, or have been designed to, achieve a greater understanding of these natural processes. This has allowed PWCC to take a realistic approach in selecting or defining input parameters for engineering designs, selecting or developing reclamation BTCA practices, and developing documentation through monitoring or effective demonstrations.

Ongoing reclamation practices establish permanent, effective, and sustainable vegetative cover on stable landforms that achieve minimized erosion on reclaimed lands (Attachment A). Data collected during small watershed studies conducted on reclaimed lands from 1985 through 1992 show water quality is better than background. Subsequent modeling based on the data and the physically-based EASI model (Zevenbergen et al., 1990) demonstrated average annual sediment yield (which is also related to soil loss) from watersheds established in more than 2,000 acres of reclaimed mined lands at the Kayenta Complex is equal to or less than background levels. The EASI model also serves as the primary tool for evaluating the performance of Best Management Practices (BMPs), which are sediment

MAR 2012 APPROVED

control practices under the Clean Water Act (CWA) described in the section entitled "Sediment Control Plan" later in this chapter and are practically synonymous with BTCA practices. Revegetation monitoring data demonstrates ground cover in the reclaimed areas achieves the success standard for cover within a few years after seeding, and has more effective hydrologic cover for surface stabilization than premine vegetation. Thus, it can be demonstrated reclamation is successful, and when compared to performance standards related to water quality and revegetation, has been effective and validates the applied BTCA practices. The results of these studies also support the continued application of the current reclamation plan as a basis for the surface stabilization plan presented in the following sections.

The surface stabilization plan is effective through a number of procedures and practices, relating both to planning and application as summarized in the following discussion. The first major step in the overall process involves developing a post-mining topographic surface (PMT) for the proposed coal resource area (CRA) to be mined (see Attachment C, Reclamation Surface Stabilization Design Process and Chapter 21, Backfilling and Grading). This process involves developing a PMT while accounting for the total overburden volume mined minus coal removed and the configuration of the spoils based on the mine plan and excavation equipment proposed for the CRA. The material balance must be quantified and verified to ensure adequate materials are available for creating the PMT. The PMT development will also take into account types of equipment available to do grading (i.e. dozers, scrapers, or draglines). In addition, the PMT must be created to incorporate a preliminary drainage network that includes the geomorphic sideboards (and targets) provided in Attachment A. Finally, based on the overall PMT and preliminary drainage network, designs for third and fourth order drainage channels must be developed in accordance with Attachment A and applicable performance standards and engineering methods as described in Chapter 6, Facilities. The PMT that will depict the preliminary drainage network and the designs of the third and fourth order channels will be submitted to OSM for approval with the five-year mine plan for the CRA. The designed PMT is an approximate quantification of the latest mine plan. Changes to the mine plan will affect the PMT in material volume moved, drainage design, and area disturbed.

The second major step involves activities associated with rough grading of the spoiled overburden materials. Depending on the configuration of mine pits, rough grading will

MAR 2012
APPROVED

begin in areas available for grading after several spoil piles have been established; and, in limited areas, rough grading may only commence after more than four spoil ridges have been created. Approval of this surface stabilization plan allows PWCC to maintain more than four spoil ridges when needed to develop the approved PMT. The timing of rough grading will allow PWCC to assess the postmining layout of spoil piles and develop on-the-ground rough grading plans to begin constructing the preliminary drainage network approved by OSM. Flexibility for initiating rough grading according to the preliminary drainage network as described in this plan will ensure PWCC complies with the requirements of SMCRA to conduct contemporaneous reclamation. PWCC shall have the flexibility to rough grade using any available equipment (not limited to just dozers). PWCC will have from time to time draglines available for grading; this would delay the rough grading schedule slightly (contemporaneous reclamation). This would allow scheduling the dragline to be used in the most effective and economic way possible.

Rough grading will establish the locations and configurations of hillslopes and the drainages based on the configuration of the spoil piles and in consideration of the preliminary drainage network depicted on the approved PMT. PWCC shall reserve the right to have flexibility in final locations of PMT channels, ridges, and suitablie soil locations (red rock). Concurrently, and after grading has achieved the desired final surface elevations, PWCC will implement the spoil sampling plan and mitigation as necessary to achieve suitable plant growth media depths required in Chapter 22, Minesoil Reconstruction. Third and fourth order channels will be constructed according to designs submitted with the PMT during the permitting or permit revision process. Locations of these channels will be determined by the locations of haulage ramps and final highwall pit in the approved mine plan. Lower order channels (1st and 2nd order), short segment terraces and swales, and drainage basin features (e.g., overall concave slopes) built during rough grading will be constructed according to designs made once rough grading has established the watershed basins and will adhere to specifications defined by the ranges of their corresponding geomorphic sideboards or target values provided in Attachment A. Other drainage features such as downdrains, drop structures, or other permanent features that may be needed to ensure long-term stability with minimal maintenance will be designed and constructed during the rough grading step. Rough grading of these features will begin only after preliminary designs are completed by a Registered Professional Engineer. Preliminary or final designs for any permanent drainage channel, downdrain, drop structure, or other conveyance structure will be completed and maintained in a

MAR 2012
APPROVED

design file that will be kept at the Kayenta Complex for guiding construction activities and for regulatory inspection purposes. The design file will be updated periodically and at a minimum of once per year in conjunction with submittal of the Annual Reclamation Status and Monitoring Report. The onsite file will be updated as changes are made to the preliminary or subsequent designs. As-built designs of each permanent conveyance feature will be developed and certified by a Registered Professional Engineer. During any given year as backfilling and grading progresses through a mined CRA, as-built designs will be submitted to OSM with the Annual Reclamation Status and Monitoring Report. These will also become part of the design file.

The third major step involves the replacement of salvaged soil resources or supplemental surface plant growth media. Final construction of grade control structures (downdrains) and placement of channel armoring materials such as large diameter riprap may also be completed during this step. In some cases, PWCC will use erosion fabric material in channels in place of riprap. Replacement of salvaged soil or supplemental surface plant growth media on hillslopes will occur once hillslopes have been constructed within the applicable geomorphic sideboards or targets in Attachment A and confirming the suitability of regraded spoil in these areas. Replacement of soil or plant growth media on hillslopes may also occur while rough grading activities, associated with permanent conveyance structures (e.g., 1st and 2nd order channels), is in progress. Replacement of salvaged soil, suitable plant growth media, or armoring materials in channels or in the vicinity of permanent conveyance structures will occur once structures conform to the preliminary design criteria (see Attachment C, Reclamation Surface Stabilization Design Process and geomorphic sideboards or targets in Attachment A). Temporary alternate sediment control measures such as check dams will also be employed during the third step. These may be retained as permanent if they have become a stable and effective part of the reclaimed watershed and removal would result in significant disturbance. Mechanical surface treatments including deep ripping and contour furrowing will be conducted after placement of soil or plant growth media.

The fourth major step involves the application of permanent seed mixes and specialty plantings as appropriate. Hay mulch will be applied at two tons per acre and anchored following completion of seeding operations. The detailed revegetation plan is described in Chapter 23, Revegetation.

MAR 2012
APPROVED

The completion of the fourth step marks the beginning of the 10-year liability period, during which PWCC is required to continue monitoring and managing the reclaimed watersheds as appropriate. Management activities include ongoing monitoring of reclaimed CRA's including periodic vegetation surveys, grazing management programs, erosion inspections in accordance with the rill and gully plan, and watershed structure monitoring (e.g., quarterly pond inspections), and items identified during quarterly OSM inspections. One of the main goals of the Surface Stabilization Plan is to construct a stable postmining landform that requires minimal long-term maintenance as practicable. However, PWCC will perform maintenance of reclaimed watershed features during the 10-year liability period or prior to final bond release as required, based on monitoring data collected and both OSM and internal inspections.

The major components of the Surface Stabilization Plan summarized above involve many details and actions that are progressive in nature and inter-related. This facilitates an approach for successful accomplishment of the surface stabilization and reclamation objectives. Many of the major component discussions are presented in terms of BTCA practices related to their inclusion as plan components, reference to appropriate PAP sections that provide the detail for procedures that implement plan components or practices, and adequate detail of a component not presented in other areas of the PAP (e.g., topographic manipulation).

In accordance with the requirements of 30 CFR, Sections 780.18, 780.21(h), 816.41, 816.43, 816.45, 816.95, 816.102, 816.111, and other appropriate sections of the regulations, PWCC implements proven BTCA practices to: 1) establish an effective vegetative cover; 2) minimize sheet erosion as a result of overland flow; 3) minimize uncontrolled rill and gully development; 4) maintain a stable landform; and 5) insure that productivity and postmining land uses are sustained.

The following references are used for design and construction of surface stabilization measures.

1. "Handbook of Alternative Sediment Control Methodologies for Mined Lands", by Mining and Reclamation Council of America and Hess & Fisher Engineers, Inc., March, 1985;

2. "Design of Sediment Control Measures for Small Areas in Surface Coal Mining", by Simons, Li & Associates, Inc., May, 1983.
3. "Surface Mining Water Diversion Design Manual", by Simons, Li & Associates, Inc., OSM/TR-82/2, September, 1982.

In addition, PWCC's engineers and reclamation personnel frequently utilize design procedures, construction techniques, and reclamation practices developed or updated by other organizations such as the U.S. Natural Resource Conservation Service (NRCS), the U.S. Bureau of Reclamation, the U.S. Department of Transportation, the U.S. Army Corps of Engineers, related state agencies, research organizations and universities, and other coal mining and reclamation related organizations. PWCC's operational history on Black Mesa has resulted in the development and implementation of effective BTCA practices which will continue to be used.

The methods and support measures necessary to implement the Surface Stabilization Plan are summarized below with reference to their location in the PAP where appropriate. Primary components of the measures to be used for reclaimed surface stabilization include the use of geomorphic sideboards or targets as described in Attachment A. In addition, PWCC will utilize engineered design and construction techniques for reclamation channels (see Topographic Manipulation section), downdrains and other related grade control structures, and limited use of short segment gradient terraces on slopes in accordance with criteria provided in Attachment A. The short segment terraces will serve as low-gradient first order stream channels that direct flow to the overall reclaimed drainage network of 2nd and higher order stream channels that will be properly designed and constructed. To further aid in the stabilization of reclaimed land, surface mechanical manipulations, mulching, and establishment of permanent cover on reconstructed hill slopes will be used. Attachment B, "Terrace Spacing", details effectiveness of these and other measures in achieving a stable reclaimed landscape.

The following is a summary of the plan components and their location in the PAP.

1. Backfilling and grading as described in Chapter 21.
2. Reclamation scale geomorphology and geomorphic sideboards and targets (Attachment A, Chapter 26).

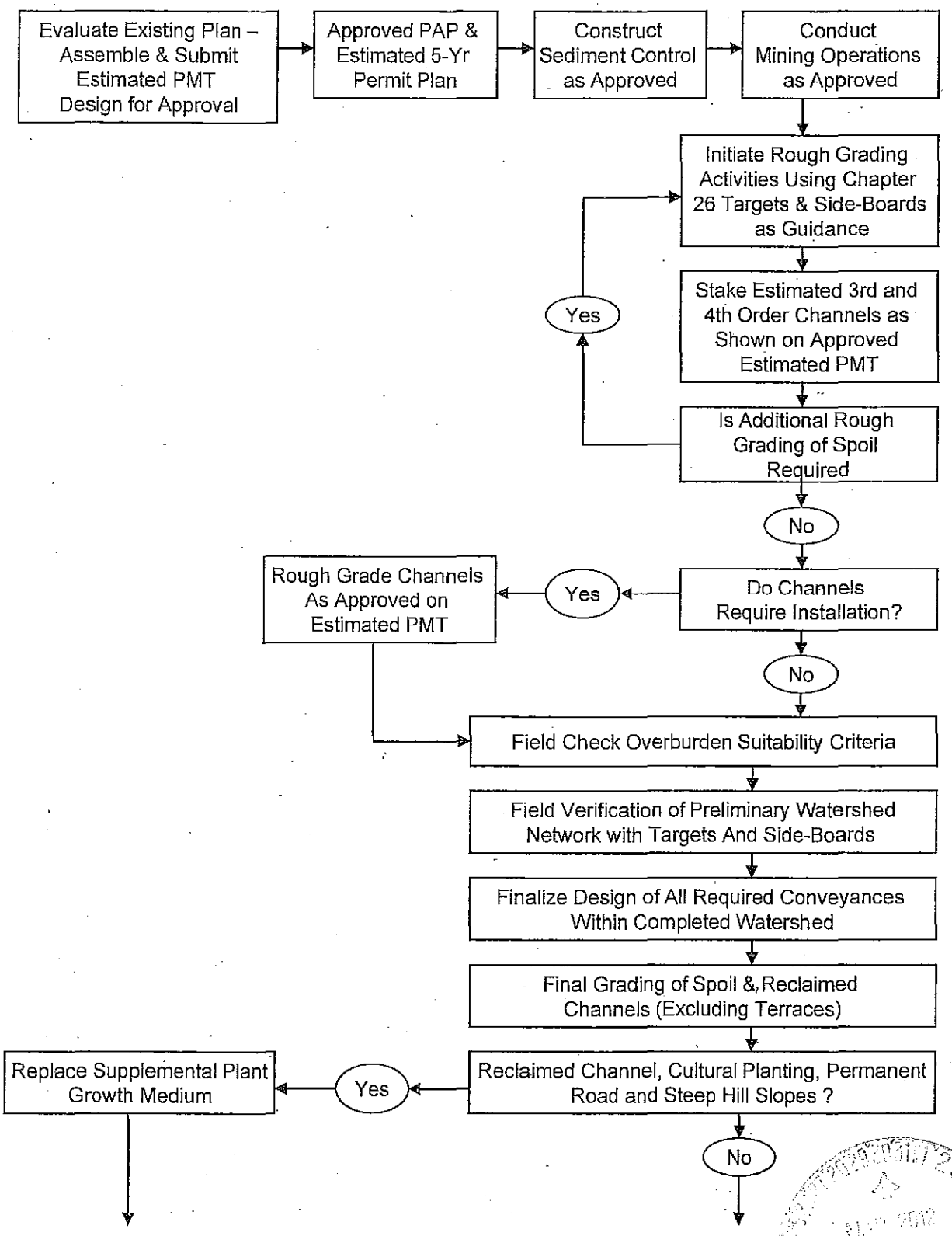
3. Implementation of the spoil suitability sampling plan and mitigation as necessary to insure four feet of suitable plant growth media (Chapter 22).
4. Identification of drainage locations and other conveyance structures (Chapter 26).
5. Design criteria for reclamation drainage structures, grade control structures, and design considerations (Attachments A, B, and C, Chapter 26; submitted SedCad hydrology data with "Exhibit 1 Hydrology Parameters" map)
6. Replacement of soil or supplemental surface plant growth medium except in primary drainages and associated conveyance structures (Chapter 22 and Chapter 26).
7. Location of drainages and other related conveyance features including permanent terraces (Chapters 21 and 26).
8. Deep ripping of all areas except select conveyance structures and design drainages (Chapters 22 and 23).
9. Contour furrowing/disking on all areas except select conveyance structures and designed drainages (Chapters 22 and 23).
10. Seed, plant, or transplant approved seed mixes or planting lists at appropriate periods and mulch with grass hay. Incorporate and anchor hay or straw mulch (Chapters 22 and 23).
11. Monitoring, maintenance, reclaimed land management prior to bond release, and rill and gully plan and conveyance structure implementation as necessary (Chapters 22, 23, and 26).
12. Postmining land use and management following bond release (Chapter 14).

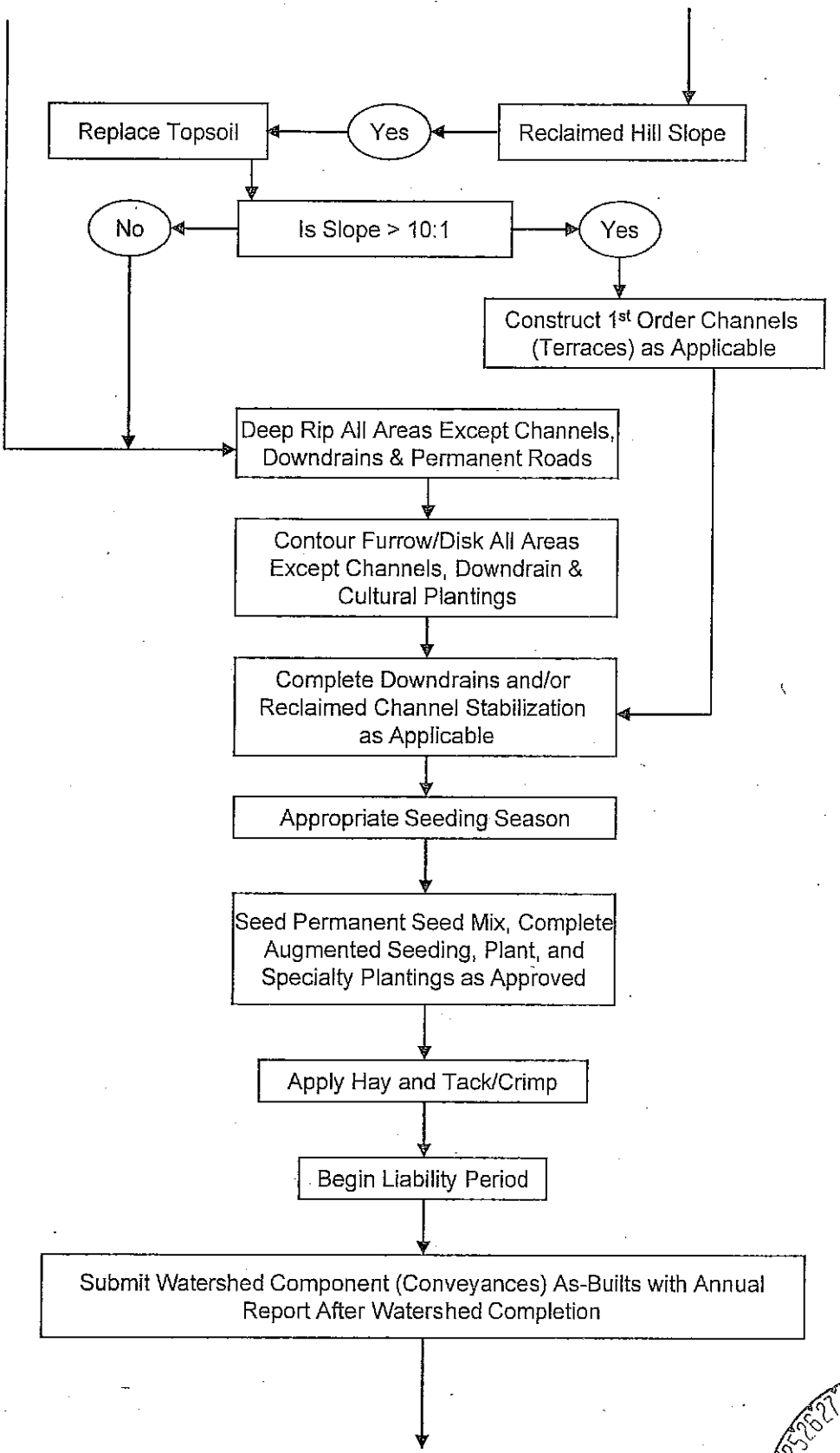
The program discussion presented below should be considered along with Figure 1 "Surface Stabilization Plan Summary", the above referenced chapters in the PAP, the specific sections of the PAP as identified in the individual component and BTCA practice discussions, and Attachments A, B, and C to this chapter.

Implementation of the Surface Stabilization Plan. As mentioned above, the first step in the overall Surface Stabilization Plan process involves developing the PMT and associated preliminary drainage network. Designs for third and fourth order channels are also developed and are submitted to OSM along with the five-year mine plan for any given CR. Upon approval of the PAP and mining disturbance and consistent with submitted water and sediment control plans, sediment control is implemented by construction of required

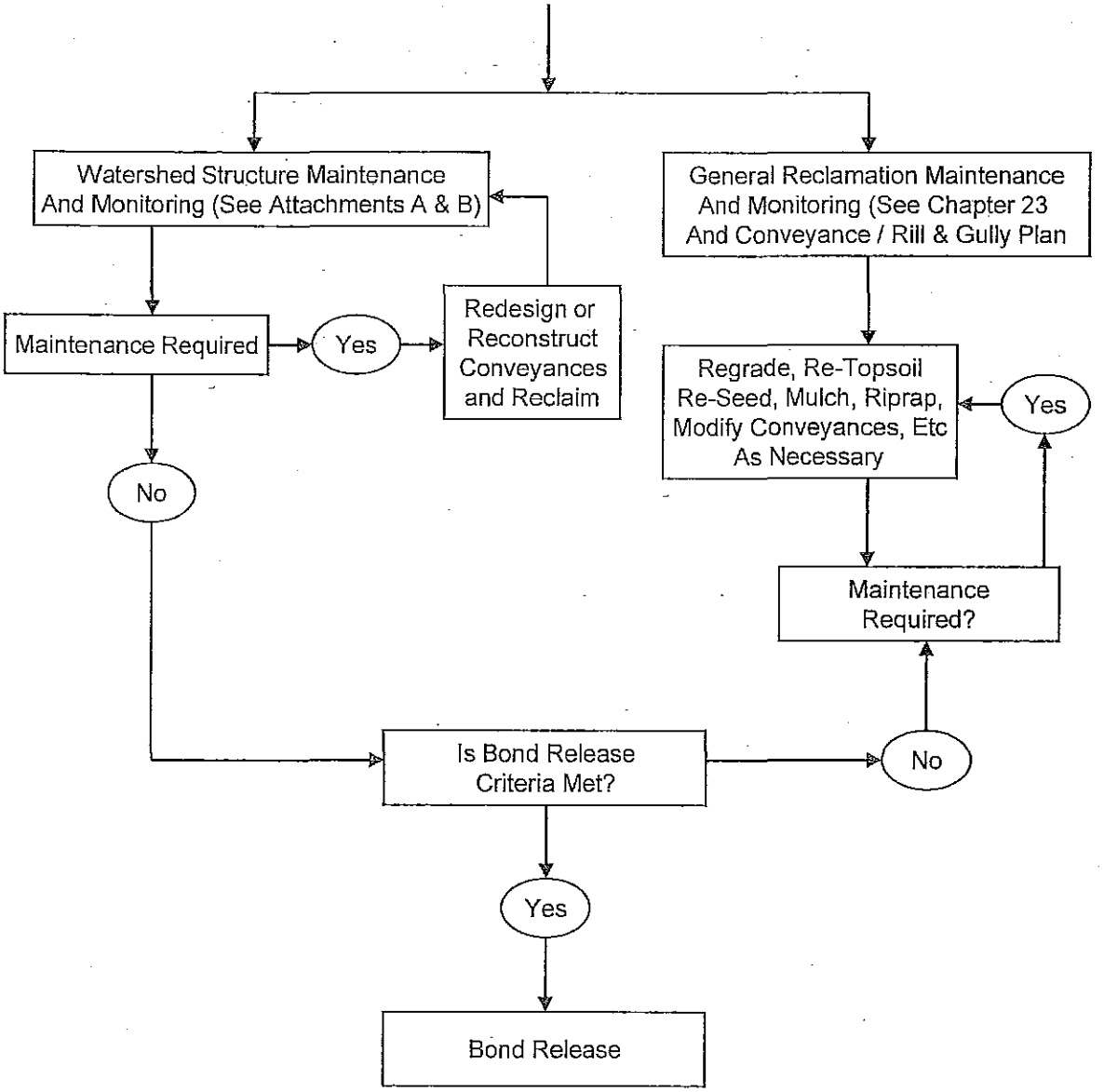
MAR 2012 APPROVED

Figure 1
Surface Stabilization Plan Summary





MAR 2012
APPROVED


Watershed Structure Maintenance And Monitoring (See Attachments A & B)
General Reclamation Maintenance And Monitoring (See Chapter 23 And Conveyance / Rill & Gully Plan
Maintenance Required
Yes
Redesign or Reconstruct Conveyances and Reclaim
Regrade, Re-Topsoil Re-Seed, Mulch, Riprap, Modify Conveyances, Etc As Necessary
Yes
No
Maintenance Required?
Is Bond Release Criteria Met?
No
Yes
Bond Release

facilities or use of other appropriate measures prior to mining or related disturbances. The following describes the Surface Stabilization Plan process and implementation.

Sedimentation Ponds and Alternate Sediment Control Measures. In accordance with 30 CFR 816.45, PWCC will design, construct, and maintain appropriate sediment ponds and other sediment control measures to prevent, to the extent possible, additional contributions of sediment to streamflow or to runoff outside the permit area due to mining activity and to minimize erosion to the extent possible. Sedimentation ponds will be the primary method used to control runoff and additional contributions of sediment from the permit area except for those permitted areas exempted in the regulations. Following reclamation operations, and for a minimum of ten years after the last year of augmented seeding or revegetative efforts during the liability period, PWCC will continue to utilize sediment ponds and alternate sediment control methods individually or in combination to meet the requirements of 30 CFR 816.45.

The location of all existing and proposed sediment ponds can be found in the PAP on Drawing 85405 "Sediment and Water Control Structures Map". All sediment ponds will be maintained until PWCC has regulatory authorization to remove the structure or control measure, or until the applicable regulatory authority approves the structure as a permanent impoundment. A discussion of the purpose and design of the sediment ponds can be found in Chapter 6, "Sedimentation Ponds and Impoundments".

Alternate sediment control measures may be used in conjunction with the sediment ponds or, in the case of the permitted areas which are exempt (e.g., roads), may be utilized individually or in combination to minimize erosion and additional contributions of sediment to streamflow or runoff outside the permitted area. Sediment control measures, singly or in combination, include practices utilized within and adjacent to the mining disturbance areas. Sediment control measures will utilize proper mining and reclamation methods. Sediment control practices may include, but are not limited to the following:

1. Disturbing the smallest practicable area at any one time during the mining and construction operation;
2. Stabilizing graded material to promote a reduction in the rate and volume of runoff;

MAR 2012 APPROVED

3. Retaining sediment within disturbed areas;
4. Diverting runoff away from disturbance areas including stockpiles, backslopes, and material storage;
5. Diverting runoff through disturbed areas using stabilized earth channels, culverts, or pipes to prevent, to the extent possible, additional contributions of sediment outside the permit area;
6. Using straw dikes, silt fences, wattles, small V-ditches, riprap, mulches, check dams, ripping, contour furrowing, vegetative sediment filters, small depressions, sediment traps, and other measures that will reduce overland flow velocity, reduce runoff volume, or trap sediment; and
7. Treating traffic areas with water or dust suppressant to reduce the potential for wind and water erosion.

Upon implementation of the sediment control plan and installation of sediment control measures and facilities, mining operations within that area are conducted as approved in the Mine Plan.

Preliminary Watershed Design. The preliminary watershed design process begins during the permitting process prior to mining operations. The first steps involve development of the PMT. After evaluating the material balance for overburden and the CRA that will be mined, an iterative process will be used to develop a postmining topographic surface and drainage network that incorporates geomorphic features that are within the ranges of the geomorphic sideboards and targets as shown on Table 6.1 in Attachment A, Reclamation Scale Geomorphology (see also Chapter 21, Backfilling and Grading).

Topographic Manipulation. Topographic manipulation is a process of recontouring spoil after coal removal to minimize the potential for soil erosion, establish a stable landform, and develop a drainage network. Utilizing the methods described in Chapter 21 "Backfilling and Grading" and according to the summary presented in Attachment C, an estimated postmining topography (PMT) is developed that approximates the original landform, creates a stable landform, and depicts a preliminary drainage network that conforms to the geomorphic sideboards and targets provided in Attachment A (see Drawing No. 85352). Grading plans will be developed and used to create a PMT and drainage network that mimics the estimated PMT within specified ranges or sideboards (see Main Reclamation Channels section and Attachment A).

The topographic manipulation process begins after the overburden is placed in the spoil piles and coal removal and mining progress several pit widths. The volumes of overburden removed as the mining pit advances can vary appreciably in the multi-seam CRA's at Kayenta Mine due to changes in coal seam lithology. Some seams can be offset by localized faults or pinch out completely, resulting in more or less overburden compared to calculations of overburden to be moved that were based on the mine plan. In addition, this variability in lithology may cause operational changes in dragline and/or truck-shovel usage and pit configurations in order to economically mine the coal while maximizing recovery of the coal resources. Operational changes may include un-anticipated volumes of additional spoil in certain locations as a result of end dumping of parting materials and dead-head routes needed for draglines during mining. Ramp locations may change, or the volume of spoil in the ramps or other locations may increase to accommodate additional spoil encountered due to local and unidentified changing coal seam lithology. As pits progress through the CRA, the resultant configuration of the spoil piles will require some degree of flexibility in grading operations in order to create a drainage network and post-mining topography that approximates the approved estimated PMT and associated preliminary drainage network and comply with the SMCRA requirement to conduct contemporaneous reclamation. PWCC believes developing PMT's and corresponding preliminary drainage networks that are based on the geomorphic sideboards and targets contained in Attachment A, combined with sound grading plans that will result in drainages and overall hillslope configurations that approximate the preliminary drainage network, will result in stable reclaimed watersheds that will require minimal long-term maintenance.

The preliminary drainage network developed as part of the PMT permitting process will be used as a template for developing grading plans and creating drainage patterns and hillslope configurations in the reclaimed watershed. The grading plans will guide the field reclamation crew during the rough grading operation, including general direction of dirt movement. Temporary roadways will be built using bulldozers initially in some locations to provide access into internal spoil piles as needed. Spoil ridges will be shaped using available equipment to form the drainage divides defined by the PMT followed by rough grading to create concave hillslopes that will feature lengths and slopes within geomorphic sideboards provided in Attachment A. The locations and directions of select haulage ramps will be used to construct larger order channels. Following these steps the locations and general configurations of the drainage channels will become more

apparent. Further rough grading of the channels will be conducted to ensure overall concave profiles, desired channel gradients, and blending with upstream and downstream native drainages. Concurrently during rough grading, PWCC will implement the spoil sampling plan (see Chapter 22) where surface elevations are at or near final grade, and perform additional spoil handling and rough grading for mitigation purposes as necessary.

Implementation of the grading plans will involve field checks to determine whether significant deviations from the preliminary drainage network have occurred and their cause. The following are general criteria PWCC will use during the field verification process to ensure the rough grading activities are creating a PMT and associated drainage network similar to those currently approved for the permit:

- Variations in graded PMT will typically be within plus or minus 20 feet (WMA-WLQD, 2003) but may range up to plus or minus 50 feet with supporting PMT flexibility demonstration as justified in the CRA design file and noted in the annual report.
- Hillslope and channel features will be within ranges of corresponding geomorphic sideboards and targets in Attachment A.
- Postmine hillslope gradients for 3:1 and 4:1 landforms will be measured and averaged from the crest to toe. Short segments may be steeper to accommodate landform blending by native areas and reconstructed drainages.

PWCC utilizes field observations, ground surveys, and updated topography based on aerial flights for comparing graded PMT to the approved estimated PMT, and to evaluate whether hillslopes and channel features created during rough grading are within geomorphic sideboards and targets (Attachment A). In addition, field verifications conducted during quarterly and partial OSM inspections will be used to assess the progress of rough grading activities towards achieving the above criteria. Field verifications will be documented during the rough grading process and kept in the associated preliminary design file corresponding to reclamation progress in a CRA. The results for rough grading activities performed during a given year by CRA (such as updated topographic maps, grading plan status, and any noted deviations from the approved PMT) will be included in the Annual Reclamation Status and Monitoring Report by May 31st of the following year.

After field verifications have been completed and the overall configuration of the reclaimed watershed has been found to meet geomorphic sideboards and targets and

approximate the approved PMT, PWCC will begin design work under the supervision of a Registered Professional Engineer in order to develop preliminary designs that will serve as construction specifications for building channels, gradient terraces, downdrains, or other conveyance structures. Information such as reclaimed watershed size, time of concentration, conveyance geometry, and other appropriate site-specific watershed characteristics will be utilized to develop preliminary designs that will in turn guide the construction of lower order channels, permanent short segment terraces (Order 1 channels) and other conveyance structures including selection and placement of channel armoring materials as appropriate.

Grade control structures such as downdrains or drop structures may be required to establish drainages in reclaimed outslope areas, reclaimed areas where steeper slopes occur, and areas where reclamation is blended into the adjacent natural or previously reclaimed topography, to control peak velocities and reduce runoff and erosion. The type and size of these structures will be based on site-specific conditions including watershed size, land use, curve number, peak discharge, topography, and soil conditions. General descriptions of these structures are provided below; however, the physical geometry and location of each structure is too site-specific to be precisely determined and shown on the preliminary drainage network prior to the rough grading process. The location and size of structures (designs) will be determined before building these structures during rough grading of the spoil.

Gradient terraces may be utilized in limited situations to serve as short, first order low-gradient ephemeral stream channels with limitations on length (no greater than 1200 feet) and gradient (between 1.5 and 2.5 percent, see Attachment A). Information regarding the specifications, construction details, and limitations for using terraces are summarized in the subsequent section Gradient Terraces and Swales.

Ephemeral channels that drain reclaimed watershed areas less than 640 acres will be designed for the 10-year, 6-hour precipitation event. Intermittent channels that drain reclaimed watershed areas greater than 640 acres will be designed for the 100-year, 6-hour precipitation event. Details regarding the design specifications and construction details for reclaimed channels are summarized in the subsequent section Main Reclamation Channels.

MAR 2012
APPROVED

A design file for each conveyance structure (including lower order channels) will be maintained at the mine site that contains the preliminary designs including calculations and design criteria used for construction during rough grading. Other designed structures, which might be used in the associated reclaimed watersheds, will also be included in the appropriate file. The design files will also be used by PWCC for performing verification checks during rough grading, and for OSM during quarterly and partial inspections.

After completing rough grading of the sub-watersheds and drainage channels and construction of permanent conveyance structures, the engineer will develop the final as-built design of all conveyances including reclaimed channels regardless of stream order based on updated topography (aerial flights) and the final surveyed configuration of the structures. As-built designs for reclaimed channels and permanent conveyance features constructed during the rough grading operations will be developed under the supervision of a Registered Professional Engineer. The as-built certification for each reclamation watershed or subwatershed completed in a given year will be submitted to OSM in the Annual Reclamation and Status Report by May 31st of the following year.

Permanent Water Conveyance Features. PWCC will design and construct several categories of permanent water conveyance structures in reclaimed watersheds in accordance with this Chapter. These include short segment gradient terraces or swales (1st order channels), reclamation meandering downdrain channels (2nd order channels), main reclamation channels (3rd and 4th order channels), and drop structures where appropriate. The following sections discuss each of these features and reference design and construction details presented in Attachment C and future submittals of the SedCad hydrology data with "Exhibit 1 Hydrology Parameters" map. The use of rock riprap or other suitable materials to serve as armoring of channels and associated conveyance structures is discussed in each subsequent section as appropriate and in more detail in future submittals of the SedCad hydrology data with "Exhibit 1 Hydrology Parameters" map.

Gradient Terraces and Swales. During the rough grading process, upper watershed areas requiring first order drainages, or areas with steep slopes may occur where there is little available spoil materials to create more diverse hillslopes or additional subwatersheds. Steep slope areas include reclaimed box cut spoils, final pit and

highwall reclamation, areas adjacent to ramps, haul roads, and drainages, and areas that blend into adjacent, previously reclaimed lands or natural topography. Permanent short segment gradient terraces or swales will be constructed into upper sub-watersheds and into the steeper regarded spoil slopes during the rough grading process. The permanent gradient terraces or swales will serve as first order, low gradient ephemeral channels to break up slope length, collect runoff, and convey the collected runoff safely off the steeper reclaimed slopes into the reclaimed drainage channel network.

Permanent gradient terraces and swales will not exceed 1200 feet in length, and will feature overall gradients between 1.5 and 2.5 percent in accordance with the geomorphic sideboards for these structures provided in Table 6.1 in Attachment A. The permanent gradient terraces and swales will be designed using the 10-year, 6-hour precipitation event because they will be ephemeral, not exceed 1200 feet in length, and drain areas well under 640 acres. In addition, permanent gradient terraces and swales will be designed to feature minimum freeboard greater than 1.0 feet to minimize overtopping. Permanent gradient terraces and swales will feature either a trapezoidal or parabolic cross section. Design guidelines for terraces are contained in Attachment B, Terrace Spacing. Permanent gradient swales (1st order channels) and terraces will be designed under the direct supervision of a Registered Professional Engineer using procedures discussed in Attachments B and C. These measures insure the short segment gradient terraces and swales will require minimal maintenance and will be as effective and sustainable as natural Order 1 drainages.

Construction of permanent gradient terraces and swales will be limited to topographic areas where average slopes are greater than ten percent. Terraces and swales will be lined with gravel or rock riprap depending on engineering criteria provided in Attachment C, or unlined using suitable soil or spoil materials to minimize erosion and meet the safety factor of 5 feet per second for the design storm.

In summary, gradient terraces and swales will:

a. Serve as low-gradient, first order ephemeral channels;

b. Reduce slope length on steeper portions of reclaimed hillslopes;

c. Control and reduce overland runoff velocities as Order 1 channels in upper sub-watersheds;

d. Convey overland runoff to the reclaimed drainage channel network.

MAR 2012
APPROVED

e. Reduce sediment content in runoff water;

f. Reduce soil loss;

g. Minimize rill and gully development; and

h. Improve water quality;

Reclamation Meandering Downdrain Channels. Reclamation meandering downdrains are erosion-resistant, trapezoidal grade control structures or channels that may be needed to convey concentrated runoff from native or reclaimed upstream contributing areas to aid in minimizing erosion and long-term maintenance. Downdrains of this type are typically constructed using erosion resistant materials such as properly sized gravel or rock riprap. During the rough grading process, there may be locations in the reclaimed area where it is necessary to provide a non-erosive transition from an up-gradient natural channel or an isolated reclaimed sub-watershed into the reclaimed drainage network. In addition, meandering downdrain channels may be required if the reclaimed watershed size is large and steep enough, or the reclaimed area does not have sufficient area to create less steep but longer channel lengths, to cause significant concentrated runoff to the downstream drainage channels, such as the outlets of higher order reclaimed channels. Examples of these situations include but are not limited to exterior reclaimed box-cut slopes, small areas adjacent to a reclaimed ramp, or natural channels up-gradient of the reclaimed drainage network in final highwall areas or areas where the reclaimed landscape blend with the undisturbed native land.

Meandering reclamation downdrains will be erosion-resistant grade control structures which will perform as short reaches of second order ephemeral or intermittent channels in steep portions of reclaimed channels. The use of erosion resistant materials for constructing these downdrains serve to increase the travel time of the runoff, reduce peak runoff and velocities, and minimize erosion in the channel reach. Engineering criteria for selecting the erosion resistant materials for these reclamation downdrains are provided in Attachment A and "Exhibit 1, Hydrology Parameters" map.

Reclamation downdrains will be field located during the rough grading process, and will be based on both site-specific conditions encountered during the rough grading process and preliminary channel designs and calculations of the volume of anticipated peak runoff from contributing watersheds. Downdrains will typically feature bottom widths of approximately 15 feet. Salvaged soil will typically not be replaced along the bottom

width of reclamation downdrains or along both sides of the downdrain alignment extending about 15 feet outward from the channel bottom to minimize loss of soil. Topsoil may be placed up to the channel freeboard limits. Design specifications for reclamation downdrains are presented and discussed in Attachments A and C and "Exhibit 1, Hydrology Parameters" map. Reclamation downdrains will be designed under the direct supervision of a Registered Professional Engineer using procedures discussed in Attachments A and C.

Main Reclamation Channels. Drainage channels of varying stream orders will be utilized to convey runoff from reclaimed watersheds constructed in the postmining landscape. As mentioned previously in this chapter, a preliminary drainage network is developed in conjunction with creating the estimated PMT during the permitting process. As hillslopes and drainage divides become more developed during the rough grading process, the locations of the channels and overall layout of the drainage network become more apparent. Table 6.1 in Attachment A presents ranges of geomorphic sideboards and targets for reclaimed channels (channel gradient and sinuousity) and drainage networks (drainage density). Third and fourth-order channel designs submitted during the permitting process will feature gradients between 0.5 and 6.0 percent. Overall drainage densities for these higher order channels will be between 80 and 120 feet per acre, and channel sinuousity for third and fourth order channels will range between 1.06 and 1.15.

Preliminary designs for first and second-order channels constructed during the rough grading process will feature gradients of 1.5 to 7.5 percent and minimal channel sinuosity (1.00 - 1.08) as specified in the geomorphic sideboards and targets for stream orders 1 and 2 as provided in Attachment A. The drainage network of lower order channels may include permanent, short segment terraces and swales as first order channels and meandering downdrain channels as second order channels; and will feature drainage densities within the range of 80 and 120 feet per acre as per the geomorphic sideboards provided in Attachment A.

Preliminary designs for first and second order channels will be developed after field verifications have been performed to confirm graded topographies approximate the estimated PMT and channel gradients, sinuosity and drainage densities conform to geomorphic sideboards and targets. Preliminary designs shown on "Exhibit 1, Hydrology Parameters" map for all reclamation channels regardless of stream order will serve as an

MAR 2012
APPROVED

estimated construction specification for building channels, and will be completed under the direct supervision of a Registered Professional Engineer using procedures discussed in Attachments A and C.

Ephemeral channels that drain reclaimed watershed areas less than 640 acres will be designed for the 10-year, 6-hour precipitation event. Intermittent channels that drain reclaimed watershed areas greater than 640 acres will be designed for the 100-year, 6-hour precipitation event. Preliminary designs will take into account site-specific information such as overall drainage area and target an overall concave channel slope. Designs will be developed using required design inputs such as curve number, free board requirements (minimum of 1.0 feet), time of concentration, etc. as detailed in Attachment C and submitted SedCad hydrology data with "Exhibit 1, Hydrology Parameters" map. Designs will also provide sound criteria regarding the selection of the appropriate channel armoring materials.

A design file for each reclamation channel will be maintained at the mine site that contains the preliminary designs including calculations and design criteria used for constructing these channels during rough grading. The design files will also be used by PWCC for performing verification checks during rough grading and for OSM during quarterly and partial inspections.

Four feet of suitable plant growth spoil material or other channel armoring materials based on design considerations will be placed in the drainage channel. Fifteen feet on each side of the designed reclaimed channel bottom will typically not be soiled to allow for containment of the high flows and to confine any low meandering flow within the channel area and away from the soiled and revegetated areas. Occasionally, topsoil may be replaced up to the designed channel freeboard limits. Revegetation of this additional 30-foot width will allow vegetation establishment within the channel as it develops its characteristics.

After completing rough grading of drainage channels, the engineer will develop the final as-built design of all conveyances including reclaimed channels regardless of stream order and main downdrains based on updated topography (aerial flights) and the final surveyed configuration of the structures. As-built designs for reclaimed channels and

other permanent conveyance features constructed during the rough grading operations will be developed under the supervision of a Registered Professional Engineer using procedures provided in Attachment C.

The "Estimated Postmine Topography Map" (PMT) will be used as a guideline for the PMT field grading control along with Attachments A, B, and C. Topographical grading and channel locations may vary from the PMT, but will follow Attachment A side-boards for design criteria. Topographical grading and channel locations will follow the estimated PMT and general design location for direction and size. Field adjustments of the PMT in the field due to changes in mine plans, grading equipment, and surface conditions give the operator flexibility in completing the Geomorphic reclamation area to standards in Attachment A.

Drop Structures. A drop structure is a relatively small riprap-lined structure (as compared to a reclamation downdrain) such as gabions or a structure built over an erosion-resistant rock ledge which outcrops in the channel and acts as a grade control structure. Erosion-resistant stilling basins are constructed at the drop structure outlet. Where large quantities of spoil are required to reduce the overall profile of the channel slope, drop structures will be used to minimize excavation costs and additional disturbance. PWCC's use of drop structures will be limited to upland portions of reclaimed areas where upstream native channels must be tied into reclaimed channels, or other limited locations in internal regraded spoils as needed.

Preliminary designs for drop structures developed after field verifications have been performed will serve as construction specifications for building drop structures, and will be completed under the direct supervision of a Registered Professional Engineer using procedures discussed in Attachments A and C and the submitted SedCad hydrology data with "Exhibit 1, Hydrology Parameters" map.

Temporary Features Used in Support of Topographic Manipulation and Conveyance Structures. Additional features used in conjunction with diversions and overland conveyances that are considered temporary include check dams, gabions, wattles, erosion-resistant liners, sediment traps, and water level spreaders. These structures are designed and constructed for grade stabilization and diversion outlet control, or solely constructed for the

MAR 2012 APPROVED

Purpose of trapping sediment. These applications are discussed in subsequent sections of this chapter, in Attachment C, and submitted SedCad hydrology data with "Exhibit 1, Hydrology Parameters" map.

Check Dams and Erosion-Resistant Liners. A check dam is a low-head structure constructed across a channel to stabilize the grade or to control head cutting in constructed channels. Check dams are used to reduce or prevent excessive erosion by reducing velocities in diversions, conveyances, and sedimentation pond inlets or by providing partially-lined channel sections or structures that can withstand high flow velocities. Check dams are used where the capability of earth and/or vegetative measures is exceeded in the safe handling of water at permissible velocities or in sections with excessive grade. An erosion-resistant liner is a surface protection measure provided in critical portions of the channel to control excessive erosion that may include gravel or rock riprap.

Sediment Traps. A sediment trap is a small storage or detention area without special inlet and outlet controls or specific side slopes. Sediment traps are typically constructed by excavation, or by creating an impoundment with logs, riprap, silt fence, or brush barrier/filter fabric as a low head dam. This measure is not considered by PWCC as a long term feature of the postmining landscape, but a temporary measure for specialized applications such as control of sediment in roadway ditches or immediate remedial control of areas contributing temporary excessive sediment yield.

In conclusion, the adherence to geomorphic sideboards and targets and development of preliminary designs and construction of reclamation channels and related conveyance structures during the rough grading process will promote the development of stable drainage networks that require minimal long-term maintenance. Following rough grading and construction of the reclaimed channels and other conveyances, minesoil reconstruction activities, finish grading, and surface mechanical manipulations will begin.

Minesoil Reconstruction. PWCC's minesoil reconstruction plan (Chapter 22) is designed to insure that four feet of suitable plant growth medium is reconstructed on reclaimed lands prior to revegetation. Specifications in the plan insure that suitable plant growth materials are identified and properly handled, and that physically and/or chemically unsuitable graded spoils are buried to a minimum depth of four feet. The four feet of

material is comprised of a combination of spoil and surface soil or of spoil and suitable soil substitutes such as scoria. The plan provides flexibility in using erosionally resistant and suitable plant growth materials on areas where the erosion potential is the greatest, that is, supplemental surface plant growth materials or residual soils with low "K" factors placed on the steepest reclaimed slopes. An example is the stable reclaimed outslope in the N11 area. Prior to or upon completion of minesoil reconstruction activities, appropriate surface mechanical treatments and revegetation measures are implemented:

Surface Mechanical Treatments. Surface mechanical treatments are conducted both prior to and after minesoil reconstruction activities and are critical to insuring surface stabilization and plant establishment are maximized and erosion is minimized. Surface mechanical treatment (ripping) may be conducted both prior to and after soil replacement of suitable spoil. The primary surface mechanical treatments are deep ripping, contour furrowing/disking, and drill seeding on the contour. Other types of mechanical manipulation that may be used include chisel plowing and slope or dozer tracking. Dozer tracking, imprinting, and pitting all create surface roughness features that reduce runoff, improve infiltration, and provide additional opportunities for seedling establishment.

Ripping of graded spoil and replaced soil is conducted with dozers equipped with multiple shanks and road graders with ripper teeth. A chisel plow may be used to achieve similar results on reclaimed lands. Soil ripping is conducted on the contour. Ripping reduces compaction, increases infiltration and soil moisture penetration, and improves plant rooting while reducing erosion potential. The reduced erosion potential and benefits to plant performance enhance both short and long term landform stability. The large modified offset disk used in contour furrowing/disking operations for seedbed preparation creates large furrows up to 15 inches deep and approximately three feet apart and has proven effective in initial and long term surface stabilization. All soiled areas are treated using this disk and operations are strictly performed on the contour.

These BTCA practices benefit initial surface stabilization and establishment of effective vegetation that provides long term surface stability as demonstrated by vegetation monitoring, successful termination of jurisdiction (TOJ) on initial program lands, and Phase II bond release on permanent program lands.

MAR 2012
APPROVED

Rock riprap is used for a variety of general and specialty applications, including downdrain construction and the armoring of drainage and reclaimed stream channels where necessary or in support of design specifications. It will also be used in the repair of rill and gully areas where it has been determined to be a more sustainable long term stabilization measure. Important criteria for the proper application of this practice include selection of competent and durable materials, proper sizing of the rock materials based on their characteristics and the application, and proper site preparation and placement of the rock.

Organic or geotextile materials may be used where needed to provide surface protection or enhance the performance of physical structures such as downdrains or rock riprap. These materials are used in concentrated flow areas, situations where intensive erosion control measures are required, or to maintain soil foundation conditions of structures. Organic materials include jute fiber matting or wood or grain straw combined with netting. Geotextile fabrics include synthetic woven fabrics used under rock riprap or downdrains and open weave netting for surface stabilization. Geotextiles also include open cell materials of variable size opening that can be anchored, filled with soil, gravel, or rock and then seeded. Where surface netting is used, the areas are seeded prior to netting placement.

Following completion of soil replacement, surface mechanical treatments, and seedbed preparation, revegetation activities are conducted to establish an effective and permanent vegetation cover.

Establishment of Effective and Permanent Vegetation Cover. The use of temporary stabilizing cover and establishment of a permanent vegetative cover insure the reclaimed landscape is protected from erosion and attains a stable and sustainable surface configuration. Permanently reclaimed areas are seeded with a predominantly native seed mix demonstrated to establish an effective, diverse, and permanent vegetative cover adapted to the regional climatic conditions. The seeding of annual grains or temporary perennial seed mixes will provide similar protection to temporarily reclaimed areas. The permanent vegetative cover has been demonstrated to be a key component in the long term surface stability of the reclaimed landscape (RCE, 1993). This is supported by extensive vegetation monitoring, RUSLE calculations (see Attachment B), successful termination of jurisdiction (TOJ), Phase II bond release, and the sustainable grazing management program

implemented on reclaimed lands. Chapter 23, Revegetation Plan, provides a detailed plan and discussion on revegetation BTCA practices and procedures developed for and adapted to local environmental conditions.

The Rangeland seed mix is the primary mix used at Kayenta Mine and contains a high percentage of grasses (approximately 65 percent of the composition) including short and mid grasses and sod-formers. Species in this seed mix provide effective ground cover and structural diversity to dissipate flow energies from overland flow, remove or filter sediment, increase infiltration, and reduce rainfall energy. The forbs and shrubs included in the mix provide benefits in the mid to tall vegetation category dissipating more rainfall energy and providing added resistance to overland flows, especially in drainages.

Increased vegetation growth, vigor, and stand diversity in reclaimed drainages due to the availability of supplemental moisture improves the effectiveness of the established vegetation. Areas have been planted to shrubland, pinyon-juniper habitat, or cultural plants to enhance overall wildlife habitat and community diversity. Most of these sites have been established on scoria (red rock) substrates providing enhanced surface stability.

Temporary stabilization will be achieved through the use of annual cover crops or the Temporary Stabilization mix presented in Chapter 23, Appendix B. This mix contains a selection of quick establishing perennial grasses that provide similar stabilization benefits as the Rangeland mix. The Temporary Stabilization mix is to be used on selected areas that have not been permanently reclaimed but require a more permanent vegetative cover. For areas requiring a protective cover for less than two years, a cover crop of annual grain will be seeded.

Surface Protection Measures. Surface protection measures include hay or straw mulch, organic fiber and geotextile fabric matting or netting, and surface soil substitutes with high coarse fragment content. Surface protection measures reduce raindrop impact and erosive overland flow velocities. The surface protection measures enhance the establishment, development, and sustainability of the vegetative cover. These measures are used in both temporary and permanent surface stabilization.

MAR 2012 APPROVED

Hay mulching is conducted as soon as practicable following permanent seeding activities. Hay is superior for mulching permanent reclamation areas because of its ability to be evenly spread, effectively anchored, benefits to seed mix germination and establishment (enhanced soil moisture and wind protection), its longer decomposition period, and good hydrologic cover value. Straw mulching is used for stabilizing temporary reclamation areas and is also applied immediately after seeding operations. The application rate for hay and straw mulch is two tons per acre and anchored. Mulching provides effective initial surface stabilization and protection while the permanent vegetative cover establishes. Mulching is used on all reclaimed areas. When combined with surface mechanical treatments that provide contouring and surface roughness benefits, highly effective surface stabilization is achieved. The detailed mulching plan (Mulching and Other Soil Stabilization Practices) is presented in Chapter 23, Revegetation Plan.

The revegetation plan has been dynamic through continued modifications and significant program improvements since 1986. More than 30 years of vegetation monitoring plus vegetation sampling to support evaluations for termination of jurisdiction (TOJ) on initial program lands, bond release on permanent program lands, and terrace spacing justifications have demonstrated the combined effectiveness of surface mechanical treatments, revegetation, and surface protection measures in establishing an effective and sustainable hydrologic cover. The EASI (Erosion And Sediment Impacts) (Water Engineering & Technology, 1990, Zevenbergen et al. 1990) model was calibrated for conditions at the Kayenta Complex. EASI combines a rainfall-runoff model with erosion and sediment transport calculations to determine erosion rates and sediment yield from a basin. The model computes runoff and erosion on hillslopes and in the receiving channels and conveys this sediment through the channel network. Hydrologic cover, predominated by vegetation and litter, is the most sensitive factor in the model and results have demonstrated the effectiveness of the reclaimed area cover. The type and level of established vegetation in reclaimed areas provides a strong and positive influence on the model results for the reclaimed watersheds. The "Terrace Spacing Justification" (Appendix B) further demonstrates through Revised Universal Soil Loss Equation (RUSLE 2003) evaluations the effectiveness of the reclaimed area vegetation in maintaining long term surface stability and significantly reducing erosion.

Proper management of the reclaimed lands following implementation of the postmining land

uses will maintain an effective vegetative cover and the longevity of supporting BTCA practices. The primary postmine land use for reclaimed lands at the Kayenta Complex is grazing. Since 1998, PWCC has implemented an annual managed grazing program on reclaimed lands using proper grazing management principles and rotational grazing systems. The grazing program serves several purposes related to the goal of surface stabilization. First, it demonstrates achievement of the postmine land use and utility to local land users. Second, it demonstrates sustainability of the vegetation and hence the long term effectiveness in maintaining a stable landform. Third, it provides stand maintenance for continued health and vigor of the vegetation for ongoing sustainability. The grazing program results are documented in Reclamation Status and Monitoring Reports submitted to OSM annually.

Either before or following completion of revegetation activities, linear detention or filtering structures may be installed. A short list of the major types of structures and their application is detailed below.

Linear Detention and Filtering Structures. Linear detention and filtering structures are used to temporarily stabilize certain reclaimed areas during vegetation establishment, provide sediment control for small or localized disturbance areas, and as aids in rill and gully repair and maintenance activities. These structures may be used to satisfy a short term requirement (e.g., attenuate flows on slopes during permanent vegetation establishment) or they may serve a longer term function (e.g., alternate sediment control). However, these structures are not considered permanent landscape features and are oriented towards complimenting other practices. These structures generally lend themselves best to treatment of smaller or more localized sites.

Linear detention and filtering structures include silt or filter fence, straw bale barriers, straw wattles, brush barriers, etc. These structures are temporary sediment barriers consisting of synthetic filter fabric or as brush or straw bales placed along the contour of a slope. A filter fence is a linear filter barrier constructed of synthetic filter fabric, posts, and, depending on the strength of the fabric used, wire fence. Straw wattles come in various lengths and are generally constructed of straw contained in a tube of plastic netting. They are used as temporary measures to reduce slope lengths and flows during vegetation establishment. They are placed perpendicular

MAR 2012
APPROVED

to the slope angle or channel. Brush barriers are linear filter barriers which makes use of residue materials available from clearing and grubbing operations. Trenching and anchoring of the brush may be required for effectiveness. A straw bale barrier consists of a row of entrenched and anchored straw bales. The structures are constructed on the contour perpendicular to the direction of surface water flow. Filter structures can be easily combined with other sediment control practices to form a complete alternate sediment control system or they may provide sediment control for a localized area.

Maintenance, Management, and Postmining Land Use. Management and implementation of the postmining land uses on reclaimed lands prior to bond release are oriented towards remedial revegetation activities, maintenance of revegetated areas, activities related to stand development or specialized planting areas, and protection and management of reclaimed areas (fencing). Maintenance and management of reclaimed areas is discussed in detail in Chapter 23 "Revegetation Plan".

Prior to and after release of reclamation liability, the postmining land uses are implemented. The primary postmining land uses for Kayenta Mine are livestock grazng, wildlife habitat, and cultural plant use. The most intensive and extensive use is livestock grazing. Under proper livestock grazing management, erosional and landform stability will not be compromised because of the sustainability of the resource. Grazing management has been approved by the regulatory authorities for a number of the reclaimed lands at the Kayenta Complex and has been implemented annually at increasing levels since 1998. Rotational grazing systems combined with proper use management levels has both sustained and improved revegetated area stand characteristics. It has demonstrated the feasibility and success of implementing the grazing postmine land use. The hydrologic cover afforded by the revegetated areas is key to the stability of the reclaimed landforms as demonstrated by previously mentioned reclaimed area modeling, monitoring, and evaluation procedures. Monitoring has demonstrated continued stand performance of the areas under livestock grazing management and demonstrates reclaimed area sustainability and utility for landform stability.

Fencing will be used to protect developing reclaimed areas. Livestock utilization and management and the continued sustainability of the resource is enhanced by fencing and water. Any fencing installed for management of reclaimed lands and which is compatible

with the grazing plan, will be retained. The distribution and number of watering sources on the postmine landscape will be enhanced from what existed prior to mining. The reader is directed to Chapter 6 and Chapter 14 for a detailed discussion of postmine water sources. A deferred rotation grazing system, as recommended and implemented, will insure proper use of forage plants and allow for periodic rest of pastures during the growing season. Thus, with basic plant physiological needs periodically met, the plant communities are better able to sustain an effective vegetative cover while providing valuable forage resources for livestock and wildlife. This in turn has and will continue to maintain long term stability of the reclaimed landscape.

Jurisdictional Applicability

On January 29, 1982, OSM issued interim program Permit AZ-0001 for the Black Mesa and Kayenta Mining areas; on December 21, 1984, OSM issued permanent program Permit AZ-0002A for the J-21 mining area; and on July 6, 1990, OSM issued permanent program Permit AZ-0001C (renewed as Permit AZ-0001D on July 6, 1995, 2000, 2005, and Permit AZ-0001E on July 6, 2010) for Kayenta Mine. All mining and related reclamation after July 6, 1990 will be implemented in accordance with the approved Permanent Program Permit and applicable regulations.

This PAP contains specific requirements for a surface stabilization plan including designed terraces and downdrains, which is not required in the pre-law, in the pre-interim permit, in the AZ-0001 permit, and in a portion of the AZ-0002A PAP areas. (Lands in the AZ-0002A PAP area that do have specific requirements for terraces, downdrains, etc., are those included in the revision approvals dated February 9, 1989 (J-21 Disturbance Line Revision) and June 26, 1989 (J-21 Incidental Boundary Revision)). The Jurisdictional Permit Map, Drawing 85360, shows where these and other jurisdictional boundaries are located.

In some locations, subwatersheds will contain multi-jurisdictional lands. The design engineer and reclamation manager will determine the best method to safely convey the runoff onto or from the AZ-0001D, AZ-0001E and portions of the AZ-0002A permanent program lands across other jurisdictional lands. New conveyance structures will be designed in accordance with accepted engineering practices and design requirements in the surface

stabilization plan provided herein. Upon completion of the preliminary watershed design process and rough grading plan, rough grading operations and topographic manipulation activities will be undertaken.

Rill and Gully Plan

The following discussion centers on the identification of rills and gullies and a remediation plan to insure that landform stability, postmining land use, and water quality are not adversely affected. The watershed structure design criteria presented in Attachments A and C to this chapter and the submitted SedCad hydrology data with "Exhibit 1, Hydrology Parameters" map compliment the rill and gully plan presented here and should be reviewed simultaneously with this plan. Together they will insure that a complete effort will be undertaken to prevent, identify, and mitigate any rill and gully development.

Reclaimed areas will be monitored for rill and gully development during routine engineering, environmental, and reclamation inspections; annual revegetation monitoring; and/or the formal annual rill and gully survey during the spring/early summer season. Emphasis will be placed on periods following heavy snowmelt or rains and areas with greater erosion susceptibility (i.e. greater slope gradients). If rills or gullies are identified, the size, extent and cause of their formation will be determined and documented. These will, in turn, provide the basis for deciding whether or not remedial actions are required, and if so, choosing the necessary remedial activities. In this regard, it is important to note the presence of rills and gullies is not necessarily an indication active or significant erosion is occurring and landform stability is compromised within a specific area, but may be the result of natural extremes in the operational environment of the region.

Rills and gullies which form in areas which have been regraded and soiled or revegetated and which either (1) affect establishment of the vegetative cover, or (2) disrupt achievement of the approved postmining land use, or (3) cause or contribute to a violation of water quality standards, will be filled, regraded, or otherwise stabilized with soil or suitable soil substitutes will be replaced and the areas will be reseeded or replanted. A larger remediation area may be required as determined by the source or contributing area to the rills or gully formation area.

The locations of rill and gully areas, a description of each feature, the type and extent of remedial action taken, and monitoring related to the remedial action will be documented in the annual files maintained at the Kayenta Complex and the Annual Survey of Rills and Gully Survey Report. The aforementioned report will be submitted annually to OSMRE by May 31 each year as part of the Reclamation Status and Monitoring Report.

The cause of rill and gully erosion outside of designed drainageways, when such cause has been determined to be persistent and likely to contribute to continued erosion, will be remedied. Examples of rills or gullies where the cause may not be detrimental and, therefore, not need to be addressed include minor rills in newly planted areas caused by rainfall or snowmelt but not detrimental to the establishment of vegetation.

Rills and gullies for which the cause has been remedied are not required to be repaired if (1) such repair would be detrimental to the overall reclamation effort in the areas where they have occurred, (2) they are no longer active after the cause has been remedied, (3) they will not interfere with the establishment of vegetation and water quality bond release standards, and (4) they are judged stable upon field investigations according to the following criteria:

(a) Rounding of channel sides;

(b) Discontinuance of channel expansion or extension;

(c) Extensive permanent establishment of vegetation on the sides and bottom of the channel;

(d) Lack of unanchored clumps of soil and vegetation that have fallen from channel sides;

(e) Discontinuance of down channel deposition of eroded materials;

(f) Establishment of a permanent vegetative cover on areas of erosional deposition;

(g) Accumulation of litter and organic matter in the channel.

Sediment Control Plan

30 CFR 816.45 requires that sediment control measures, including sediment ponds as best technology currently available (BTCA), be designed, constructed, and maintained to meet the more stringent of applicable state or federal effluent limitations. Consequently, PWCC obtained National Pollutant Discharge Elimination System (NPDES) Permit NN0022179

from the U.S. Environmental Protection Agency (USEPA). As part of the wastewater permitting process, USEPA assigned discharge monitoring locations or outfalls that coincide with the spillways at temporary sediment ponds constructed at the Kayenta Complex where effluent must meet water quality criteria.

The effluent limitations at 40 CFR Part 434 for Subpart H, Western Alkaline Coal Mining are applicable to alkaline drainage from reclaimed areas at Western coal mining operations, including permitted outfalls at the Kayenta Complex that have eligible reclaimed areas. The portions of the watersheds that were mined above several temporary ponds have been regraded to achieve an acceptable postmining topography. These regraded areas have been soiled using suitable salvaged soil in accordance with the requirements in Chapter 22, Minesoil Reconstruction or the initial regulatory program. These areas have also been seeded with a permanent seed mix as required in Chapter 23, Revegetation Plan or the initial regulatory program and have an established vegetative cover at least two years old.

Attachment D contains the Sediment Control Plan (Plan) for eligible outfalls (temporary or proposed permanent sediment ponds) in NPDES Permit No. NN0022179. The plan includes descriptions of the best management practices (BMP's) PWCC has implemented above the ponds to control sediment and erosion, and to minimize disturbance to the prevailing hydrologic balance. The plan also summarizes design and construction specifications for BMP's, inspection criteria, and maintenance schedules.

Sediment yield demonstrations were conducted using the EASI computer model (Zevenbergen et al. 1990; WET 1990). This model was calibrated using site-specific data collected at the Black Mesa Complex over an eight-year period (RCE, 1993). EASI has been used to predict mean annual runoff and sediment yield from several large areas that were reclaimed under both the initial and permanent regulatory programs. These predictions have been reviewed and approved by OSMRE and other agencies in support of applications for Termination of Jurisdiction (N1/N2 and N7/N8 initial program areas), and in support of approved Phase II performance bond release applications (J19, J21, and N14 permanent program reclamation) at the Kayenta Complex.

Results of the modeling demonstrations for each temporary sediment pond are provided in

separate modeling reports in the Appendices to the Plan. Each appendix also includes a 1"=400' scale map that shows outfall locations, current topography of the entire watershed, affected lands boundary within each pond's watershed, and the BMP's installed in each watershed above each outfall in order to control sediment. The modeling demonstrations show that average annual sediment yields predicted at each outfall location taking into account the postmining, or reclaimed mine-land conditions within the watershed are less than or equal to the average annual sediment yields for the premining, or undisturbed conditions. Average annual sediment yields are provided in each modeling report as tons/acre/yr, which are normalized values that account for differences between premining and postmining acreages and topography. The sediment yield data shows that the BMP's utilized by PWCC at the Kayenta Complex are effective in minimizing erosion and sediment loads from reclaimed minelands, and ultimately, protecting the prevailing hydrologic balance.

Literature Cited

Mining and Reclamation Council of America and Hess & Fisher Engineers, Inc. Handbook of Alternative Sediment Control Methodologies for Mined Lands. March, 1985.

Resource Consultants & Engineers, Inc. (RCE). 1993. Surface Water Modeling of Reclaimed Parcels at the Kayenta Complex, prepared for Peabody Western Coal Company.

Simons, Li & Associates, Inc. Design of Sediment Control Measures for Small Areas in Surface Coal Mining. May, 1983.

Simons, Li & Associates, Inc. Surface Mining Water Diversion Design Manual. OSM/TR-8212, September, 1982.

Water Engineering & Technology, Inc. (WET). 1990. Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control Technology at Surface Mines in the Semiarid West, prepared for Office of Surface Mining and the National Coal Association, Fort Collins, Colorado.

Wyoming Mining Association and Wyoming Land Quality Department (WMA-WLQD). 2003. Performance Measures for PMT Flexibility, July 8, 2003 Draft memorandum - Post Mine Topography Working Group, 5 p.

Zevenbergen, L.W., M.R. Peterson, and C.C. Watson. 1990. Computer simulation of watershed runoff and sedimentation processes. Proceedings of the Billings Symposium: Planning, Rehabilitation and Treatment of Disturbed Lands.

ATTACHMENT A

RECLAMATION SCALE GEOMORPHOLOGY

MAR 2012
APPROVED

Attachment A

Reclamation Scale Geomorphology
Peabody Western Coal Company
Kayenta Complex

1.0 Introduction

This document provides information on Peabody Western Coal Company's (PWCC) – Kayenta Complex geomorphic reclamation activities. These activities focus on applying Best Technology Currently Available (BTCA) and designing structures that are intended to be stable and control erosion on a landscape-wide basis. Premine (background, or unmined) and postmine (reclaimed) runoff, sediment transport, and sediment yields are measured, analyzed, and compared. PWCC activities also include application of effective seed mixes and the most current revegetation BTCA practices (see Chapters 23 and 26), and the use of scoria and rocky substrates to stabilize watersheds, control erosion, and support the approved postmine land use.

In the following section (Section 2.0), the concept of geomorphic reclamation is characterized and discussed in the context of the Office of Surface Mining Reclamation and Enforcement (OSM) performance standards for reclamation and Recommended Geomorphic Reclamation Guidance (OSM, 2010). Section 3.0 includes data from PWCC's stream gages and small watershed study to compare pre- and postmine runoff and sediment transport. These data show sediment transport is capacity limited at the Kayenta Complex for pre- and postmine conditions. Section 4.0 provides data on the geomorphic characteristics of a premine basin at the Kayenta Complex. The primary goal of reclamation is to provide a functional and stable landscape within the context of OSM performance standards. Section 5.0 provides a discussion of the select use and characteristics of gradient terraces specific to the Kayenta Complex. Section 6.0 provides a summary of this attachment and conclusions that can be drawn from it. Section 7.0 presents references used for preparing this document.

2.0 Background

OSM's Western Region has provided PWCC's – Kayenta Complex with guidance on recommended geomorphic reclamation practices. OSM defines geomorphic reclamation as "reclamation practices that provide stable, natural functioning postmining surfaces with designed structures that do not require ongoing maintenance. OSM recognizes geomorphic reclamation as a BTCA and states geomorphic reclamation can minimize erosion, stabilize postmine land surfaces, enhance vegetation diversity, typically require less long-term maintenance, and support the approved postmining land use.

There are a number of performance standards relative to surface mine reclamation that deal with the function of the postmine landscape and appurtenant structures. In summary, these standards include minimizing or controlling erosion, providing landform and structure stability, preventing additional contributions of suspended solids, minimizing disturbance and preventing material damage of the hydrologic balance, restoring aquatic habitat, providing riparian vegetation, and supporting an approved postmine land use.

MAR 2012
APPROVED

PWCC's reclamation practices are designed to satisfy performance standards and are aided by the application of geomorphic reclamation methods. PWCC recognizes the importance of minimizing disturbances to the sediment balance and managing impacts to receiving streams. PWCC has collected extensive data to assess the erosional and hydrologic balance of the premine landscape at the Kayenta Complex. PWCC also analyzes the pre- and postmine sediment yield of areas to be mined and reclaimed to determine potential impacts of erosion. Additionally, PWCC continues to improve its seed mixes, revegetation plans, and BTCA practices in order to manage erosion and to support the postmine land use.

3.0 Discharge and Sediment Transport from Pre- and Postmine Conditions

PWCC has monitored discharge and sediment transport on the main channels, principal tributaries, and small watersheds within the leasehold. **Figures 3.1** and **3.2** show sediment discharge and sediment concentration versus discharge that were measured for unmined and reclaimed conditions.

The diamond symbols in both figures depict measured background data and the squares are measured data from reclaimed areas. The range of flows (runoff) is generally greater for the background data but there is significant overlap between the two data sets between 0.1 cfs and 100 cfs. This is because the reclaimed data are from small watersheds and the unmined data are from channels draining larger basins. These data show the same trend for sediment transport and sediment concentration over the entire range of flows and very close agreement in the area of discharge overlap. This, in itself, is strong evidence that: (1) the sediment yields are channel transport capacity limited, and (2) reclaimed areas are not contributing additional suspended solids to receiving streams.

APPROVED

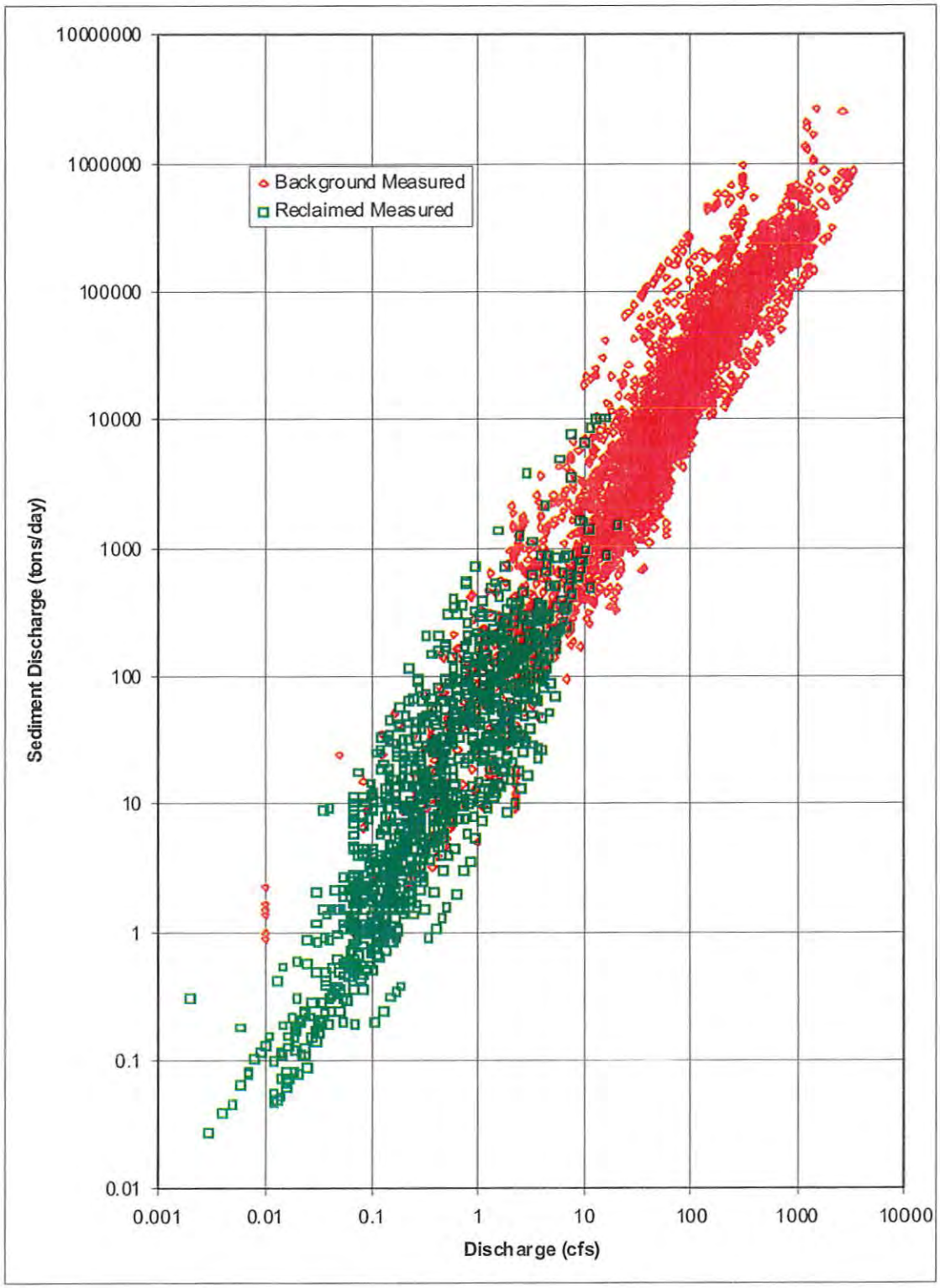


Figure 3.1. Background and Reclaimed Areas Sediment and Water Discharge (PWCC).

MAR 2012
APPROVED

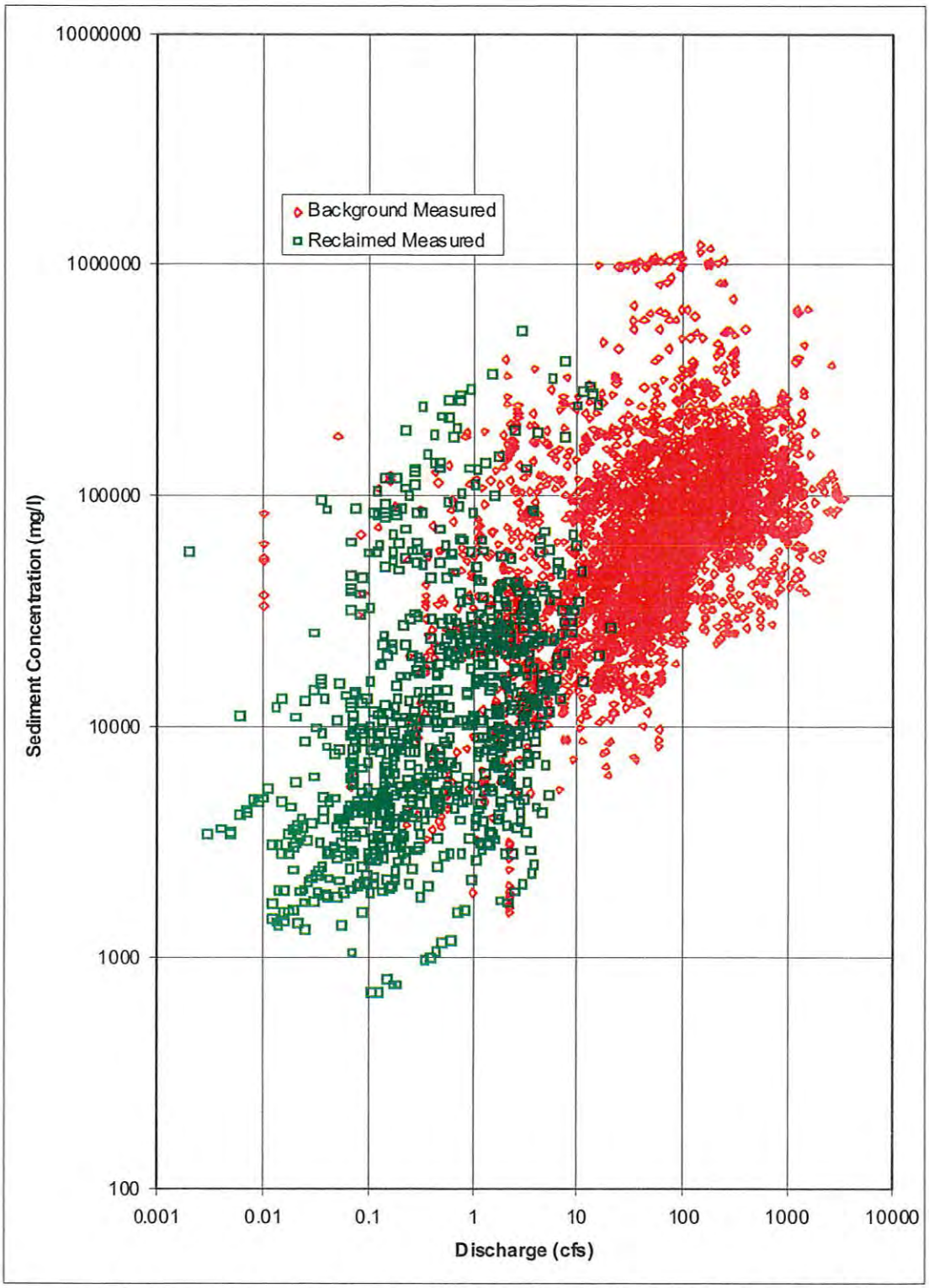


Figure 3.2. Background and Reclaimed Areas Sediment Concentration and Water Discharge (PWCC).

The sediment discharge plot (Figure 3.1) shows a stronger trend than the sediment concentration plot (Figure 3.2) because it is plotting discharge (sediment) against discharge (flow). This is expected because the sediment discharge does depend on flow discharge. The concentration plot (Figure 3.2) shows the two separate variables and, therefore, more scatter among the data is expected. PWCC believes data measurement may have some influence on the scatter (outliers were removed), but the process variability is probably the major influence. A major process that would produce large variability in this data is the correlation between flow velocity and sediment concentration. Given these data are from many gage locations, a discharge of 100 cfs could transport far more sediment at a location with high velocity than the same discharge in a less steep channel with a low velocity. The majority of the data collected from background sites, however, fall in a group centered on 100 cfs and 100,000 mg/l. This discharge and sediment concentration is most often seen in larger unmined channels. The majority of the data collected from reclaimed areas have lower discharges (10 cfs and lower) and lower sediment concentrations (lower than 100,000 mg/l). For flows less than 10 cfs, the sediment concentration data are comparable between unmined and reclaimed conditions. From Figures 3.1 and 3.2 it is apparent that sediment loads and concentrations are dependent on the channel sediment transport capacity for both pre- and postmine conditions. Therefore, channel transport capacity limits sediment yields from the small tributaries, large channels, and the reclaimed areas as a whole.

Smith and Best (2000) analyzed the measured data (background and reclaimed) shown in Figure 3.1 to develop an approach that can be used to determine if channels in reclaimed areas have similar sediment transport characteristics as background channels. The method they used was to develop Sen lines (Sen 1968) and confidence intervals around the data. The slope of the Sen line is a non-parametric statistic computed as the median slope of all possible slopes determined from pairing all the data points. The Sen line is drawn through the median coordinate of the data. Smith and Best first showed the large channel stream monitoring site data (background) and the small watershed background data could be combined. They concluded since the data from one data set fall within the Sen line confidence intervals (95 % at 0.05 Alpha) of the other data set the two data sets are merely extensions of each other and could be combined. Also, because the main channel and background small watershed site data could be combined, it indicated there is an unlimited supply of sediment and the channels are conveying sediment at (or near) capacity. The Sen line and 95 % confidence intervals (Alpha at 0.05) are shown with the background measured data in **Figure 3.3.**

They then plotted the reclaimed measured data (**Figure 3.4**) with the Sen line and confidence intervals from the background data to show the reclaimed data have the same characteristics even though the flow range of the measurements is lower. The data indicate channel flows in this environment achieve the sediment transport capacity of the channel, whether in reclaimed or background conditions.

MAR
APPROVED

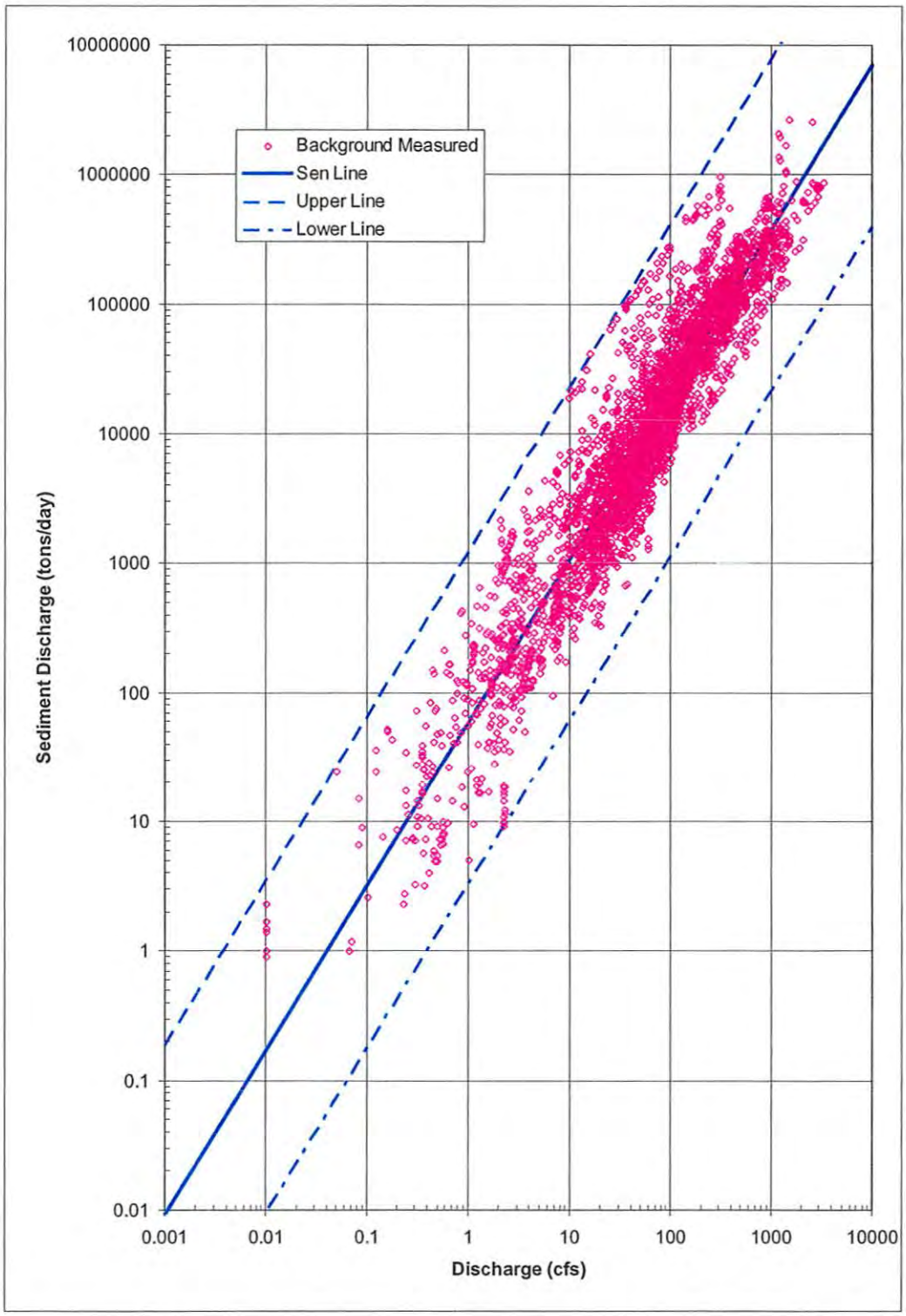


Figure 3.3. Background measured sediment and water discharge (PWCC).

MAR 2012
APPROVED

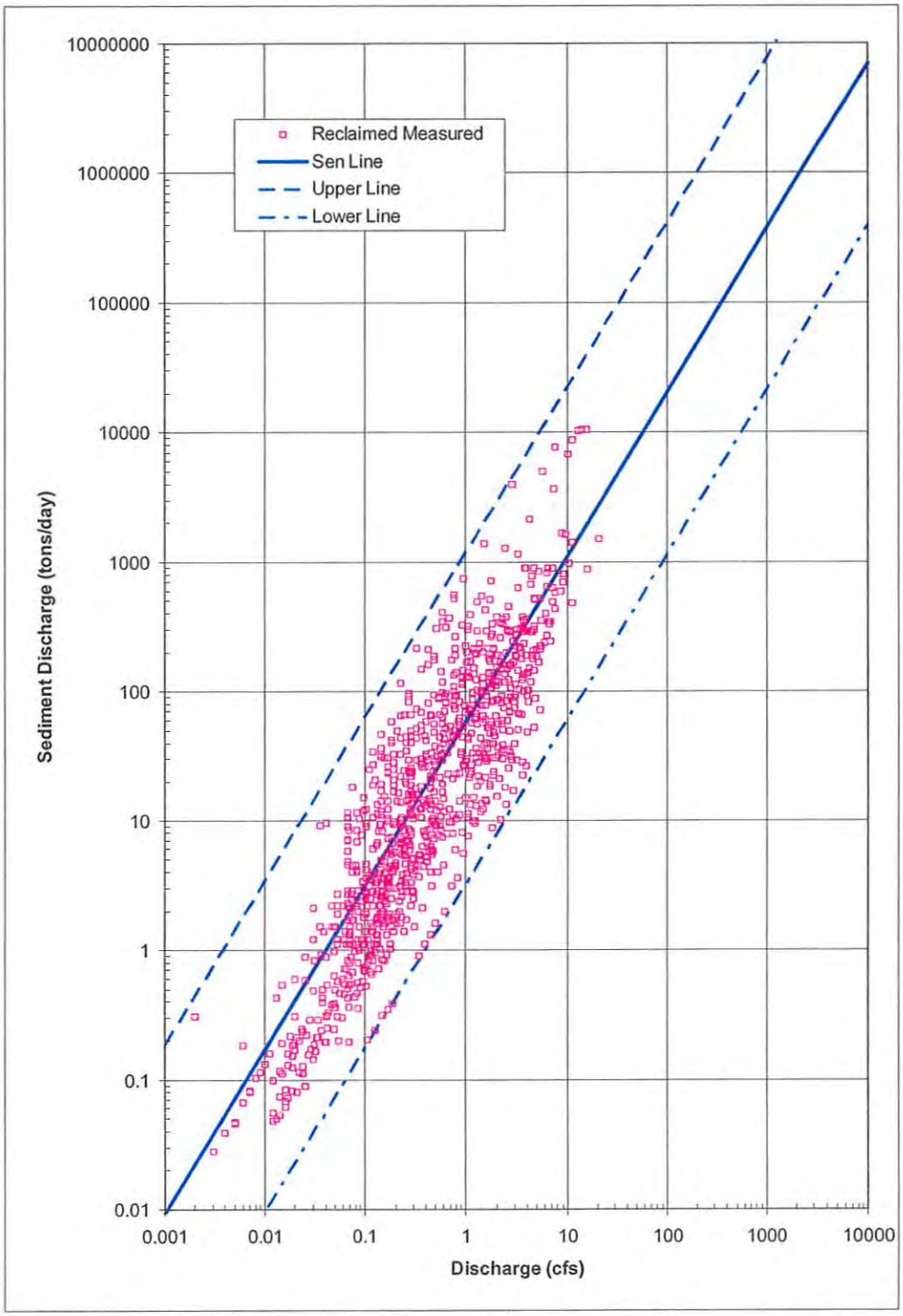


Figure 3.4. Reclaimed measured sediment and water discharge (PWCC).

MAR 2012
APPROVED

The EASI (Erosion And Sediment Impacts) (Water Engineering & Technology, 1990, Zevenbergen et al., 1990) model was calibrated for conditions at the Kayenta Complex. EASI combines a rainfall-runoff model with erosion and sediment transport calculations to determine erosion rates and sediment yield from a basin. The model computes runoff and erosion on hillslopes and in the receiving channels and conveys this sediment through the channel network. Channels can be sources of additional sediment or can accumulate sediment depending on the amount of sediment supplied from upstream sources and the channel's capacity to transport sediment. The amount of sediment eroded from hillslopes depends on hillslope geometry (length and gradient) as well as hydrologic ground cover (vegetation, litter, and rock) and soil type. **Figures 3.5 and 3.6** show an example of computed pre- and postmine (EASI) sediment transport rates and concentrations from the N14 Coal Resource Area (CRA) along with the measured data from Figures 3.1 and 3.2 (Ayres Associates, 2008). One difference between these plots and Figures 3.1 and 3.2 is the measured data were collected throughout the flow hydrograph whereas the modeled data are tabulated at the peak of the simulation flow hydrograph. The computed data from the EASI model are extremely similar to the measured data, though with less scatter. The computed reclaimed data for the N14 CRA show generally lower sediment transport and sediment concentration indicating lower erosion and sediment yield in the reclaimed condition.

It should also be noted the EASI model was calibrated using small plot (hillslope) and small watershed data. EASI results indicate the majority of sediment yield is derived from the channels, not hillslopes, at the Kayenta Complex. This conclusion applies to both unmined (background) and reclaimed areas. Therefore, any analysis of sediment yield that does not include channel sources of sediment is ignoring the primary source of sediment.

Several conclusions can be drawn from these data plots: (1) the EASI model has been calibrated and can be used to predict erosion and sediment transport processes at the mine site for background and reclaimed conditions, (2) all data show similar trends and are within the Sen line confidence intervals, (3) data trends indicate channels are transporting sediment at or near capacity, and (4) amounts of sediment leaving the modeled reclaimed area for postmine conditions are similar to premine conditions and within the range expected for the background conditions. Therefore, the overall conclusion is the postmine reclaimed condition is not contributing additional suspended solids to receiving streams, and related impacts to the hydrologic balance have been minimized.

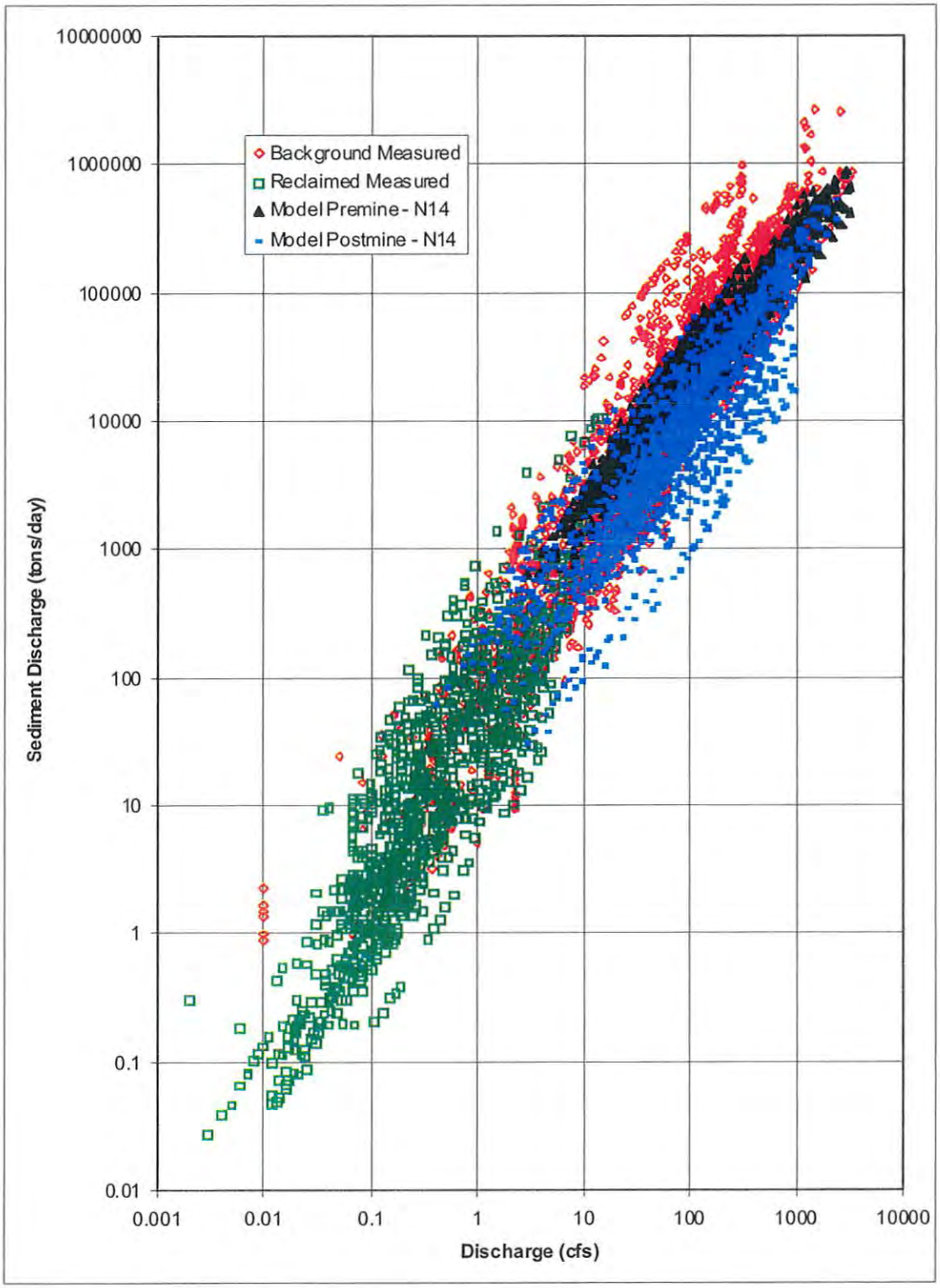


Figure 3.5. Example of Modeled sediment and Water Discharge (PWCC).

MAR 2012
APPROVED

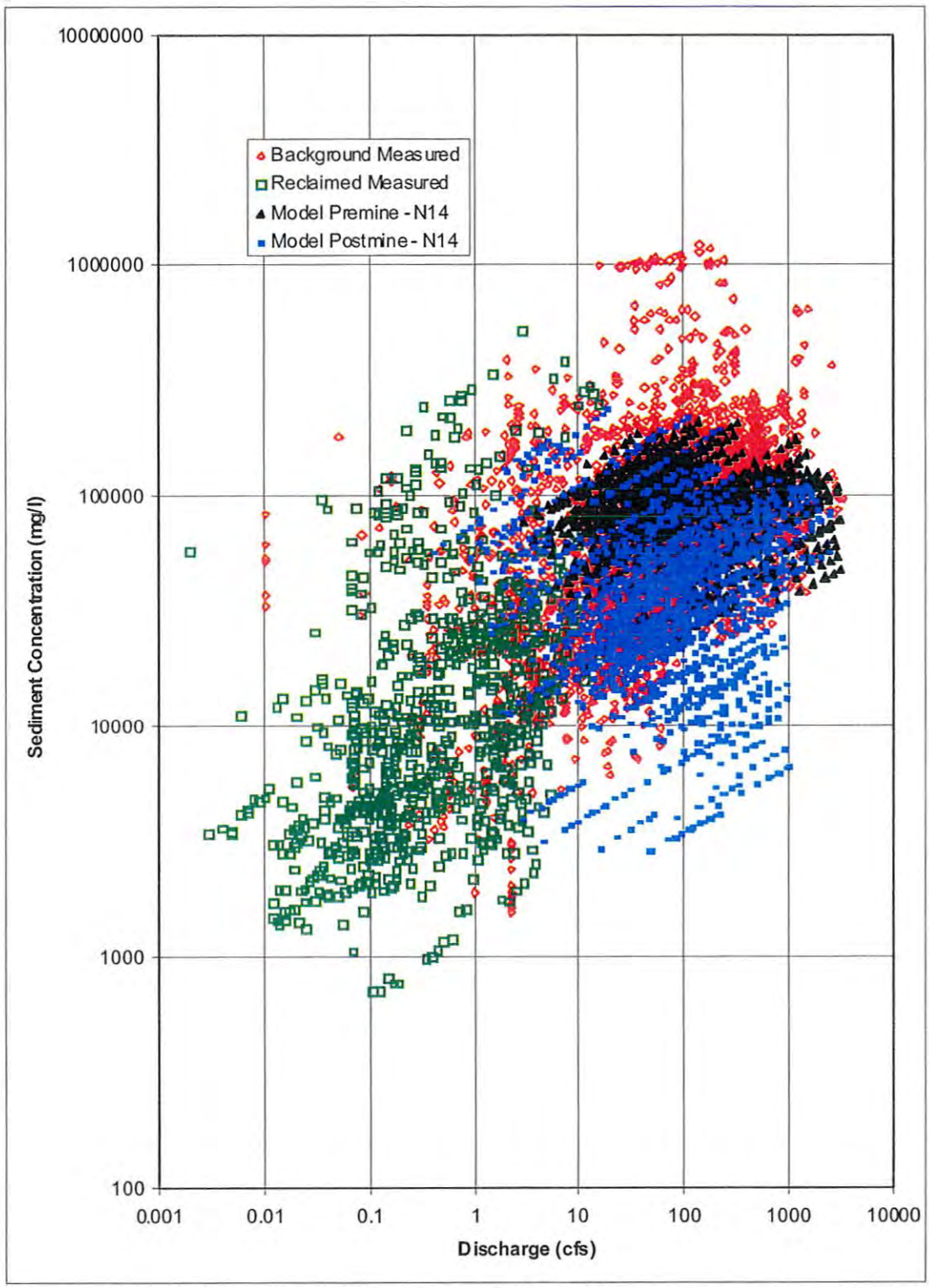


Figure 3.6. Example of Modeled Sediment Concentration and Water Discharge (PWCC).

4.0 Geomorphic Characteristics of an Unmined Basin at Kayenta Complex

Geomorphic characteristics of an unmined basin at the Kayenta Complex were measured and analyzed to assess the range of these characteristics. Although this individual basin does not represent conditions for the entire complex, it does provide insight into premine conditions. These data are not intended to serve as absolute limits for postmine geomorphology as reclamation creates an overall less steep and more gently rolling terrain with different cover conditions. However, several of the geomorphic characteristics presented in the following sections are proposed as targets or "side-boards" for designing and constructing reclaimed watersheds at the Kayenta Complex. The basin is shown in **Figure 4.1** and is located just north of the N14 CRA. It was selected because of its proximity to the Kayenta Complex mining area, its drainage area (887 acres) being similar in size to the larger reclaimed postmine basins, and because detailed topographic mapping (10-ft contour interval) was available.

A range of geomorphic parameters were determined for this basin. These include hillslope and channel geometry, basin characteristics, and erosion and sediment yields for hillslopes and channels. Ultimately, the sediment yield is the geomorphic parameter that integrates all the other geomorphic processes in the basin. These include hydrologic, vegetation, soils, and geology. In the postmine landscape, erosion control measures (BTCAs) are also factored into the resulting sediment yields.

Each parameter was measured and correlated to stream order. Stream order (Strahler 1952) is based on identifying the smallest channels located at the head of a drainage network and assigning them an order of 1, and increasing the order as channels combine. A second order channel occurs below the confluence of two first order channels. Similarly, a third order channel occurs below the confluence of two second order channels. If a first order channel flows into a higher order channel, the order of the higher order channel does not change. This basin has 48 first, 11 second, 4 third, and 1 fourth order channels. The total number of hillslopes is 348. Data were also obtained for "zero" order basins. These are areas above the first order channels where flow converges in a low area, or swale, but a defined channel is not present.

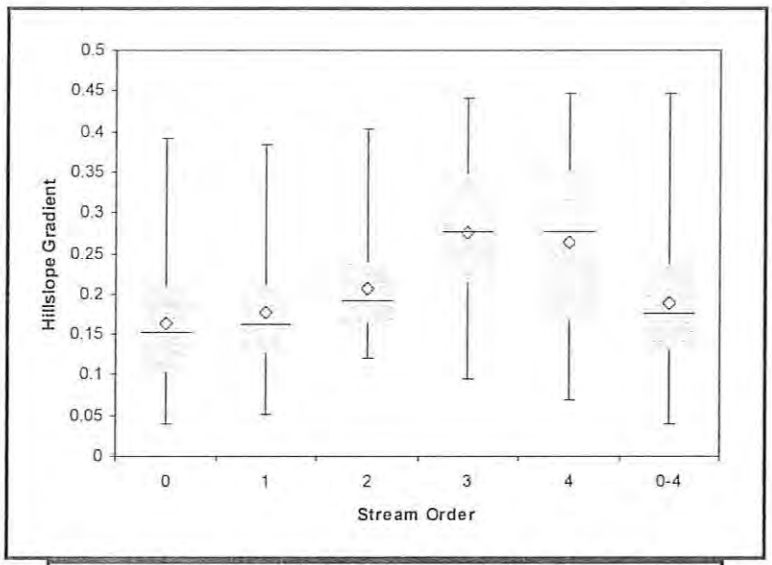
The data for each geomorphic variable are presented in "box and whiskers" plots and in tables. Box and whiskers plots were chosen because they show the distribution, variability, and range of the geomorphic parameter and the process represented by that parameter. The box and whiskers plots show the minimum and maximum value at the ends of each whisker, the whiskers show the upper and lower quartile of the data (25 percent), the box shows the middle 50 percent of the data with a line depicting the median, and a diamond shows the mean value. The median (50 percent value) and the mean (average) are both shown to give and indication of the data skew. In general, if the median and mean are similar, then the data is fairly uniform. A mean value that is much higher than the median value indicates positive skew, and vice versa. For much of the data, only the results for the first through fourth order is shown. In some cases the zero order data are shown and in some cases the cumulative values for the entire basin are shown. Eleven variables were evaluated in total. The first group includes eight topographic or geometric variables. These include hillslope gradient, hillslope length, channel gradient, channel length, channel sinuosity, basin relief, drainage area, and drainage density. Three variables were evaluated related to erosion and sediment transport. These are hillslope erosion, channel erosion, and unit sediment yield.

MAY 2012
APPROVED

Figure 4.1 Basin used for computing geomorphic properties (PWCC).

MAR 2012
APPROVED

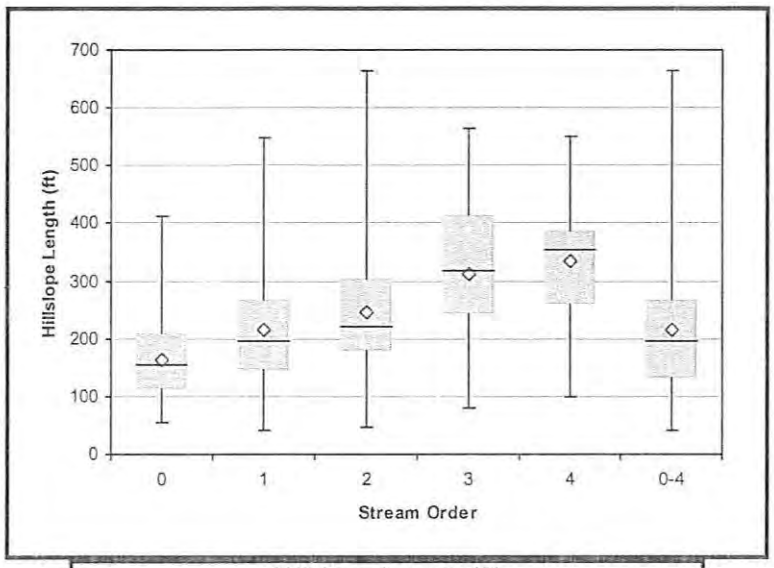
Hillslope gradient and length are shown in **Figures 4.2 and 4.3**. Hillslope gradients range from 4 to 45 percent with an average of approximately 19 percent. Nearly one quarter of the hillslopes have gradients more than 25 percent. Gradients tend to increase for hillslopes that flow into higher order channels. This is because the crest elevations of the hillslopes do not drop as rapidly as the base elevations where the hillslopes drain into the channels. The same trends are also true for hillslope lengths. Hillslopes that flow into higher order channels tend to be longer. Hillslope lengths range from less than 50 feet to more than 650 feet with an average length of approximately 215 feet.



Hillslope Gradient (ft/ft)						
Stream Order	0	1	2	3	4	0-4
Count	124	128	52	26	18	348
Minimum	0.04	0.05	0.12	0.09	0.07	0.04
1st Quartile	0.10	0.13	0.16	0.21	0.17	0.13
Median	0.15	0.16	0.19	0.28	0.28	0.17
3rd Quartile	0.21	0.21	0.24	0.35	0.35	0.24
Maximum	0.39	0.38	0.40	0.44	0.45	0.45
Mean	0.16	0.18	0.21	0.27	0.26	0.19
Std. Deviation	0.08	0.07	0.06	0.09	0.11	0.08

Figure 4.2 Hillslope Gradient

APPROVED

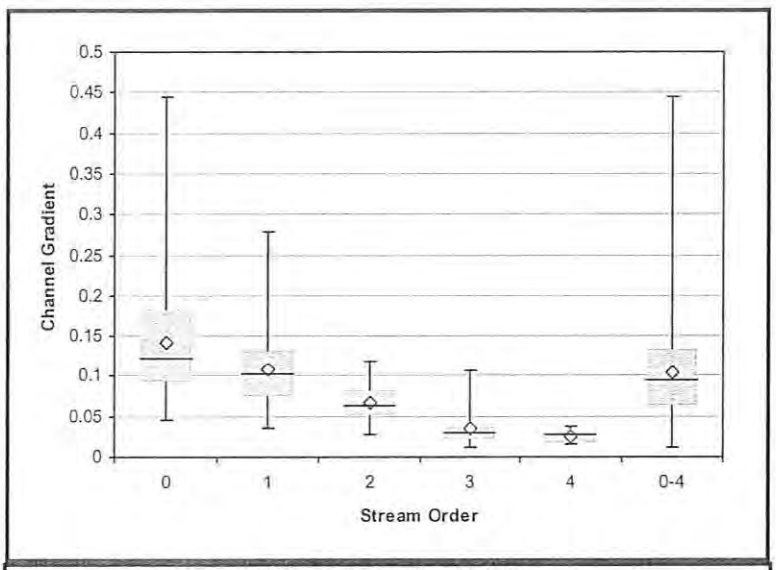


Hillslope Length (ft)						
Stream Order	0	1	2	3	4	0-4
Count	124	128	52	26	18	348
Minimum	55	43	48	81	99	43
1st Quartile	111	147	179	244	260	134
Median	151	198	220	319	355	197
3rd Quartile	209	267	304	414	388	269
Maximum	412	610	664	565	550	664
Mean	163	215	245	313	335	214
Std. Deviation	68	104	109	129	125	109

Figure 4.3 Hillslope Length

MAR 2002
APPROVED

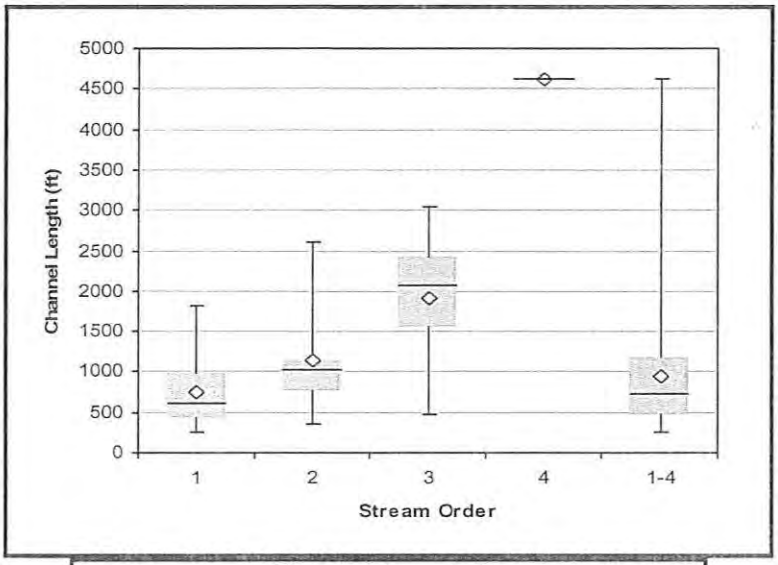
Figures 4.4 and 4.5 show channel gradient and channel length. As expected, channel gradient decreases significantly for higher order channels. This is an indication that the channel profiles are concave (steep in the upper basin and flattening downstream). This is the opposite trend seen in the hillslopes flowing into these channels. The range of gradient is from approximately 1 percent to as high as 44 percent. Nine values of gradient were recorded for the fourth order channel because there were nine segments of this channel defined by the locations of the tributary channels flowing into it. These nine values were very consistent ranging from approximately 2 to 4 percent with a mean of 2.7 percent. Channel length was measured along the entire channel of a given order. Therefore, there was only one value of length for the single fourth order channel. Channel length increases dramatically for higher order channels with the fourth order channel measuring over 4500 feet in length. First and second order channels are generally less than 2000 feet in length and third order channels are, on average, approximately 1900 feet in length.



Channel Gradient (ft/ft)						
Stream Order	0	1	2	3	4	0-4
Count	62	64	26	13	9	174
Minimum	0.046	0.035	0.027	0.012	0.016	0.012
1st Quartile	0.093	0.075	0.051	0.023	0.018	0.063
Median	0.122	0.102	0.064	0.029	0.027	0.095
3rd Quartile	0.184	0.133	0.083	0.037	0.032	0.134
Maximum	0.444	0.279	0.119	0.107	0.038	0.444
Mean	0.143	0.108	0.068	0.035	0.027	0.105
Std. Deviation	0.071	0.047	0.025	0.024	0.008	0.064

Figure 4.4 Channel Gradient

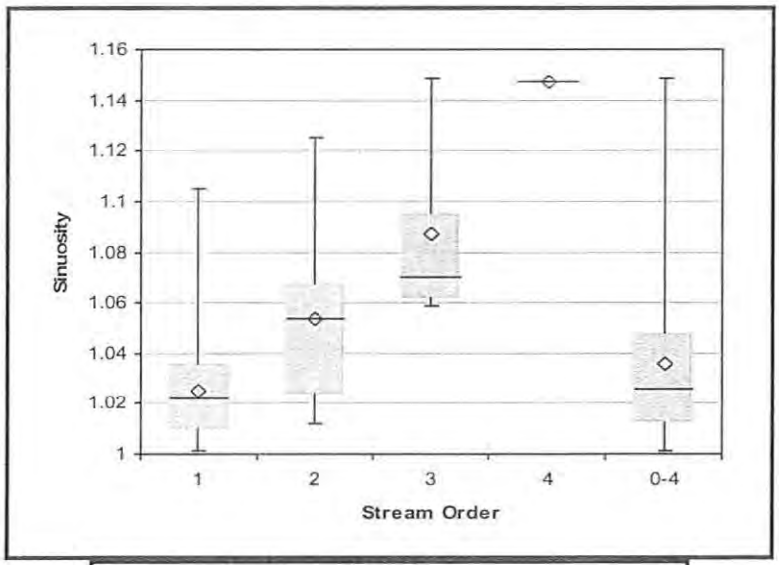
APPROVED



Channel Length (ft)					
Stream Order	1	2	3	4	1-4
Count	48	11	4	1	64
Minimum	255	351	476	4620	255
1st Quartile	442	775	1568	4620	472
Median	611	1037	2074	4620	735
3rd Quartile	979	1148	2422	4620	1190
Maximum	1815	2609	3041	4620	4620
Mean	755	1148	1916	4620	955
Std. Deviation	392	681	1069		743

Figure 4.5 Channel Length

Channel sinuosity is shown in **Figure 4.6.** Sinuosity is defined as the ratio of channel length to the valley length (Brice and Blodgett 1978). They indicate that sinuosity of less than 1.05 is usually considered a straight channel and "sinuous" channels are between 1.06 and 1.25. Highly meandering channels have sinuosity greater than 2. The highest measured sinuosity in this unmined basin was 1.15, which was the maximum value for a third order channel and the value measured for the fourth order channel. The average values for the first and second order channels were approximately 1.03 and 1.05, essentially straight. The limiting possible value of sinuosity is 1.0. In this basin, 75 percent of channels are "straight" (sinuosity <1.05) with the remaining 25 percent in the lower end of the "sinuous" classification. Imposing significantly higher sinuosity on a steep channel would result in significant bank erosion and the channel would tend to cut off the bends, thereby forming a straighter alignment. The bank erosion and cutoffs could only be avoided by locking the channel alignment with riprap.

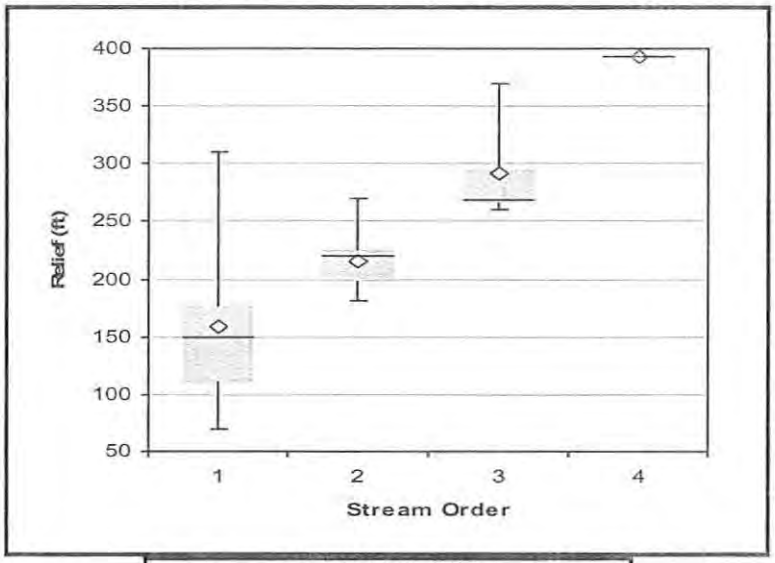


Sinuosity					
Stream Order	1	2	3	4	0-4
Count	48	11	4	1	64
Minimum	1.00	1.01	1.06	1.15	1.00
1st Quartile	1.01	1.02	1.06	1.15	1.01
Median	1.02	1.05	1.07	1.15	1.03
3rd Quartile	1.04	1.07	1.10	1.15	1.05
Maximum	1.11	1.13	1.15	1.15	1.15
Mean	1.03	1.05	1.09	1.15	1.04
Std. Deviation	0.02	0.03	0.04		0.03

Figure 4.6 Sinuosity

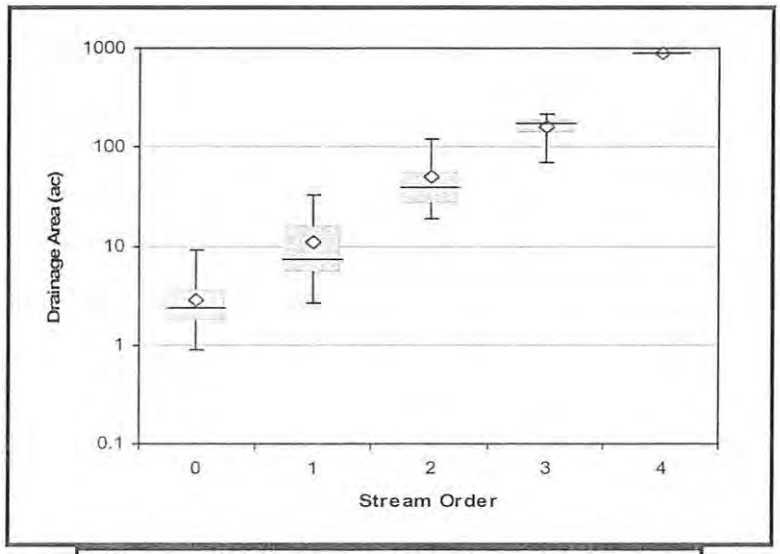
APPROVED

Three other geomorphic parameters that are related to geometry are basin relief, drainage area, and drainage density. Relief (**Figure 4.7**) is the elevation difference between the channel outlet and the highest point along the drainage divide. Drainage area (**Figure 4.8**) is the area drained at the outlet of each channel (Schumm 1956). Drainage density (**Figure 4.9**) is the sum of channel lengths (in miles) contained in a basin divided by that area in square-miles. Relief and drainage area increase with stream order. There are, however, some first order channels that have significant relief. This is because there are first order basins that are low in the overall basin. Drainage area increases dramatically with stream order. The average drainage areas are approximately 3 acres for zero order basins, 10 acres for first order basins, 50 acres for second order basins, 160 acres for third order basins, and nearly 900 acres for the fourth order basin. This is an increase of an average factor of 4.1 for each increment in stream order.



Basin Relief (ft)				
Stream Order	1	2	3	4
Count	48	11	4	1
Minimum	69	181	260	393
1st Quartile	111	199	266	393
Median	150	220	269	393
3rd Quartile	178	225	295	393
Maximum	310	270	370	393
Mean	159	216	292	393
Std. Deviation	61	27	52	

Figure 4.7 Basin Relief

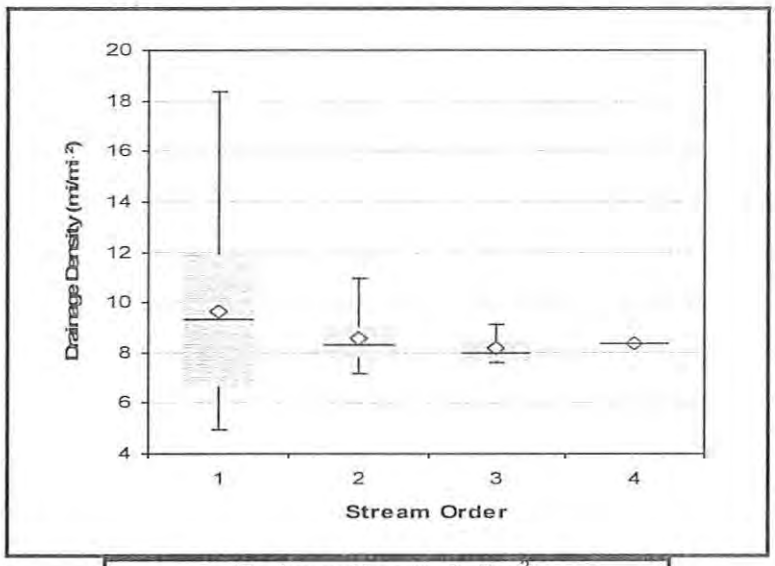


Drainage Area (ac)					
Stream Order	0	1	2	3	4
Count	62	48	11	4	1
Minimum	0.9	2.6	19.2	69.4	887.0
1st Quartile	1.8	5.5	27.7	139.2	887.0
Median	2.4	7.4	38.7	177.3	887.0
3rd Quartile	3.7	16.2	57.3	197.6	887.0
Maximum	9.0	32.3	122.7	213.8	887.0
Mean	2.9	11.1	50.5	159.5	887.0
Std. Deviation	1.6	7.8	35.1	63.6	

Figure 4.8 Drainage Area

APPROVED

Drainage density is most meaningful at the third and fourth orders because at lower orders it is extremely variable. It is also a variable that is typically only measured at a larger basin scale. For this unmined basin used in the analysis, the drainage density is approximately 9.4. Drainage densities for premine basins at Kayenta Complex are typically between 7 and 10. Higher drainage density indicates a more developed channel network to convey flow and sediment. Therefore, in a natural basin, higher drainage density usually indicates a higher sediment yield, although channel gradient also has a strong influence on sediment yield. The large range of drainage densities for first and second order channels indicates a large range of sediment yields from these small basins.

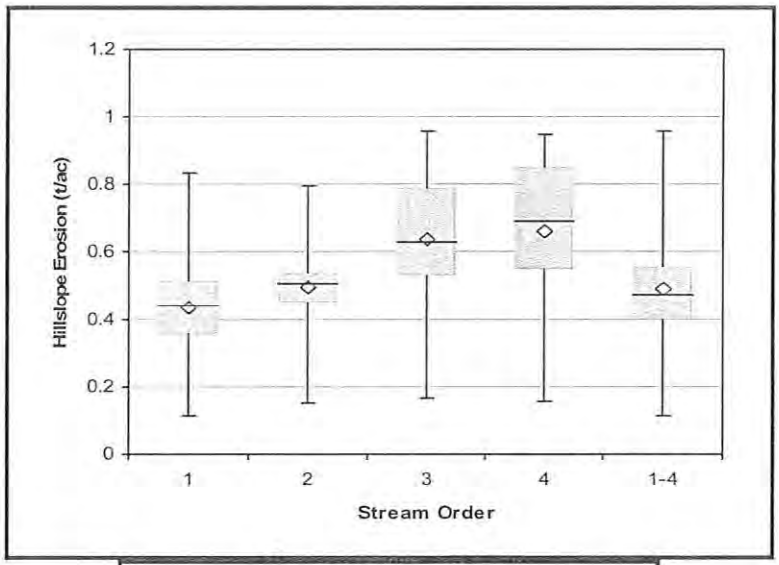


Drainage Density (mi/mi^2)					
Stream Order	1	2	3	4	0-4
Count	48	11	4	1	64
Minimum	5.0	7.1	7.6	8.4	5.0
1st Quartile	6.7	7.8	7.7	8.4	7.1
Median	9.3	8.3	8.0	8.4	8.8
3rd Quartile	11.9	9.0	8.4	8.4	11.6
Maximum	18.4	11.0	9.1	8.4	18.4
Mean	9.7	8.6	8.2	8.4	9.4
Std. Deviation	3.4	1.2	0.7		3.0

Figure 4.9 Drainage Density

Hillslope erosion, channel erosion, and sediment yield were calculated through the EASI model. All rainfall and soil inputs to the model were taken from models calibrated in previous studies (RCE 1993). The vegetative cover was assigned according to the premine aerial photo. The EASI model was then used to simulate runoff and sediment yield from a series of storm events having recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100-years and the average annual runoff, erosion, and sediment yield were computed using the event weighted equation of Lagasse et al. (1985).

Erosion and sediment transport are geomorphic processes that occur on hillslopes and in channels for both unmined and reclaimed areas. All hillslopes erode and produce sediment during runoff-producing events. Channels will either erode or accumulate sediment depending on the supply of sediment from adjacent hillslopes and upstream channels, and the channels capacity to move sediment (sediment transport capacity). The EASI model was used to quantify erosion, sediment transport, and sediment yield for this basin. The sediment yield of a channel or basin is the amount of sediment (typically expressed in tons per acre) exiting the channel or basin outlet. Sediment yield is the total erosion minus the total amount of sediment accumulation (deposition) in the basin. **Figures 4.10 and 4.11** show hillslope and channel average annual erosion rates in tons/acre. **Figure 4.12** shows the basin drainage network, whether a channel is erosional or depositional, and the rate of erosion and deposition. Figure 4.12 also shows the channel (Strahler) order. The lower order channels (0 and 1) are the most erosional. Second order channels tend to erode less and some are depositional. Third order channels tend to be slightly depositional and the fourth order channel appears to be in equilibrium with the upstream sediment supply.

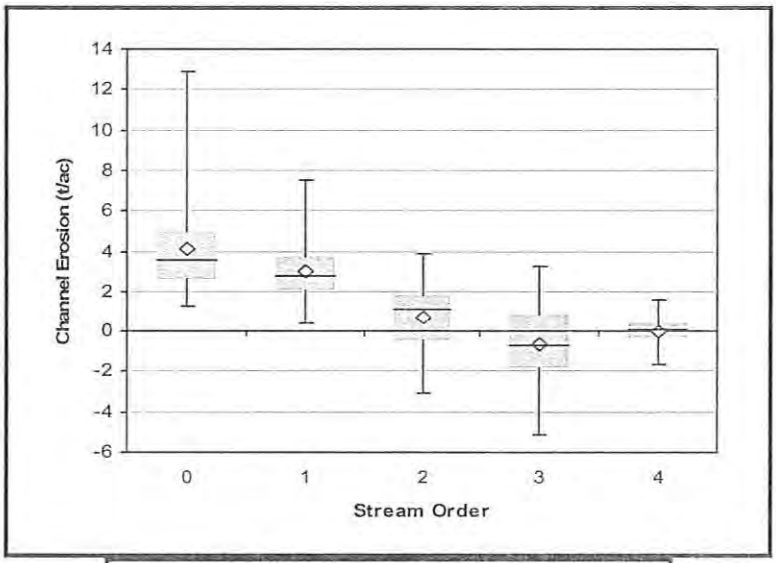


Hillslope Erosion (t/ac)					
Stream Order	1	2	3	4	1-4
Count	128	52	26	18	224
Minimum	0.1	0.2	0.2	0.2	0.1
1st Quartile	0.4	0.5	0.5	0.6	0.4
Median	0.4	0.5	0.6	0.7	0.5
3rd Quartile	0.5	0.5	0.8	0.9	0.6
Maximum	0.8	0.8	1.0	1.0	1.0
Mean	0.4	0.5	0.6	0.7	0.5
Std. Deviation	0.1	0.1	0.2	0.2	0.2

Figure 4.10 Hillslope Erosion

APPROVED

The hillslope erosion tends to increase for areas draining into higher order channels. This is expected because hillslope gradient and length (Figure 4.2 and 4.3) were higher for these areas. Channel gradients (Figure 4.4) were highest for the low order channels. These channels showed the highest erosion rates. Some second, third, and fourth order channel segments have negative erosion (deposition). Areas of deposition are common in natural channels in this region. This is because sediment supplied from upstream is highly variable and the sediment transport capacity of the channels is highly variable. Areas of deposition and erosion in the third and fourth order channels are transitory in that an area of deposition may erode into the accumulated sediment at a later time. The fact that there are areas of deposition (or erosion) is primarily related to the highly variable amounts of upstream erosion and sediment transport capacity. Figures 4.10 and 4.11 show highly variable rates of erosion. The variability is expected in this environment. A reach of channel may erode in one event and accumulate sediment in another. Because hillslope lengths and gradients vary significantly, erosion rates also vary significantly. This is a primary reason for the large amount of scatter in the sediment transport and sediment concentration figures shown in **Section 3.**



Channel Erosion (t/ac)					
Stream Order	0	1	2	3	4
Count	62	64	26	13	9
Minimum	1.3	0.4	-3.1	-5.1	-1.7
1st Quartile	2.6	2.0	-0.4	-1.8	-0.3
Median	3.6	2.8	1.1	-0.7	0.1
3rd Quartile	5.0	3.8	1.8	0.9	0.4
Maximum	12.9	7.5	3.9	3.3	1.6
Mean	4.1	3.0	0.7	-0.6	0.0
Std. Deviation	2.1	1.4	1.8	2.0	1.1

Figure 4.11 Channel Erosion

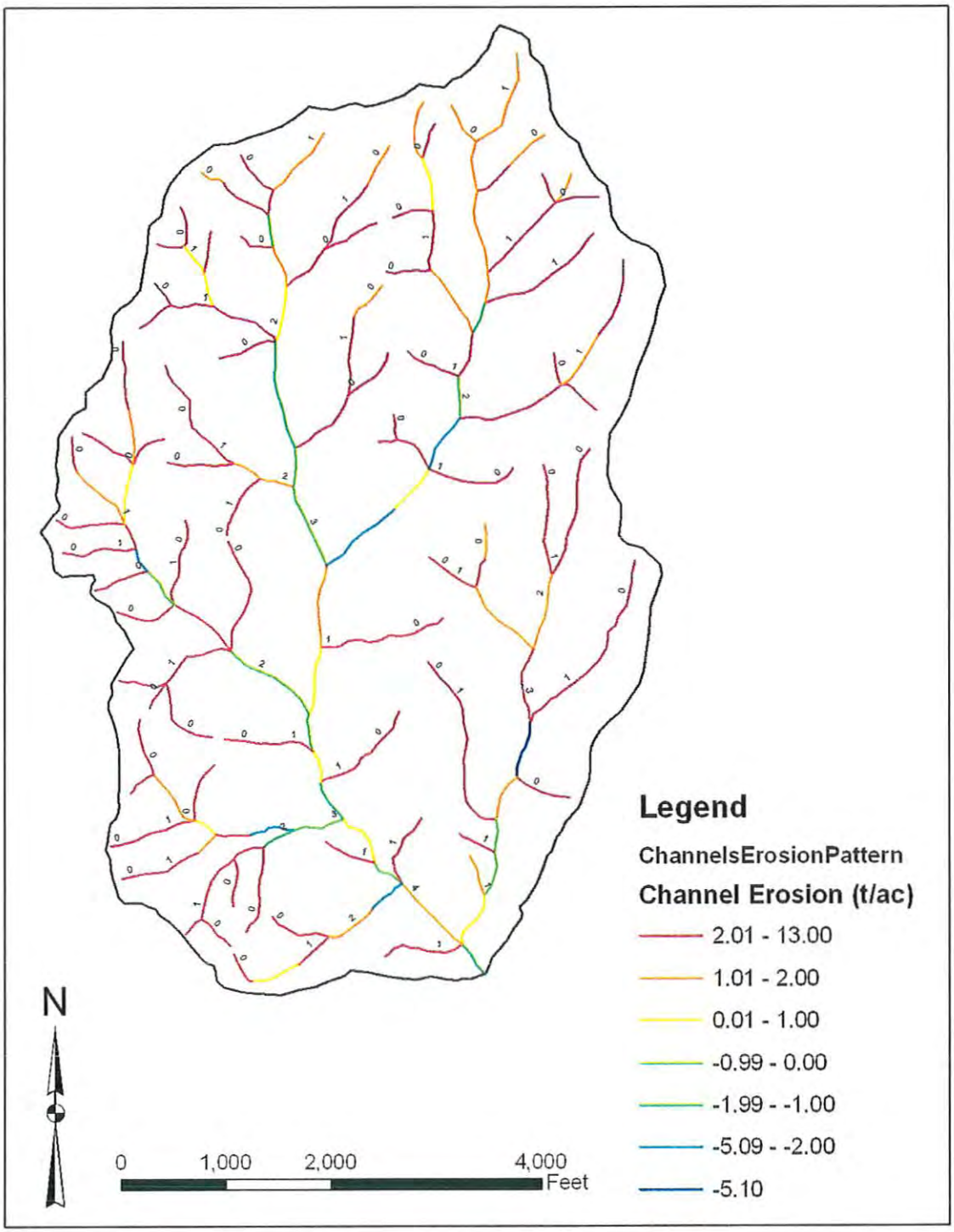
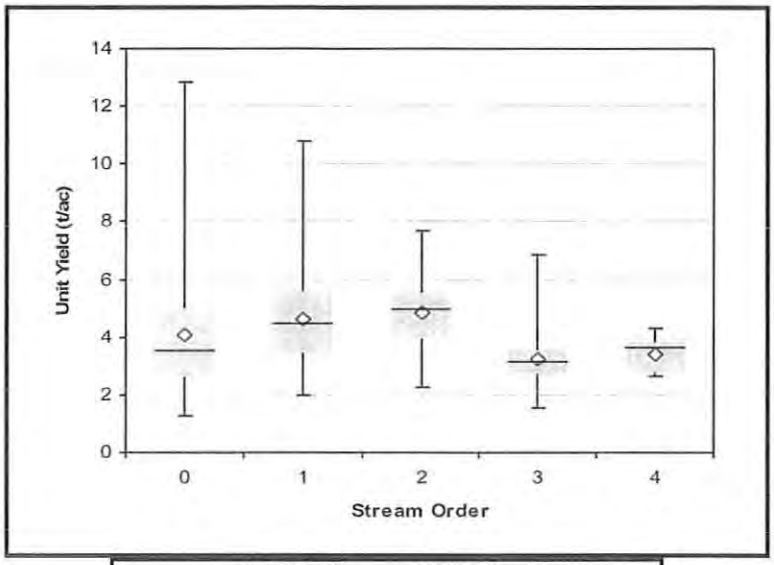


Figure 4.12 Channel Erosion and Deposition Pattern

MAR 2012
APPROVED

Figure 4.13 shows average annual sediment yield in tons/acre for the basin and sub-basins. Based on the results of the EASI modeling, channels produce much more sediment than the hillslopes. The average hillslope erosion rate for the basin is approximately 0.5 tons/acre with a range of 0.1 to nearly 1 ton/acre. Given the sediment yield of the basin of over 3 tons/acre, channels in this basin produce nearly five (5) times as much sediment, on average, than the hillslopes.



Unit Sediment Yield (t/ac)					
Stream Order	0	1	2	3	4
Count	62	64	26	13	9
Minimum	1.3	2.0	2.2	1.6	2.6
1st Quartile	2.6	3.4	4.0	2.7	2.8
Median	3.6	4.5	5.0	3.1	3.7
3rd Quartile	5.0	5.7	5.6	3.6	3.9
Maximum	12.8	10.8	7.7	6.9	4.3
Mean	4.1	4.6	4.9	3.3	3.4
Std. Deviation	2.1	1.8	1.2	1.3	0.7

Figure 4.13. Unit Sediment Yield

5.0 Terracing in the Reclaimed Landscape

PWCC acknowledges that over-dependence on the use of terraces to establish hillslope drainage systems and insufficient quality control during construction of these terraces has been problematic. However, there is sufficient evidence at the Kayenta Complex that when carefully placed and properly constructed, terraces can be effective in drainage control and safely moving water and sediment off of reclaimed landscapes. Further, both the USEPA (1992) and ASAE (1983) suggest the value of these structures in moving water off slopes, controlling erosion, and contributing to landform stability.

PWCC will incorporate a reduced use of terracing on reclaimed landscapes. After careful consideration of the conditions at the Kayenta Complex and the regrading of prevalent and uniform dragline spoils, the select use of short segment terraces will be included as a tool for establishing permanent, first order channels in the reclaimed landscape. The terrace channel lengths will generally be within the range of 450 to 1000 feet and will not exceed 1200 feet. The terrace gradients shall not be less than 1.5 percent and typically not greater than 2.5 percent with a target of 2.0 percent. Terrace spacing will be dependent on slope gradient, soil factors, and hydrologic cover. Attachment B, Terrace Spacing contains supporting information and shall be used to determine the terrace spacing.

An additional consideration for the use of terraces is for interim watershed stabilization in situations where longer slopes with more linear or planar landform features are present and where the eventual vegetated and stabilized watershed characteristics are such that terraces are no longer needed. The terrace gradients will be similar as above but the terrace lengths may be as long as 2000 feet. The use of terraces for this practice will be limited and in consultation with OSM. Note that PWCC, in cooperation with OSM, has instituted a terrace removal and monitoring program under similar circumstances. To date this has proven to be successful and the established watersheds included in the removal study have proven stable without terraces.

Certain historic terraces were constructed with gradients less than optimal. In certain settings, these terraces have filled with sediment, are very well vegetated, and stable. PWCC will leave these terraces permanently as part of the postmine landscape. These healed terraces will be shown on postmine maps; however, no further maintenance or disturbance will be performed.

6.0 Summary and Conclusions

Attachment A demonstrates the Kayenta Complex is located in a sediment-rich environment and significant amounts of sediment can be produced by hillslopes and channels in the pre- and postmine landscape. Measurements of sediment concentration are similar for pre- and postmine conditions when the flow rates are similar. When flow rates are greater, which is the case for larger, unmined channels, sediment concentrations are also higher. The measurements indicate reclaimed areas do not contribute additional sediment to the downstream channel system and reclamation practices are successful in preventing disturbance to the hydrologic balance.

PWCC has been practicing "geomorphic reclamation" by developing postmine landscapes and drainage networks that meet the applicable performance standards.

APPROVED

PWCC has evaluated and compared the sediment yield characteristics of pre- and postmine landscapes in a number of CRA's at the Kayenta Complex using the EASI model. Implemented BTCA reclamation practices to control erosion and sediment yield are considered in the modeling. Further, these analyses reflect improved reclamation practices including establishment of significantly more effective hydrologic cover characteristics than in premine conditions. Numerous terraces no longer needed as BTCA have been removed, and PWCC is modifying terrace designs to address conditions where terraces have not performed as desired. These modifications include using fewer and shorter terraces, increasing terrace gradient to make them self-maintaining, and by using trapezoidal or parabolic terraces rather than triangular (v-notch) geometry.

The geomorphic characteristics that were measured for an unmined basin adjacent to the N14 CRA also show extreme variability. This high variability in the geomorphic characteristics explains the large amount of scatter in the sediment yield and sediment concentration measurements. The EASI model supports this and predicted a high level of variability in erosion and sediment yield. One watershed parameter that does not show a large amount of variability is channel sinuosity. Within the scale of typical reclamation areas, premine channels are essentially straight with sinuosity generally less than 1.05. The analysis of geomorphic characteristics also included erosion and sediment yield rates. These results and previous analysis continue to indicate channels are the primary source of sediment at the Kayenta Complex.

These analyses were used to develop guidance for spacing, gradient, and length associated with the limited use of terraces. The terrace gradients shall have a target of 2 percent, with a typical range between 1.5 and 2.5 percent and will keep the terrace channels self-maintaining. Terrace lengths will be 1200 feet or less when included as first order stream segments. Temporary terraces to aid in watershed cover development and stabilization will have similar gradients but lengths upward of 2000 feet. Removal of these latter terraces in whole or a portion thereof will be in consultation with OSM.

Table 6.1 lists ranges of geomorphic characteristics PWCC will use as targets or "side-boards" for designing and constructing reclaimed watersheds at the Kayenta Complex. The target value will be the norm; however, the full range of values will be used during watershed development. PWCC also recognizes designs must adhere to specific performance standards at 30 CFR 816, which may narrow some of the side-board ranges (e.g., channel gradient) listed below. Channel lengths, basin relief, and drainage area side-boards are not proposed because the overall size and location of the reclaimed watershed will dictate the magnitude of these features. Ranges provided in Table 6.1 for hillslope gradient, hillslope length, channel gradient, sinuousity, and drainage density are grouped according to stream order. Ranges for terrace gradients and lengths are presented by stream order 1 because these features will only serve as first order channels.

Table 6.1 – Geomorphic Characteristic Targets

Geomorphic Characteristic	Stream Order	Range	Target
Hillslope Gradient (%)	0 1 2 3 4	4 – 24 5 – 25 12 – 27 9 – 36 7 – 37	10 13 16 21 17
Hillslope Length (ft)	0 1 2 3 4	55 – 240 45 – 335 50 – 370 80 – 460 100 – 480	110 150 180 245 260
Channel Gradient (%) Note: See order 1 channel gradients when terraces used	1 2 3 4	3.5 – 15.5 2.7 – 9.3 1.2 – 5.9 1.6 – 3.5	7.5 5.1 2.3 1.8
Sinuosity (channel length/valley length)	1 2 3 4	1.00 – 1.05 1.01 – 1.08 1.06 – 1.13 1.15	1.01 1.02 1.06 1.15
Drainage Density (mi./sq. mi.)	1 2 3 4	5.0 – 13.0 7.0 – 10.0 7.5 – 9.0 8.4	6.7 7.8 7.7 8.4
Terrace Gradients (%)	1 and temporary	1.5 – 2.5	2.0
Terrace Lengths (ft)	1 Temporary	no greater than 1200 feet No greater than 2000 feet	450 – 1000 Conditional

APPROVED

7.0 References

Ayres Associates. 2008. Surface water modeling of the reclaimed N14 Coal Resource Area at Kayenta Mine, prepared for Peabody Western Coal Company.

ASAE. 1983. Design, Layout, Construction and Maintenance of Terrace Systems. ASAE Standard: ASAE S268.3. American Society of Agricultural Engineers, St. Joseph, Michigan.

Brice, J.C., and J.C. Blodgett. 1978. Countermeasures for Hydraulic Problems at Bridges, Vol. 1, Analysis and Assessment, FHWA/RD-78-162, Federal Highway Administration, Washington, D.C.

USEPA. 1992. Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices. EPA 832-R-92-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Lagasse, P.F., J. D. Schall, and M. R. Peterson. 1985. Erosion Risk Analysis for a Southwestern Arroyo, Journal of Urban Planning and Management, American Society of Civil Engineers, v. III, no. I, November, 1985, Paper No. 20165.

Office of Surface Mining Reclamation and Enforcement (OSM). 2010. Recommended Geomorphic Reclamation Guidance. OSM Western Region, Denver, Colorado.

Resource Consultants & Engineers, Inc.(RCE). 1993. Surface Water Modeling of Reclaimed Parcels at the Kayenta Complex, prepared for Peabody Western Coal Co.

Schumm, S.A. 1956. Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey, Geological Society of America Bulletin, v. 67, p. 597-646.

Sen, P.K. 1968. Estimates of Regression Coefficient Based on Kendall's tau, Journal of American Statistical Association, v. 63, p. 1379-1389.

Smith, T. and A. Best. 2000. Assessing Sedimentation and Protection of the Hydrologic Balance in Disturbed and Reclaimed Areas at the Black Mesa and Kayenta Mines, Arizona, Using Baseline Sediment Data Collected in Receiving Streams, presentation given at the Billings Mined Land Reclamation Symposium in 2001, Billings, MT.

Strahler, A.N. 1952. Dynamic basis of geomorphology, Geological Society of America Bulletin, v. 63, p. 923-938.

Water Engineering & Technology, Inc. (WET). 1990. Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control Technology at Surface Mines in the Semiarid West, prepared for Office of Surface Mining and the National Coal Association, Fort Collins, Colorado.

Zevenbergen, L.W., M. R. Peterson, and C. C. Watson. 1990. Computer simulation of watershed runoff and sedimentation processes, Proceedings of the Billings Symposium; Planning, Rehabilitation and Treatment of Disturbed Lands.

ATTACHMENT B

TERRACE SPACING

MAR 2012
APPROVED

ATTACHMENT B

TERRACE SPACING

Table of Contents

	Page
Introduction	1
Analysis Approach	1
Revised Universal Soil Loss Equation Factors	2
R-Factor	3
K-Factor	3
LS-Factor	3
C-Factor	3
P-Factor	4
Soil Loss Predictions	4
Scenario 1	4
Scenario 2	6
Scenario 3	8
Scenario 4	8
Terrace Spacing	12
References	14

MAR 2012
APPROVED

Table of Contents (Cont.)

List of Tables

Table No.		Page
1	RUSLE Soil Loss Estimates for Newly Reclaimed Hillslopes with No Conservation or BTCA Practices Except Contour Drill Seeding (Scenario 1)	5
2	RUSLE Soil Loss Estimates for Newly Reclaimed Hillslopes with Terraces Installed at the Specified Slope Lengths and Conservation And BTCA Practices Applied (Scenario 2)	7
3	RUSLE Soil Loss Estimates for Permanently Reclaimed Hillslopes at Year 10, Conservation and BTCA Practices Applied and Terraces Installed; No Terraces on K = 0.27 Material (Scenario 3)	9
4	RUSLE Soil Loss Estimates for Permanently Reclaimed Hillslopes at Year 10 With No Installed Terraces, Conservation, or BTCA Practices Applied at Initial Reclamation Except Contour Seeding (Scenario 4)	10

List of Figures

Figure No.		
5.1	Reclaimed Area Erosion Rates Based on Hillslope Gradient and Length	11

List of Appendices

Appendix	
A	K Factor Determination and Supporting Information

Introduction

The use of gradient terraces on farmland, rangeland, and reclaimed hillslopes is an effective practice to control runoff, prevent erosion, and provide landform stability (ASAE, 1997 and USEPA, 2006). Gradient terraces have been used in certain permanent program lands at the Kayenta Complex as a part of Peabody Western Coal Company's (PWCC) Surface Stabilization Program since permit approval in July 1990. Terrace spacing specifications used to date were determined using Revised Universal Soil Loss Equation (RUSLE) Version 1.06 (Toy and Foster, 1998). This version addresses mined and reclaimed lands and considered improved current BTCA reclamation procedures and measurements reflecting actual field conditions found in reclaimed areas for RUSLE input factors. The American Society of Agricultural Engineers (ASAE) promotes the use of slope length and gradient factors, as found in RUSLE, for calculating terrace spacing (ASAE, 1997). This method requires that horizontal terrace spacing not exceed the slope length determined for an allowable soil loss predicted by RUSLE. Another correlative requirement is that sufficient data is available to realistically apply RUSLE. The following details supporting information for determining the horizontal spacing of short segment gradient terraces as first order drainages on upper reclaimed hillslopes at the Kayenta Mine Complex. The information also supports using terraces on only a temporary basis, and it supports the slope configuration situations where no terraces are required.

Analysis Approach

The approach analyzes for erosion and soil loss on newly reclaimed slopes with or without Best Technology Currently Available (BTCA) practices applied and in what scenarios use of terraces would reduce erosion and soil loss. These BTCA practices substantially reduce erosion from what would occur without the use of these systems and in many cases show terraces may only be needed as a temporary measure until vegetation in the watershed is established. In support of this premise, PWCC in cooperation with the Office of Surface Mining Reclamation and Enforcement (OSM) has embarked on a terrace removal and monitoring program at the Kayenta Mine in watersheds stabilized by an effective vegetative cover. The use of residual soils, red rock (scoria), or similar suitable overburden materials that have a high coarse fragment or rock content have been used on select final graded box cuts and highwalls at the Kayenta Complex to enhance reclaimed slope stability and negate or reduce the need for terraces. The approach considers the effectiveness of conservation systems, BTCA practices, use of coarse fragment materials and measures to

APPROVED

reduce slope lengths for a given slope gradient to reduce erosion and provide landform stability. Both RUSLE and EASI (WET, 1990 and Zevenbergen et al., 1990) were used in the soil loss evaluations and in determining where terraces may be appropriate or necessary to aid in landform stability or for use in first order drainages. The following discusses input factors, supporting information, and assumptions for situations where short-segment permanent terraces or temporary terraces will be used.

In order to evaluate where permanent short segment or temporary terraces are used and determine acceptable horizontal spacing of gradient terraces, four reclamation scenarios were developed using RUSLE soil loss estimates as a basis. EASI evaluations were also used for soil loss estimates under similar conditions to support the RUSLE evaluations. The first scenario reflects newly reclaimed areas with minimal BTCA practices, representative reclaimed hillslope topography, the primary plant growth medium or soiling materials including red rock (scoria) mediums, and seeding on the contour. The second scenario includes similar soils and landform factors, but adds conservation system components and BTCA practices (terraces, ripping, contour furrowing, revegetation, and mulching), and evaluates cover and roughness factors from the BTCA practices. The third scenario includes similar reclamation situations found in scenarios one and two, but reflects established vegetation conditions at bond release (year 10), the weathering of contour furrows and roughness, and terraces are in place to reduce slope length. Scenario 4 reflects year 10 with minimal BTCA practices initially applied.

Revised Universal Soil Loss Equation Factors

The Revised Universal Soil Loss Equation is written as follows:

$$A = RKLSCP$$

where,

A = average annual soil loss in tons/acre/year

R = rainfall/runoff erosivity factor

K = soil erodibility factor

LS = hillslope length and steepness factor

C - cover-management factor

P = support practice factor

Further factor development or basis may be found in the four scenario discussions and their accompanying tables. A detailed discussion of RUSLE and the various factor inputs may be found in Guidelines for the Use of the Universal Soil Loss Equation (RUSLE)

Version 1.06 on Mined Lands, Construction Sites, and Reclaimed Lands (Toy and Foster, 1998).

R-Factor. The R factor reflects the erosivity of rainfall and runoff for a given geographical area. The value of R increases as the amount and intensity of rainfall increases. Values for R have been computed for Arizona locations, and for the Black Mesa region, a value of 35 is representative. This value was used in all evaluations.

K-Factor. The K factor is an expression of the inherent erodibility of the soil or surface material at a particular site under standard experimental conditions. The value of K is a function of the particle size distribution, organic matter content, structure, and permeability of the soil or surface material. The K factors used in the RUSLE calculations represent the typical soils used in reclamation as well as values for residual or coarse fragment soils. The basis for determining the K factors used in the evaluations can be found in Appendix A to this document. The mean weighted postmine K value for the PWCC leasehold is 0.38. A K value of 0.43 represents the extreme postmine erodibility situation for soiling materials. The K factor for residual soils, red rock (scoria), or similar suitable overburden materials that have a high coarse fragment or rock content is 0.27.

LS-Factor. Erosion as influenced by topography is accounted for by the LS factor in RUSLE. The effects of a hillslope length factor (L) are combined with a hillslope gradient factor (S) in the calculated LS factor. Soil loss tends to increase as the length or gradient of a hillslope increases. As the length of a hillslope increases, total soil loss and soil loss per unit area increase as a result of progressive accumulation of runoff downslope. With an increase in hillslope gradient, velocity and erosivity of runoff increases. Hillslope lengths and gradients for the four scenarios are representative of conditions that currently exist or are anticipated for reclaimed areas.

C-Factor. The C factor (cover-management) reflects the effect of plants; soil cover including rock cover, soil biomass (roots and incorporated residue); and soil disturbing activities on soil loss. A sub-factor routine in RUSLE is used to compute soil-loss ratios (SLR), which are the ratios of soil loss at any given time in the cover-management sequence to soil loss from the standard condition. The C value is the average soil loss ratio weighted by the distribution of rainfall EI (energy x intensity) during the year.

Inputs for the sub-factors were mostly derived from actual field data or conditions, with the remainder selected from the most representative options in the RUSLE sub-routine. The time-invariant method option was used in all runs and for all scenarios. This method was used because all scenarios represented a point in time or a conservative evaluation for comparison purposes. The specific input parameters or assumptions to determine C factors are discussed in the scenarios and the footnotes of the accompanying tables.

P-Factor. The P factor accounts for practices designed to reduce erosion. The C and P factors are closely allied in their importance. The P factor accounts for practices that reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration, runoff velocity, and hydraulic forces exerted by runoff on soil. Mechanical practices used at the Kayenta Complex including contour deep ripping, disking, and contour seeding are accounted for in the P factor calculation. The type of soiling materials also has an effect on factor P; less erosive soils (lower K factor values) retain contouring features over a longer period of time. These same soils may have more pronounced contouring features when initially developed. The contour furrows have an effect on the establishing vegetation by establishing greater cover in the furrows where moisture is more concentrated. This contouring pattern of the vegetation remains for many years after the soil ridges associated with the furrowing have dissipated. Specific P factor assumptions are presented under the scenario and table discussions.

Soil Loss Predictions

Soil loss predictions calculated from RUSLE were evaluated to aid in determining acceptable horizontal spacing of gradient terraces, either as permanent short segment first order drainage terraces or temporary terraces. These predictions also support the basis for not installing terraces on hill slopes. Three reclamation scenarios were used to provide the RUSLE estimates and management decision criteria.

Scenario 1. This scenario evaluates soil loss on typical reclaimed hillslopes with soil or scoria cover and no BTCA practices except contour drill seeding. Table 1 illustrates the resulting estimated soil loss when evaluated under Scenario 1. As can be seen in Table 1, soil loss is high for all hillslope and gradient combinations except where scoria materials (K = 0.27) are used as a cover/plant growth medium. The more erosive soiling material (K = 0.43) has the highest soil loss estimates. The scoria

MAR 2012

TABLE 1. RUSLE Soil Loss Estimates for Newly Reclaimed Hillslopes with No Conservation or BTCA Practices Except Contour Drill Seeding (Scenario 1)

Slope Length (Feet) [1]	Slope Gradient (%) [2]	RUSLE FACTORS [3]					Estimated Soil Loss T/AC/YR
		R	K	LS	C	P	
350	33	35	0.27	13.40	0.07	0.56	5.0
300	33	35	0.38	12.00	0.77	0.86	106
300	33	35	0.43	12.00	0.77	0.90	125
750	25	35	0.27	16.00	0.07	0.56	5.9
400	25	35	0.38	10.63	0.77	0.86	94
400	25	35	0.43	10.63	0.77	0.90	111
500	20	35	0.38	9.23	0.77	0.86	81
500	20	35	0.43	9.23	0.77	0.90	96
600	15	35	0.38	6.86	0.77	0.86	61
600	15	35	0.43	6.86	0.77	0.90	72
800	10	35	0.38	4.17	0.77	0.86	37
800	10	35	0.43	4.17	0.77	0.90	42

(1) Typical slope lengths corresponding to slope gradients found in reclaimed areas.

(2) Typical slope gradients found in newly reclaimed areas.

(3) Basis for RUSLE subfactors

R = Rainfall erosivity factor for the Black Mesa region

K = Soil erosivity factor

K = 0.27 = Average for scoria derived materials.

K = 0.38 = Typical soiling material

K = 0.43 = Soiling material with higher silt and very fine sand

LS = Hillslope length and gradient factor

Variable based on the combination of gradient and slope length

C = Cover-management factors

C = 0.07 = Scoria material with average 49 percent rock cover, not ripped, seeded on contour, some surface roughness

C = 0.77 = Soiling material with minimal rock cover (1.3 percent), no BTCA except contour seeding

P = Support-practice factor

P = 0.56 = Minimal contouring and roughness effects for scoria materials

P = 0.86 = Minimal contouring effects on typical soils (K = 0.38)

P = 0.90 = Minimal contouring effects on more erosive soils (K = 0.43)

material has high rock content and a fairly rough surface configuration resulting in a

low C factor of 0.07 and a P factor of 0.56. The more typical soiling materials have much higher C factors due to no cover other than a low rock cover of 1.3 percent and very little surface roughness. The P factors for the scoria soils are low due to some contouring but principally from roughness. Again, Scenario 1 demonstrates resulting soil loss with minimal BTCA practices applied. Scenario 1 does not reflect normal BTCA reclamation practices at the Kayenta Complex but is included as a baseline measure, not the typical reclamation.

Scenario 2. Scenario 2 addresses new reclamation of hillslopes where the conservation measures and BTCA practices used at the Kayenta Complex have been applied (Table 2). Slope lengths may reflect the placement of terraces or a typical reclaimed slope length. The exception to this is the 33 percent slope with scoria that is 350 feet long and the 25 percent slope with scoria that is 750 feet long. The scoria rock cover and the contoured surface roughness from ripping results in very low soil loss levels and thus terraces are not required. The more typical soils (K = 0.38 and K = 0.43) also have low soil loss estimates resulting from various conservation and BTCA practices. The conservation and BTCA practices reflect current procedures applied to reclaimed areas at the Kayenta Complex. These include ripping and deep furrow disking on the contour, seeding of a permanent seed mix, and application of an anchored hay mulch at two tons per acre on non-scoria soils (K = 0.38 and K = 0.43).

The low C and P factors of 0.034 and 0.28, respectively, for scoria material reflect the high percentage of rock cover (field measured average of 49 percent) and the very rough field condition following contour ripping and disking. The C factor of 0.05 for soils with K = 0.38 reflects a surface cover of 58.5 percent (57.2 percent mulch and 1.3 percent rock cover) based on field measurements from a 1999 representative reclaimed area in J19 that was hay mulched at two tons per acre. The K = 0.38 soils have a higher random roughness than K = 0.43 soils since surface features are more prevalent and not as impacted by equipment operations resulting in a slightly lower C factor for the K = 0.38 soils. The lower P factors for soils where K = 0.38 also reflect greater ridge height and contouring features than the K = 0.43 soils. Consequently, soils with K = 0.43 have greater C factor values and P factor values because surface roughness, ridge heights, and contouring affects are reduced due to soil textural characteristics and equipment operations. The mulch cover is similar for soils with K = 0.38 or K = 0.43. Slope gradient also has an affect on the P factor.

TABLE 2. RUSLE Soil Loss Estimates for Newly Reclaimed Hillslopes with Terraces Installed at the Specified Slope Lengths and Conservation and BTCA Practices Applied (Scenario 2)

Slope Length (Feet) [1]	Slope Gradient (%) [2]	RUSLE FACTORS [3]					Estimated Soil Loss T/AC/YR
		R	K	LS	C	P	
350	33	35	0.27	13.40	0.034	0.28	1.2
200	33	35	0.38	9.14	0.05	0.36	2.2
200	33	35	0.43	9.14	0.055	0.39	3.0
750	25	35	0.27	16.00	0.034	0.28	1.4
300	25	35	0.38	8.82	0.05	0.29	1.7
250	25	35	0.43	7.83	0.055	0.40	2.6
350	20	35	0.38	7.38	0.05	0.28	1.4
300	20	35	0.43	6.70	0.055	0.41	2.3
450	15	35	0.38	5.79	0.05	0.31	1.2
400	15	35	0.43	5.41	0.055	0.43	1.9
800	10	35	0.38	4.17	0.05	0.34	1.0
800	10	35	0.43	4.17	0.055	0.46	1.6

[1] Typical slope lengths corresponding to slope gradients found in reclaimed areas.

[2] Typical slope gradients found in newly reclaimed areas.

[3] Basis for RUSLE subfactors

R = Rainfall erosivity factor for the Black Mesa region

K = Soil erosivity factor

K = 0.27 = Average for scoria derived materials.

K = 0.38 = Typical soiling material

K = 0.43 = Soiling material with higher silt and very fine sand

LS = Hillslope length and gradient factor

Variable based on the combination of gradient and slope length

C = Cover-management factor

The C factor varies based on the amount of cover and the type and configuration of surface roughness.

P = Support-practice factor

The P factor varies based on the type or degree of tillage practice, contouring, or other surface configuration patterns and the results of the practices relative to the type of soiling materials used.

Scenario 3. The soil loss estimates in the third scenario (Table 3) reflect permanently reclaimed hillslopes at year ten. They also reflect the previous application of a variety of conservation and BTCA practices. Soils or plant growth medium include scoria derived materials (K = 0.27) and more typical soiling materials (K = 0.38 and K = 0.43).

The C factor of 0.039 for the scoria areas reflects potential vegetation cover and residual rock cover based on sampling of several scoria areas reclaimed at the Kayenta Mine in the last several years. The C factor for scoria areas is based on 14 percent non-stratified vegetation cover and 39 percent rock and residue cover, but is also heavily influenced by the remaining good surface roughness. Ridges also influence the P factor of 0.8 and the contouring effects remaining as a result of this more resistant material. Where scoria materials are used, soil loss estimates are low even for very long slopes, and thus terraces are not required.

The C factors for soils with K = 0.38 and K = 0.43 were derived from spring 1998 vegetation sample data for the Black Mesa Complex. Precipitation prior to the sampling was near average. The data were averaged from eight large random sample units located in reclaimed areas from all active coal resource areas of the Complex. Many of the units contained vegetation more than ten years old, and a wide variety of soils and topography were present in the sample units. The resulting cover values included 30 percent non-stratified vegetation cover with 25 percent rock and residue cover. Annual production averaged 960 pounds per acre. The C factor for soils with K = 0.38 is 0.059 reflecting the above cover and production characteristics, but also considers residual surface roughness features. The C factor for soils with K = 0.43 is 0.077 considering the same cover and production values, but with less surface roughness due to more weathering effects for these types of soils. The P factor for both soiling materials equals 1, or no contouring affects remaining. This is a conservative estimate for P since many reclaimed areas retain some contouring and ridge features ten or more years after reclamation. Also, because seeding operations are conducted on the contour and contour furrows provide areas of enhanced moisture during vegetation establishment, vegetation typically becomes oriented in contour strips.

Scenario 4. The soil loss estimates in the fourth scenario (Table 4) reflect permanently reclaimed hillslopes at year ten, but with no application of the variety of conservation and BTCA practices in Scenario 3. This scenario is presented to illustrate the amount of soil loss that would occur if no terraces, conservation, or BTCA practices except

TABLE 3. RUSLE Soil Loss Estimates for Permanently Reclaimed Hillslopes at Year 10, Conservation and BTCA Practices Applied and Terraces Installed; No Terraces on K = 0.27 Material (Scenario 3)

Slope Length (Feet) [1]	Slope Gradient (%) [2]	RUSLE FACTORS [3]					Estimated Soil Loss T/AC/YR
		R	K	LS	C	P	
350	33	35	0.27	13.40	0.039	0.8	3.4
200	33	35	0.38	9.14	0.059	1	7.2
150	33	35	0.43	7.52	0.077	1	8.7
750	25	35	0.27	16.00	0.039	0.8	4.0
300	25	35	0.38	8.82	0.059	1	6.9
200	25	35	0.43	6.77	0.077	1	7.8
350	20	35	0.38	7.38	0.059	1	5.8
250	20	35	0.43	5.98	0.077	1	6.9
450	15	35	0.38	5.79	0.059	1	4.5
300	15	35	0.43	5.00	0.077	1	5.8
600	12	35	0.38	4.85	0.059	1	3.8
600	12	35	0.43	4.85	0.077	1	5.6
800	10	35	0.38	4.17	0.059	1	3.3
800	10	35	0.43	4.17	0.077	1	4.8

[1] Typical slope lengths corresponding to slope gradients found in reclaimed areas.

[2] Typical slope gradients found in established and newly reclaimed areas.

[3] Basis for RUSLE subfactors

R = Rainfall erosivity factor for the Black Mesa region

K = Soil erosivity factor

K = 0.27 = Average for scoria derived materials.

K = 0.38 = Typical soiling material

K = 0.43 = Soiling material with higher silt and very fine sand

LS = Hillslope length and gradient factor

Variable based on the combination of gradient and slope length

C = Cover-management factor

The C factor varies based on the amount of cover and the type and configuration of surface roughness.

P = Support-practice factor

The P factor varies based on the type or degree of tillage practice, contouring, or other surface configuration patterns and the results of the practices relative to the type of soiling materials used.

TABLE 4. RUSLE Soil Loss Estimates for Permanently Reclaimed Hillslopes at Year 10 with No Installed Terraces, Conservation, or BTCA Practices Applied at Initial Reclamation Except Contour Seeding (Scenario 4)

Slope Length (Feet) [1]	Slope Gradient (%) [2]	RUSLE FACTORS [3]					Estimated Soil Loss T/AC/YR
		R	K	LS	C	P	
300	33	35	0.38	12.00	0.18	1	28.7
300	33	35	0.43	12.00	0.18	1	32.5
400	25	35	0.38	10.63	0.18	1	25.4
400	25	35	0.43	10.63	0.18	1	28.8
500	20	35	0.38	9.23	0.18	1	22.1
500	20	35	0.43	9.23	0.18	1	25.0
600	15	35	0.38	6.86	0.18	1	16.4
600	15	35	0.43	6.86	0.18	1	18.6
800	10	35	0.38	4.17	0.18	1	10.0
800	10	35	0.43	4.17	0.18	1	11.3

(1) Typical slope lengths corresponding to slope gradients found in reclaimed areas.

(2) Typical slope gradients found in established and newly reclaimed areas.

(3) Basis for RUSLE subfactors

R = Rainfall erosivity factor for the Black Mesa region

K = Soil erosivity factor

K = 0.38 = Typical soiling material

K = 0.43 = Soiling material with higher silt and very fine sand

LS = Hillslope length and gradient factor

Variable based on the combination of gradient and slope length

C = 0.18 = Cover management factor.

The C factor of 0.18 reflects reduced permanent cover and production because of limited initial BTCA and conservation practices applied.

P = Support-practice factor

The P factor of 1 reflects limited remaining contouring or other surface features.

establishment of vegetation were present. In comparing the results of Table 3 and Table 4, it can be seen that a substantial reduction in soil loss will occur with installed terraces and applied conservation and BTCA practices.

MAR 2012
APPROVED

EASI was also used to investigate how hillslope sediment yield varies with hillslope gradient and hillslope length and to determine the conditions when erosion could be controlled using terraces. The model used rectangular hillslopes with straight terraces located at the downstream ends of the hillslopes. The hillslopes were configured with different gradients, lengths, and hillslope base lengths for the different scenarios. The terraces were configured with different gradients and lengths. The hillslope base length was always set equal to the terrace length. The vegetative cover was assumed to be typical for reclaimed cover types and amounts from previous modeling, such as the modeling of the Phase 2 bond release for CRA N14 (Ayres Associates, 2008).

Figure 5.1 shows the impacts of hillslope gradient and length on the hillslope's annual average unit sediment yield. The unit sediment yield increases as hillslope gradient and length increase. Hillslopes that are long and steep (i.e. at the top right corner of the figure) have the greatest erosion and sediment yield. Terraces, as an erosion control measure, are necessary only for the longest and steepest hillslopes. Terraces control erosion by reducing hillslope length. Based on the EASI analysis it is reasonable to have few hillslopes that are eroding at rates greater than 0.8 t/ac/yr. For example, a hillslope with a gradient of 25% and a length of 500 feet will have a unit sediment yield slightly larger than 1 t/ac/yr. If a terrace is designed to cut the long hillslope into halves, the two hillslopes become 250 feet in length and have a unit sediment yield less than 0.8 t/ac/yr. Figure 5.1 also implies the relation between terrace spacing and hillslope gradient. As hillslope gradient increases, terrace spacing should be reduced to maintain a specific erosion rate. It may therefore be beneficial to include terraces for areas with erosion rates in excess of 1 ton/acre/year.

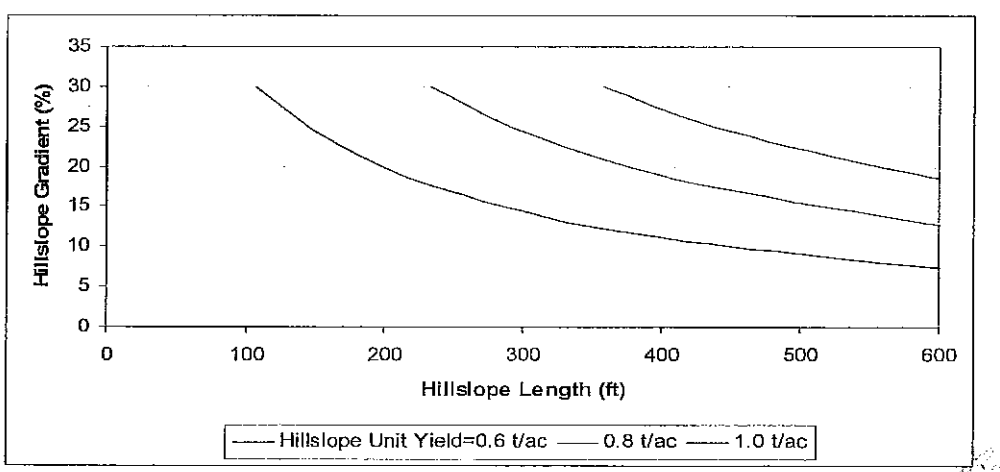


Figure 5.1 Reclaimed Area Erosion Rates Based on Hillslope Gradient and Length.

Terrace Spacing

Terrace spacing is based on the slope length, slope gradient, soil K factors, RUSLE factors, and RUSLE soil loss estimates presented in Tables 2 and 3. Comparing Tables 2 and 3 shows terraces could be spaced farther apart and still achieve low soil losses. Table 2 is based on initial reclamation and considers slope lengths based on installed terraces and applied BTCA and conservation practices. Applied BTCA practices greatly influence surface roughness and contouring features and have a resulting lowering effect on the C and P factors for initial reclamation. These effects are gradually reduced over time and P will approach 1. Therefore, determining terrace spacing on the basis of factors presented in Table 3 is a more realistic approach for long-term stability evaluations. Hillslopes covered with high coarse fragment soils such as scoria-derived materials have low soil loss estimates regardless of hillslope gradients and lengths and thus terraces are not required on slopes with these materials. High coarse fragment materials may be placed on portions of reclaimed slopes to reduce soil loss and a need for terraces. For slopes with more common soiling K factors (0.38 or 0.43), slope gradient will be a significant factor in the spacing, as will the type of soiling materials. Terrace spacing for soiling materials with K factor 0.43 (more erosive soils with higher silt and very fine sand) will be reduced when compared to areas with slopes soiled with materials approximating K = 0.38. Generally, slopes of 15 percent or less will not require terraces and terraces will not be required for any areas with slopes 10 percent or less.

The cover-management factor (C) in Table 3 has been determined from extensive data and accurately reflects the benefits of long-term cover achievable at the Kayenta Complex and documented by annual vegetation monitoring and observation. The J-21 reclaimed areas have a significant reduction in the number of installed terraces, particularly in more recently reclaimed areas. The J-21 reclaimed landform is well vegetated and stable; analysis for Phase 2 bond release shows sediment yields are less than unmined conditions. Further, PWCC is removing a number of previously installed terraces in well vegetated reclaimed lands and to date show no negative impacts in terms of added erosion or landform instability. This confirms significantly fewer terraces, or the linear extent of terraces, need to be considered in ongoing reclamation operations. This is also supported by the EASI analysis. The focus is now on periodic placement of first order short segment gradient terraces and the possible use of terraces on a temporary basis for certain large planar slopes in regraded areas that are transitional to more geomorphic

grading practices or reflect a unique operational/reclamation constraint.

The effectiveness of applied BTCA practices is demonstrated when looking at Tables 3 and 4. Permanently reclaimed lands ten or more years old with applied BTCA practices and terraces installed (Table 3) are estimated to have greater than a 70 percent reduction in soil loss compared to permanently reclaimed lands with little or no BTCA practices and no terraces installed (or as longer slope lengths) (Table 4). The cover-management factor (C) used in Table 4 evaluations is based on reduced cover and productivity as a result of increased soil loss and reduced landform stability.

Based on the above analyses and the concept of substantial reductions in soil loss, the following horizontal spacings of gradient terraces for corresponding slopes and soil types K = 0.38 and K = 0.43 are recommended. Horizontal spacing will be interpolated for intermediate gradients. Terraces are not required for scoria derived materials or other plant growth medium with K values of 0.27 or less.

Soil Type K = 0.38

Horizontal Spacing (ft)[1]	Slope Gradient[2]
200	33
300	25
350	20
450	15
800	10

Soil Type K = 0.43

Horizontal Spacing (ft)[1]	Slope Gradient[2]
150	33
200	25
250	20
300	15
800	10

[1] Maximum recommended distance between terraces for a corresponding gradient.

[2] Horizontal spacing will be interpolated for intermediate gradients.

APPROVED

References (also includes Appendix A)

ASAE. 1997. Design, Layout, Construction and Maintenance of Terrace Systems. ASAE Standard S268.4. American Society of Agricultural Engineers. St. Joseph, MI. December 1997.

Ayres Associates. 2008. Surface water modeling of the reclaimed N14 Coal Resource Area at Kayenta Mine, prepared for Peabody Western Coal Company.

McCormack D.E., K.K. Young, and G.M. Darby. 1984. Rock fragments and the K factor of the universal soil loss equation. In: Erosion and Productivity of Soils Containing Rock Fragments. Special Publication Number 13. Soil Science Society of America. Madison, Wisconsin. p. 73-81.

Nyenhuis, J. (ERT, Inc.). 1988. Soil Baseline Study for Nucla East. In: Nucla Mine Permit Revision No. 2. Peabody Coal Company, Western Division, Flagstaff, Arizona. p. 9-5-47.

Peabody Coal Company (PCC). 1988 and 1992. 1986 and 1988-1991 Minesoil Reconstruction Reports for the Kayenta Mine J-21 Resource Area. Flagstaff, Arizona. Reports prepared for: The Office of Surface Mining Reclamation and Enforcement, Western Service Center, Denver Colorado.

Peabody Western Coal Company (PWCC). 1993-2001. 1992-2000 Minesoil Reconstruction and Revegetation Activities Reports, Black Mesa and Kayenta Mines. Flagstaff, Arizona. Reports prepared for: The Office of Surface Mining Reclamation and Enforcement, Western Service Center, Denver Colorado.

Schafer, W.M., G.A. Nielsen, D.J. Dollhopf, and K. Temple. 1979. Soil Genesis, hydrological properties, root characteristics, and microbial activity of 1- to 50-year old strip-mine spoils. EPA-600/7-79-100. U.S. Environmental Protection Agency. Washington, D.C.

Toy and Foster. 1998. Guidelines for the Use of the Revised Universal Soil Loss Equation (RUSLE) on Mined Lands, Construction Sites, and Reclaimed Lands. Version 1.06. T.J. Toy and G.R. Foster co-editors. OTT,WRC,OSM. Denver, Colorado.

Trenholme, J.R. (InterMountain Soils). 1985. K Factor Determination for Black Mesa Small Watershed Study Plots. Peabody Coal Company, Western Division. Flagstaff, Arizona.

USEPA. 2006. National Pollutant Discharge Elimination System (NPDES) National Menu of Stormwater Best Management Practices (BMPs). Gradient Terraces. URL:http://cfpub.epa.gov/npdes/sotrmwater/menuofbmps/index.cfm.

Water Engineering & Technology, Inc. (WET). 1990. "Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control Technology at Surface Mines in the Semiarid West", prepared for the Office of Surface Mining and the National Coal Association, Fort Collins, Colorado.

Zevenbergen, L.Z., M.R. Peterson, and C.C. Watson. 1990. "Computer Simulation of Watershed Runoff and Sedimentation Processes". Proceedings of the Billings Symposium; Planning, Rehabilitation and Treatment of Disturbed Lands.

APPENDIX A

K FACTOR DETERMINATION AND SUPPORTING INFORMATION

Appendix A to Attachment B, Terrace Spacing

K factor Determination and Supporting Information

Appendix A

K factor Determination and Supporting Information

K Factor for Topsoil. The K factors for topsoil salvage materials were determined as follows. Premine soil erodibility (K) values were determined for each projected mine pit disturbance area using Order 1/2 soil survey maps prepared by Intermountain Soils (IMS). These Order 1/2 maps (Volume 19, Drawing 85305A, Sheets 1-15) have a scale of 1"=400'. These maps were used to calculate the percentage of the different map units and soil series in each mine pit disturbance area as presented in Tables 15 and 16, respectively, as found in Appendix A of Volume 11A). This provides an estimate of the type and amount of soiling materials available for reclamation within the various pit areas.

Postmine K factor values are dependent upon premine soil types and projected topsoil salvage depths. IMS determined premine soil types and projected topsoil salvage depths as discussed in Appendix A (Volume 11A) and as shown on Drawings 85305A (Sheets 1-15, Volume 19) and 85305B (Sheets 1-15, Volumes 19 and 20). A K factor for each surface and subsurface horizon by soil series sample site was calculated using the RUSLE program and site specific analyses data contained in Attachments 2, 3, 4, and 5 of Appendix A (Volume 11A). The K Factor values were not adjusted for the volumetric rock fragment content as recommended by Toy and Foster (1998). Table 1 shows each sample site, soil horizon thickness, and the respective K factors. This information was used to determine weighted "K" values. These weighted values were summed for the entire topsoil salvage section to determine mean weighted postmine K values for each sample site and each soil series. The estimated disturbance areas for these soils types were multiplied by the respective "K" factor and topsoil salvage depth for the respective soil series to determine weighted postmine K values (Table 2). These weighted values were then summed to determine the mean weighted postmine K value of 0.38 for the entire projected Black Mesa leasehold disturbance area (Table 2). The mean postmine K value of 0.38 was utilized to determine the terrace spacing for a commonly anticipated reclaimed area soiling material as presented in the scenarios in Attachment B.

The upper limit K = 0.43 utilized in the scenarios represents the extreme postmine erodibility situation for soiling materials. The 0.43 K value was determined from information presented in Tables 1 and 2. Mean soil series K factor information presented in Table 2 shows 96 percent of the salvaged topsoil will have an erodibility value less than 0.43. Individual soil type and sample increment K factor values presented in Table 1 indicates 85 percent of the salvaged

topsoil will have an erodibility value less than 0.43. The actual percentage of postmine K values less than 0.43 will range between 85 and 96 percent depending upon the degree of mixing which occurs during topsoil salvage, storage, and redistribution. K = 0.43 provides a conservative estimate.

K Factor for Supplemental Plant Growth Medium. Suitable overburden will be utilized as a surface plant growth medium (topsoil supplement) for reclamation of steep slope areas and to develop planting sites for cultural plants at the Kayenta Complex (see the Material Redistribution Plans section of Chapter 22). Suitable overburden is recommended primarily for its inherent stability, low erodibility potential, and as an appropriate plant growth medium for pinyon pine and other culturally significant plants. Rock fragments on the surface and in the surface layer will protect the plant growth medium from wind and water erosion. Rock fragments protect the soil from erosion mainly by attenuating raindrop impact energy, causing flow energy to be dissipated on nonerodible fragments, and slowing the velocity of surface runoff (McCormack et al., 1984). Rock fragments in the supplemental plant growth medium profile have been disregarded for factor K in RUSLE as recommended by Toy and Foster (1998). Rock fragments on the surface are accounted for in C factor calculations.

K factor values for typical suitable overburden materials (red rock) and suitable regraded spoil are shown in Table 3. The suitable overburden material values are derived from samples collected in reclaimed areas with established red rock sites. These red rock sites are in the J19, J21, N11, and N14 pit areas. Rock or coarse fragment volumetric content for the suitable overburden materials ranged from 50 percent to 75 percent. K factors for these materials averaged 0.27 and varied from .32 for clay loam red rock materials to .23 for sandy loam red rock materials. Sandy loam red rock materials are highly representative of the types of red rock areas established. However, the more conservative average K value of 0.27 was used in the scenarios. The K factor value of .29 for suitable regraded spoil represents a value determined from the averaged parameter information contained in the extensive PWCC spoil sampling database for regraded areas at the Kayenta Mine. Rock or coarse fragment volumetric content for the suitable regraded spoil material averaged 45 percent. This regraded spoil data was included in annual Minesoil Reconstruction and Revegetation Activities Reports submitted to OSMRE (PCC, 1988; PCC, 1992; PWCC, 1993-2001).

Table 1

Postmine Soil Erodibility (K) Factor Determination by

Soil Type and Sample Increment[1]

Stop No. 27-108: Begay

Depth (Inches)	0-3	3-13	13-33	33-50	50-71	71-86
Permeability[2]	2	2	3	2	2	2
Organic Matter(%)[3]	2.0	1.5	1.5	1.0	0.5	0.5
K Value	0.41	0.32	0.36	0.35	0.44	0.25

Stop No. 12-12: Begay

Depth (Inches)	0-3	3-9	9-21	21-35	35-59	59-83	83-112	112-137
Permeability	2	2	2	3	2	2	3	3
Organic Matter (%)	2.0	2.0	1.5	1.5	1.0	0.5	0.5	0.5
K Value	0.53	0.45	0.40	0.46	0.54	0.50	0.55	0.50

Stop No. ISS-30079 - 12 Thru 16: Begay

Depth (Inches)	0-10	10-22	22-33	33-43	43-60
Permeability	2	2	2	2	2
Organic Matter (%)	2.0	1.5	1.0	1.0	0.5
Very Fine Sand (%)[4]	30	32	29	29	31
K Value	0.33	0.34	0.37	0.38	0.38

Stop No. ISS-28979 - 1 thru 5: Begay

Depth (Inches)	0-6	6-12	12-38	38-50	50-60
Permeability	2	2	2	2	3
Organic Mater (%)	2.0	1.5	1.5	1.0	0.5
Very Fine Sand (%)	23	24	24	25	31
K Value	0.29	0.30	0.31	0.30	0.39

Stop No. ISS-28979 - 6 thru 9: Begay

Depth (Inches)	0-2	2-26	26-52	52-65
Permeability	2	2	2	2
Organic Matter (%)	2.0	1.5	1.0	0.5
Very Fine Sand (%)	28	27	25	25
K Value	0.39	0.28	0.33	0.37

Table 1 (Cont.)

Postmine Soil Erodibility (K) Factor Determination by

Soil Type and Sample Increment[1]

Stop No. ISS-28979 - 10 thru 14: Begay

Depth (Inches)	0-7	7-20	20-41	41-54	54-60
Permeability	2	2	2	2	2
Organic Matter (%)	2.0	1.5	1.0	0.5	0.5
Very Fine Sand (%)	23	24	26	26	28
K Value	0.34	0.32	0.35	0.35	0.31

Stop No. 19-5: Bond

Depth (Inches)	0-3	3-10	10-16
Permeability	2	3	3
Organic Matter (%)	2.0	1.5	1.0
K Value	0.49	0.45	0.42

Stop No. 12-48: Cahona

Depth (Inches)	0-2	2-10	10-25	25-39	39-71	71-88
Permeability	2	3	3	2	2	3
Organic Matter (%)	2.0	1.5	1.5	1.0	0.5	0.5
K Value	0.41	0.38	0.40	0.40	0.44	0.45

Stop No. 10-2: Cahona

Depth (Inches)	0-3	3-11	11-22	22-39	39-55
Permeability	2	2	3	3	3
Organic Matter (%)	2.0	1.5	1.5	1.0	0.5
K Value	0.61	0.47	0.47	0.40	0.28

Stop No. 121-224: Cahona

Depth (Inches)	0-2	2-4	4-12	12-20	20-38	38-54	54-77	77-102	102-119	119-141	141-171	171-186
Permeability	2	3	3	2	3	3	3	3	2	3	3	2
Organic Matter (%)	2.0	2.0	1.5	1.5	1.0	1.0	1.0	0.5	0.5	0.5	0.0	0.0
K Value	0.48	0.37	0.43	0.45	0.46	0.47	0.37	0.40	0.36	0.28	0.37	0.24

Table 1 (Cont.)

Postmine Soil Erodibility (K) Factor Determination by

Soil Type and Sample Increment[1]

Stop No. 11-1: Cahona

Depth (Inches)	0-3	3-15	15-23	23-48	48-83
Permeability	2	2	2	2	2
Organic Matter (%)	2.0	1.5	1.0	1.0	0.5
K Value	0.64	0.55	0.50	0.55	0.70

Stop No. 19-61: Cahona

Depth (Inches)	0-1	1-3	3-12	12-19	19-29	29-40	40-64
Permeability	2	2	2	2	2	2	2
Organic Matter (%)	2.0	2.0	1.5	1.5	1.0	1.0	0.5
K Value	0.42	0.34	0.27	0.34	0.27	0.25	0.13

Stop No. 11-6: Cahona

Depth (Inches)	0-3	3-9	9-18	18-42	42-61	61-73	73-83	83-97
Permeability	2	2	2	2	2	2	3	2
Organic Matter (%)	2.0	1.5	1.5	1.0	0.5	0.5	0.5	0.5
K Value	0.58	0.45	0.47	0.48	0.43	0.24	0.38	0.48

Stop No. 11-67: Cahona

Depth (Inches)	0-3	3-12	12-22	22-29	29-46	46-75	75-93
Permeability	2	2	2	2	2	2	2
Organic Matter (%)	2.0	1.5	1.5	1.0	1.0	0.5	0.5
K Value	0.53	0.47	0.39	0.41	0.43	0.48	0.32

Stop No. ISS-29879 - 11 thru 14: Cahona

Depth (Inches)	0-9	9-20	20-32	32-60
Permeability	3	2	2	5
Organic Matter (%)	1.5	1.5	1.0	0.5
Very Fine Sand (%)	30	34	28	18
K Value	0.38	0.35	0.28	0.33

Table 1 (Cont.)

Postmine Soil Erodibility (K) Factor Determination by

Soil Type and Sample Increment[1]

Stop No. ISS-29979 - 1 thru 4: Cahona

Depth (Inches)	0-7	7-24	24-45	45-60
Permeability	2	3	5	3
Organic Matter (%)	2.0	1.5	1.0	0.5
Very Fine Sand (%)	25	28	12	29
K Value	0.39	0.35	0.27	0.30

Stop No. ISS-2997 - 7 thru 10: Cahona

Depth (Inches)	0-10	10-22	22-35	35-46
Permeability	2	2	2	3
Organic Matter (%)	1.5	1.5	1.0	0.5
Very Fine Sand (%)	27	30	29	32
K Value	0.31	0.41	0.36	0.37

Stop No. ISS-29979 - 11 thru 14: Cahona

Depth (Inches)	0-10	10-17	17-30	30-40
Permeability	3	2	5	5
Organic Matter (%)	1.5	1.5	1.0	0.5
Very Fine Sand (%)	30	25	23	16
K Value	0.38	0.36	0.31	0.34

Stop No. ISS-2997 - 15 thru 18: Cahona

Depth (Inches)	0-10	10-26	26-39	39-60
Permeability	2	3	3	3
Organic Matter (%)	1.5	1.0	1.0	0.5
Very Fine Sand (%)	28	28	32	26
K Value	0.42	0.40	0.38	0.34

Table 1 (Cont.)

Postmine Soil Erodibility (K) Factor Determination by

Soil Type and Sample Increment[1]

Stop No. ISS-29879 - 18 thru 20: Dulce

Depth (Inches)	0-2	2-9	9-12
Permeability	2	3	2
Organic Matter (%)	2.0	1.5	1.5
Very Fine Sand (%)	22	31	23
Rocky Frag (% by vol)[5]	40	25	25
K Value	0.30	0.35	0.33

Stop No. ISS-300079 - 3 thru 5: Dulce

Depth (Inches)	0-1	1-7	7-12
Permeability	2	2	2
Organic Matter (%)	1.5	1.0	0.5
Very Fine Sand (%)	24	22	22
Rock Frag (% by vol)	40	25	25
K Value	0.35	0.34	0.35

Stop No. ISS-30079 - 6 thru 8: Dulce

Depth (Inches)	0-2	2-9	9-14
Permeability	2	2	2
Organic Matter (%)	2.0	1.5	1.0
Very Fine Sand (%)	22	28	28
Rock Frag (% by vol)	40	25	25
K Value	0.37	0.37	0.43

Stop No. 12-110: Dulce

Depth (Inches	0-1	1-6
Permeability	2	2
Organic Matter (%)	2.0	2.0
K Value	0.31	0.21

Table 1 (Cont.)

Postmine Soil Erodibility (K) Factor Determination by

Soil Type and Sample Increment[1]

Stop No. 12-263: Dulce

Depth (Inches)	0-2	2-7
Permeability	3	3
Organic Matter (%)	2.0	2.0
K Value	0.40	0.34

Stop No. 19-64: Las Lucas

Depth (Inches)	0-1	1-4	4-17	17-31
Permeability	2	5	5	3
Organic Matter (%)	2.0	2.0	1.5	1.5
K Value	0.36	0.34	0.32	0.33

Stop No. 14-13: Las Lucas

Depth (Inches)	0-5	5-20	20-38	38-59	59-96	96-110	110-132
Permeability	3	5	5	2	1	1	2
Organic Matter (%)	2.0	2.0	1.5	1.0	1.0	0.5	0.5
K Value	0.32	0.31	0.33	0.51	0.22	0.20	0.19

Stop No. 15-9: Las Lucas

Depth (Inches)	0-4	4-9	9-26	26-60	60-84	84-108	108-120
Permeability	2	2	3	4	3	2	3
Organic Matter (%)	2.0	2.0	1.5	1.0	0.5	0.5	0.5
K Value	0.33	0.33	0.38	0.39	0.34	0.22	0.29

Stop No. 15-9DSS: Las Lucas

Depth (Inches)	120-144	144-168	168-192	192-216	216-240	240-264
Permeability	3	3	2	2	3	2
Organic Matter (%)	0.5	0.0	0.0	0.0	0.0	0.0
K Value	0.35	0.32	0.25	0.27	0.36	0.35

Table 1 (Cont.)

Postmine Soil Erodibility (K) Factor Determination by

Soil Type and Sample Increment [1]

Stop No. 12-111: Las Lucas

Depth (Inches)	120-144	144-168	168-192	192-216
Permeability	4	4	3	4
Organic Matter (%)	0.0	0.0	0.0	0.0
Very Fine Sand (%)	20	18	34	24
K Value	0.35	0.37	0.37	0.34

Stop No. 19-67: Las Lucas

Depth (Inches)	0-24	24-48	48-72	72-96
Permeability	3	2	3	3
Organic Matter (%)	1.5	1.0	1.0	0.5
Very Fine Sand (%)	27	25	27	26
K Value	0.38	0.30	0.34	0.39

Stop No. 19-69: Las Lucas

Depth (Inches)	0-24	24-48	48-72	72-96
Permeability	3	4	3	4
Organic Matter (%)	1.5	1.0	1.0	0.5
Very Fine Sand (%)	30	19	26	19
K Value	0.38	0.36	0.38	0.37

Stop No. ISS-28979 - 15 thru 18: Las Lucas

Depth (Inches)	0-10	10-22	22-40	40-60
Permeability	2	2	3	2
Organic Matter (%)	1.5	1.5	1.0	0.5
Very Fine Sand (%)	27	27	27	40
K Value	0.31	0.27	0.24	0.34

Table 1 (Cont.)

Postmine Soil Erodibility (K) Factor Determination by

Soil Type and Sample Increment [1]

Stop No. ISS-28979 - 19 thru 22: Las Lucas

Depth (Inches)	0-8	8-19	19-43	43-60
Permeability	2	2	2	3
Organic Matter (%)	1.5	1.5	1.0	0.5
Very Fine Sand (%)	26	24	20	34
K Value	0.47	0.51	0.33	0.39

Stop No. ISS-29879 - 1 thru 5: Las Lucas

Depth (Inches)	0-8	8-24	24-36	36-46	46-60
Permeability	2	3	2	2	2
Organic Matter (%)	2.0	1.5	1.0	1.0	0.5
Very Fine Sand (%)	30	26	30	32	32
K Value	0.39	0.33	0.31	0.32	0.32

Stop No. ISS-29879 - 6 thru 10: Las Lucas

Depth (Inches)	0-10	10-30	30-40	40-50	50-60
Permeability	2	3	2	2	2
Organic Matter (%)	1.5	1.5	1.0	0.5	0.5
Very Fine Sand (%)	24	31	22	25	23
K Value	0.30	0.39	0.35	0.38	0.39

Stop No. 190-55: Oelop

Depth (Inches)	0-4	4-10	10-20	20-40	40-60	60-84	84-108	108-132	132-156
Permeability	2	2	3	5	4	5	5	5	5
Organic Matter (%)	2.0	2.0	1.5	1.5	1.0	0.5	0.5	0.5	0.0
K Value	0.38	0.29	0.33	0.29	0.32	0.37	0.39	0.38	0.34

Stop No. 12-259: Oelop

Depth (Inches)	0-3	3-7	7-13	13-28	28-55	55-72	72-96	96-132	132-156	156-180	180-210
Permeability	3	4	4	3	4	2	3	3	2	3	3
Organic Matter (%)	2.0	2.0	1.5	1.5	1.0	0.5	0.5	0.5	0.5	0.0	0.0
K Value	0.39	0.40	0.36	0.37	0.38	0.35	0.41	0.44	0.51	0.45	0.48

Table 1 (Cont.)

Postmine Soil Erodibility (K) Factor Determination by

Soil Type and Sample Increment [1]

Stop No. 12-231: Oelop

Depth (Inches)	0-24	24-48	48-72	72-96	96-120	120-144	144-168
Permeability	4	4	3	3	2	3	3
Organic Matter (%)	1.5	1.0	1.0	0.5	0.5	0.5	0.0
Very Fine Sand (%)	25	22	32	31	28	35	31
K Value	0.33	0.33	0.36	0.32	0.33	0.38	0.35

Stop No. 5-1: Pulpit

Depth (Inches)	0-3	3-12	12-23	23-30
Permeability	2	2	3	3
Organic Matter (%)	2.0	1.5	1.5	1.0
K Value	0.59	0.43	0.41	0.43

Stop No. 13-14: San Mateo

Depth (Inches)	0-4	4-9	9-24	24-47	47-73	73-97	97-111	111-144	144-168
Permeability	2	3	4	3	2	3	2	2	2
Organic Matter (%)	2.0	1.5	1.5	1.0	1.0	0.5	0.5	0.5	0.0
K Value	0.53	0.49	0.40	0.43	0.42	0.52	0.50	0.44	0.45

Stop No. 19-65: San Mateo

Depth (Inches)	0-6	6-13	13-30	30-48	48-72	72-96
Permeability	4	3	2	3	5	5
Organic Matter (%)	2.0	1.5	1.5	1.0	0.5	0.5
K Value	0.35	0.28	0.19	0.39	0.40	0.40

Stop No. 19-68: San Mateo

Depth (Inches)	0-24	24-48	48-72	72-96
Permeability	3	4	3	3
Organic Matter (%)	1.5	1.0	1.0	0.5
Very Fine Sand (%)	20	16	25	24
K Value	0.36	0.37	0.38	0.37

Table 1 (Cont.)

Postmine Soil Erodibility (K) Factor Determination by

Soil Type and Sample Increment [1]

Stop No. 12-213: Sharps

Depth (Inches)	0-2	2-5	5-10	10-17	17-24	24-31
Permeability	2	2	2	3	3	5
Organic Matter (%)	2.0	2.0	1.5	1.0	1.0	0.5
K Value	0.33	0.34	0.31	0.36	0.32	0.32

Stop No. 19-48: Sharps

Depth (Inches)	0-2	2-6	6-15	15-21	21-27
Permeability	2	3	4	3	5
Organic Matter (%)	2.0	2.0	1.5	1.0	0.5
K Value	0.46	0.41	0.38	0.33	0.26

Stop No. 12-54: Sharps

Depth (Inches)	0-2	2-5	5-11	11-27	27-34
Permeability	2	3	3	3	4
Organic Matter (%)	2.0	2.0	1.5	1.0	0.5
K Value	0.42	0.32	0.34	0.38	0.33

Stop No. 6-2: Sharps

Depth (Inches)	0-2	2-10	10-30
Permeability	2	2	2
Organic Matter (%)	2.0	2.0	1.0
K Value	0.60	0.69	0.54

Stop No. 27-41: Travessilla

Depth (Inches)	0-2	2-7
Permeability	2	2
Organic Matter (%)	1.5	1.0
K Value	0.25	0.14

Table 1 (Cont.)

Postmine Soil Erodibility (K) Factor Determination by

Soil Type and Sample Increment[1]

Stop No. 12-66: Zyme

Depth (Inches)	0-1	1-3	3-6
Permeability	3	5	5
Organic Matter (%)	1.0	1.0	0.5
K Value	0.37	0.28	0.32

Stop No. 12-261: Zyme

Depth (Inches)	0-3	3-6
Permeability	5	5
Organic Matter (%)	1.0	0.5
K Value	0.33	0.38

Stop No. ISS-29879 - 15 thru 17: Zyme

Depth (Inches)	0-6	6-11	11-15
Permeability	5	5	5
Organic Matter (%)	1.0	0.5	0.5
Very Fine Sand (%)	12	5	10
Rock Frag (% by vol)	40	15	15
K Value	0.34	0.32	0.35

Stop No. ISS-30079 - 1 thru 2: Zyme

Depth (Inches)	0-5	5-8
Permeability	4	5
Organic Matter (%)	1.0	0.5
Very Fine Sand (%)	24	14
Rock Frag (% by vol)	40	15
K Value	0.32	0.28

Table 1 (Cont.)

Postmine Soil Erodibility (K) Factor Determination by

Soil Type and Sample Increments[1]

Stop No. ISS-30079 - 9 thru 11: Zyme

Depth (Inches)	0-8	8-13	13-16
Permeability	4	3	5
Organic Matter (%)	1.0	0.5	0.5
Very Fine Sand (%)	12	13	7
Rock Frag (% by vol)	40	15	15
K Value	0.37	0.35	0.34

Stop No. ISS-30079 - 17 thru 20: Zyme

Depth (Inches)	0-3	3-9	9-19	19-23
Permeability	3	3	5	2
Organic Matter (%)	1.0	0.5	0.5	0.5
Very Fine Sand (%)	21	20	9	20
Rock Frag (% by vol)	40	15	15	20
K Value	0.37	0.34	0.33	0.51

---

[1]Textural analysis data is contained in Volume 11A, Appendix A, Attachments 2, 3, 4, and 5. Very fine sand data is presented in Volume 11A, Appendix A, Attachments 2 and 4. Soil structure for the postmine soil surface was assumed to be blocky, platy, or massive.

[1]Soil permeability determined from guideline information presented in Trenholme (1985) and Nyenhuis (1988): 1 - rapid; 2 - moderately rapid; 3 - moderate; 4 - moderately slow; 5 - slow.

[1]Organic matter percentages were estimated based upon normal depth/organic carbon distribution patterns (Schafer et al., 1979) and historical postmine topsoil organic matter content sampling at Black Mesa/Kayenta whereby the mean organic matter percentages for 207 samples was 1.1 percent with a standard deviation of 0.6 percent.

[1]Very fine sand values were estimated by texture class using very fine sand/sand ratio information presented in Volume 11A, Appendix A. Attachments 2 and 4 whereby silty clay loam - 73 percent; silty clay - 67 percent; silt loam - 61 percent; loam - 58 percent; sandy clay loam- 57 percent; clay loam - 57 percent; sandy loam - 41 percent; and clay - 40 percent.

[1]Rock fragment content (percent by volume) was estimated from typical series description data presented in Volume 11, Appendix A, Attachments 2 and 6.

MAR 2012
APPROVED

Table 2

Mean Postmine Soil Erodibility (K) Factor Values by Soil Series, Disturbance Area, and Topsoil Salvage Depth

Soil Type	Map Unit Designation	Area (Acres)[1]	Salvage Depth[2] (feet)	K Value[3]
Bond	2B	74.9	1.0	0.45
Dulce	1A,1,1B,1C,1D,3A,3BC,3C,3D,3E	4)	4)	0.33[4]
Pulpit	5	493.3	2.5	0.44
Sharps	6,6A,6B,6C	451.0	2.5	0.40
Travessilla	7B,7C,7D,7E	4)	4)	0.17[4]
Cahona	10,10A,10B,10C	4990.8	5.0	0.38
Cahona	11,11A,11B,11C	806.0	10.0	0.41
Cahona	X11,X11A,X11B,X11C	326.7	7.6	0.40
Begay	12,12A,12B,12C	251.9	9.7	0.39
San Mateo	13A	182.4	14.7	0.40
Oelop	14A,14B	68.3	9.7	0.38
Las Lucas	15A	859.9	11.6	0.33
Zyme	3A,3BC,3C,3D,3E,7B,7C,7D,7E	4)	4)	0.34[4]
TOTAL		4014.2	7.78	0.38

[1]This information is presented in Volume 11A, Appendix A, Table 15.

[2]This information is presented in Volume 19, Drawing 85305A, Sheets 1-15.

[3]Weighted means for the soil series were calculated from data presented in Table 1.

[4]The Dulce and Travessilla soils will be salvaged on as an needed direct haul basis for replacement within key habitat, cultural plantings, or steep-slope reclamation areas (see Chapter 22, Material Redistribution Plan). Zyme soils may also be replaced within these unique reclamation areas because the soil comprises a complex map unit with Dulce and Travessilla.

Table 3

K Factor Values for Typical Suitable Overburden Materials (Red Rock) and Suitable Regraded Spoil[1]

Material	Sand (%)	Silt (%)	Clay (%)	Silt & Very Fine Sand (%)	Texture[2]	Coarse Fragment (%)	Organic Matter (%)	Strc[3]	Perm[4]	K Factor
Sandy Loam Red Rock	66	20	14	32	SL	65	1	M/L	MR	0.23
Sandy Clay Loam Red Rock	55	22	23	35	SCL	75	1	M/L	M	0.25
Clay Loam Red Rock	35	34	31	48	CL	50	1	M/L	MS	0.32
Averge K Factor for Red Rock Materials										0.27
Suitable Regraded Spoil	46	25	29	37	CL	45	0	M/L	MS	0.29

[1]Suitable overburden material (red rock) information is from samples taken in established reclaimed sites in J19, J21, N11, and N14. Suitable regraded spoil material information was derived from the PWCC spoil sampling database for regraded areas at the Kayenta Mine.

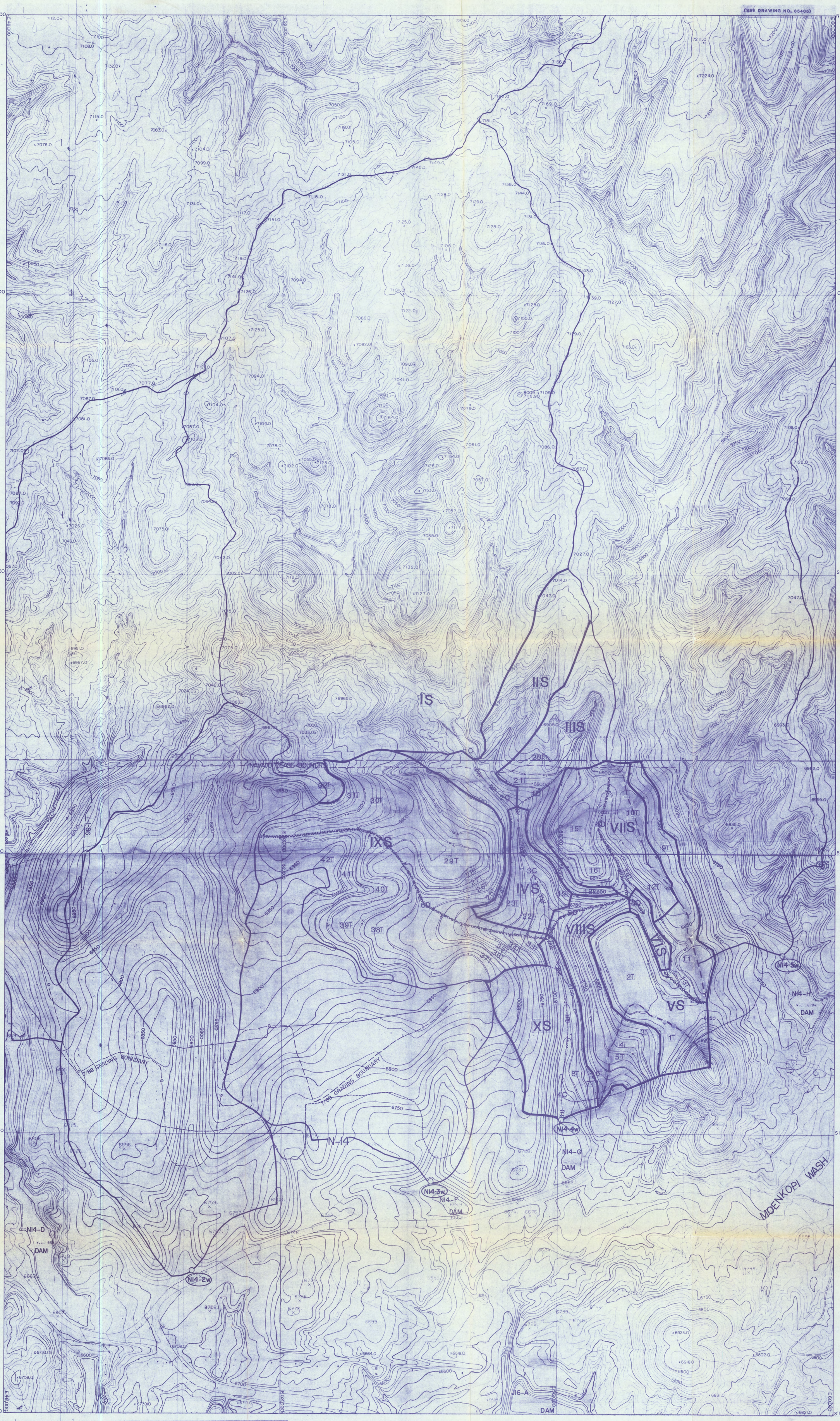
[2]Texture: SL-sandy loam, SCL-sandy clay loam, CL-clay loam

[3]Structure: M/L-massive/loose

[4]Permeability: MR-moderately rapid, M-moderate, MS-moderately slow

MAR 2012

(SEE DRAWING NO. 85405)



LEGEND

- PEABODY LEASEHOLD BOUNDARY
- N-6 COAL RESOURCE AREA
- POSTMINING SURFACE CONTOURING EXTENT (SEE CHAPTER 21)
- MINING HIGHWALL AS OF 1-1-86
- RECLAMATION WATERSHED BOUNDARY; I.D. No.= (RESERVE AREA-XXW)(SEE DRAWING No. 85352)
- 5 YEAR (1993) COAL RECOVERY LINE
- G 7/8 GRADING BOUNDARY
- PROPOSED PERMANENT POND OR DAM; I.D. No.= AREA-XX POND/DAM
- T RECLAMATION TERRACE; I.D. No.=XXT
- D RECLAMATION DOWNDRAIN; I.D. No.=XXD
- C RECLAMATION CHANNEL; I.D. No.=XXC
- RECLAMATION SUBWATERSHED, I.D. No =XXS
- GRADE CONTROL STRUCTURE

NOTE: - 5 YEAR POSTMINING CONTOURS AT C.I.=10'
- L.O.M. POSTMINING CONTOURS AT C.I.=20'

SCALE: 1" = 400'

400 200 0 400 800

ENGINEER'S CERTIFICATION

Registered Professional Engineer (Civil) Certificate No. 18782 James G. Schlewicht

JAMES G. SCHLEWICHT
SENIOR ENGINEER
Peabody Coal Company

ARIZONA P.E. 18782

DATE: JAN 14 1989

PEABODY COAL COMPANY
BLACK MESA - KAYENTA MINE
P.O. BOX 625
KAYENTA, ARIZONA 86033

GENERIC WATERSHED
(ESTIMATED POSTMINING TOPOGRAPHIC MAP)

DWG. No.	85354
SHEET No.	M-7,M-8
DRAWN BY.	G.A.
DATE	1/10/89
SCALE	1"=400'
C.I.	10'

DRAWN BY	APP'D BY	DATE	REVISION DESCRIPTION

JAN 31 1989

ATTACHMENT B-1

GENERIC WATERSHED EXAMPLE

WORKSHEETS

GENERIC WATERSHED DESIGN EXAMPLE

TIME OF CONCENTRATION CALCULATIONS

JAN 31 1989

GENERIC WATERSHED

N14-4W

$$tc = \left[\frac{11.9(L)^3}{H}\right]^{0.385}$$

Subwatershed #1

L = 10840' = 2.053 miles

H = 7181' - 6770' = 411'

$$tc = \left[\frac{11.9\ (2.053)^3}{411}\right]^{0.385} = 0.587 \text{ hrs.}$$

Subwatershed #2

L = 10840' + 900' = 11,740 = 2.224 miles

H = 7181' - 6755' = 426'

$$tc = \left[\frac{11.9\ (2.224)^3}{426}\right]^{0.385} = 0.635 \text{ hrs.}$$

Subwatershed #3

L = 3200' = 0.606 miles

H = 7000' - 6755' = 245'

$$tc = \left[\frac{11.9\ (0.606)^3}{245}\right]^{0.385} = 0.175 \text{ hrs.}$$

Subwatershed #4

L = 11740' + 2000' = 13740' = 2.602 miles

H = 7181' - 6697' = 484'

$$tc = \left[\frac{11.9\ (2.603)^3}{484}\right]^{0.385} = 0.725 \text{ hrs.}$$

JAN 31 1989

Subwatershed #5

L = 5100' = 0.966 miles

H = 7041' = 6800' = 241'

$$tc = \left[\frac{11.9\ (0.966)^3}{241}\right]^{0.385} = 0.302 \text{ hrs.}$$

Subwatershed #6

L = 5100' + 1300' = 6400' = 1.212 miles

H = 7041' - 6780' = 261'

$$tc = \left[\frac{11.9\ (1.212)^3}{261}\right]^{0.385} = 0.380 \text{ hrs.}$$

Subwatershed #7

L = 3100' = 0.606 miles

H = 6850' - 6780' = 70'

$$tc = \left[\frac{11.9\ (0.606)^3}{70}\right]^{0.385} = 0.284 \text{ hrs.}$$

Subwatershed #8

L = 6400' + 1400' = 7800' = 1.477 miles

H = 7041' - 6697' = 344'

$$tc = \left[\frac{11.9\ (1.477)^3}{344}\right]^{0.385} = 0.430 \text{ hrs.}$$

Subwatershed #9

L = 7400' = 1.402 miles

H = 7000' - 6697' = 303'

$$tc = \left[\frac{11.9\ (1.402)^3}{303}\right]^{0.385} = 0.425 \text{ hrs.}$$

JAN 31 1989

Subwatershed #10

L = 13740' = 2540' = 16280' = 3.083 miles

H = 7181' - 6651' = 530'

$$tc = \left[\frac{11.9\ (3.083)^3}{530}\right]^{0.385} = 0.851 \text{ hrs.}$$

JAN 31 1989

GENERIC WATERSHED DESIGN EXAMPLE

10-Year, 6-Hour Storm Event

Input and Output

JAN 31 1989

```
GENERIC WATERSHED(N14-4W):SUBWATERSHED #1
       2       2
    1.60    6.00    0.10    1.00
       1       1
       1
       1
     0.0     0.0     0.0
       1       1       1       1       1
   902.8    81.0   0.587     0.0     0.0     0.0     1.0     2.0     0.0
```

JAN 31 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ********************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #1

          ********************************************


  ********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       1.60   INCHES
```

JAN 31 1989

```
* * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	902.80	81.00	0.587	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	210.36	0.37

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	27.6747	ACRE-FT
PEAK DISCHARGE	=	210.3598	CFS
AREA	=	902.8000	ACRES
TIME OF PEAK DISCHARGE	=	3.40	HRS

```
* * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

GENERIC WATERSHED(N14-4W):SUBWATERSHED #2

2	2							
1.60	6.00	0.10	1.00					
1	1							
1								
1								
0.0	0.0	0.0						
1	1	1	1	1				
971.9	81.0	0.635	0.0	0.0	0.0	1.0	2.0	0.0

JAN 31 1980

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ********************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #2

          ********************************************


  ********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       1.60   INCHES
```

JAN 31 1989

```
* * * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	971.90	81.00	0.635	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	216.00	0.37

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	29.7929	ACRE-FT
PEAK DISCHARGE	=	215.9967	CFS
AREA	=	971.8999	ACRES
TIME OF PEAK DISCHARGE	=	3.40	HRS

```
* * * * * * * * * * * * *
     NULL STRUCTURE
* * * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

GENERIC WATERSHED(N14-4W):SUBWATERSHED #3

2	2							
1.60	6.00	0.10	1.00					
1	1							
1								
1								
0.0	0.0	0.0						
1	1	1	1	1				
52.9	81.0	0.175	0.0	0.0	0.0	1.0	2.0	0.0

JAN 31 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ********************************************

               WATERSHED IDENTIFICATION CODE
               -----------------------------
               GENERIC WATERSHED(N14-4W):SUBWATERSHED #3

          ********************************************


  ********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       1.60   INCHES
```

JAN 31 1990

```
* * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	52.90	81.00	0.175	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	22.71	0.37

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	1.6216	ACRE-FT
PEAK DISCHARGE	=	22.7063	CFS
AREA	=	52.9000	ACRES
TIME OF PEAK DISCHARGE	=	3.10	HRS

```
* * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

GENERIC WATERSHED(N14-4W):SUBWATERSHED #4

2	2							
1.60	6.00	0.10	1.00					
1	1							
1								
1								
0.0	0.0	0.0						
1	1	1	1	1				
1048.9	81.0	0.725	0.0	0.0	0.0	1.0	2.0	0.0

JAN 31 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ******************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #4

          ******************************************


  ********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       1.60   INCHES
```

JAN 31 1989

```
* * * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	******	81.00	0.725	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	215.05	0.37

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	32.1533	ACRE-FT
PEAK DISCHARGE	=	215.0471	CFS
AREA	=	1048.8999	ACRES
TIME OF PEAK DISCHARGE	=	3.50	HRS

```
* * * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

GENERIC WATERSHED(N14-4W):SUBWATERSHED #5

2	2							
1.60	6.00	0.10	1.00					
1	1							
1								
1								
0.0	0.0	0.0						
1	1	1	1	1				
76.1	81.0	0.302	0.0	0.0	0.0	1.0	2.0	0.0

MAR 31 1980

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ******************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #5

          ******************************************


  ********************INPUT VALUES********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       1.60   INCHES
```

JAN 31 1989

```
* * * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	76.10	81.00	0.302	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	25.72	0.37

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	2.3328	ACRE-FT
PEAK DISCHARGE	=	25.7226	CFS
AREA	=	76.1000	ACRES
TIME OF PEAK DISCHARGE	=	3.20	HRS

```
* * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

```
GENERIC WATERSHED(N14-4W):SUBWATERSHED #6
       2       2
    1.60    6.00    0.10    1.00
       1       1
       1
       1
     0.0     0.0     0.0
       1       1       1       1       1
    82.0    81.0   0.380     0.0     0.0     0.0     1.0     2.0     0.0
```

JAN 31 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ********************************************

               WATERSHED IDENTIFICATION CODE
               -----------------------------
               GENERIC WATERSHED(N14-4W):SUBWATERSHED #6

          ********************************************


  ********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       1.60   INCHES
```

JAN 31 1989

```
* * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	82.00	81.00	0.380	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	24.62	0.37

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	2.5137	ACRE-FT
PEAK DISCHARGE	=	24.6176	CFS
AREA	=	82.0000	ACRES
TIME OF PEAK DISCHARGE	=	3.20	HRS

```
* * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

```
GENERIC WATERSHED(N14-4W):SUBWATERSHED #7
       2       2
    1.60    6.00    0.10    1.00
       1       1
       1
       1
     0.0     0.0     0.0
       1       1       1       1       1
    57.9    81.0   0.284     0.0     0.0     0.0     1.0     2.0     0.0
```

JAN 31 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ********************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #7

          ********************************************


  ********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       1.60   INCHES
```

JAN 31 1983

```
* * * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	57.90	81.00	0.284	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	20.15	0.37

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	1.7749	ACRE-FT
PEAK DISCHARGE	=	20.1505	CFS
AREA	=	57.9000	ACRES
TIME OF PEAK DISCHARGE	=	3.10	HRS

```
* * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

```
GENERIC WATERSHED(N14-4W):SUBWATERSHED #8
       2       2
    1.60    6.00    0.10    1.00
       1       1
       1
       1
     0.0     0.0     0.0
       1       1       1       1       1
   188.0    81.0   0.430     0.0     0.0     0.0     1.0     2.0     0.0
```

JAN 31 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ******************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #8

          ******************************************


  ********************INPUT VALUES********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       1.60   INCHES
```

JAN 31 1989

```
* * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	188.00	81.00	0.430	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	52.69	0.37

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	5.7630	ACRE-FT
PEAK DISCHARGE	=	52.6936	CFS
AREA	=	188.0000	ACRES
TIME OF PEAK DISCHARGE	=	3.20	HRS

```
* * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

GENERIC WATERSHED(N14-4W):SUBWATERSHED #9

2	2							
1.60	6.00	0.10	1.00					
1	1							
1								
1								
0.0	0.0	0.0						
1	1	1	1	1				
200.9	81.0	0.425	0.0	0.0	0.0	1.0	2.0	0.0

JAN 31 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ***********************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #9

          ***********************************************


  ********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       1.60   INCHES
```

JAN 21 1989

```
* * * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	200.90	81.00	0.425	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	56.69	0.37

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	6.1585	ACRE-FT
PEAK DISCHARGE	=	56.6944	CFS
AREA	=	200.9000	ACRES
TIME OF PEAK DISCHARGE	=	3.20	HRS

```
* * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

```
GENERIC WATERSHED(N14-4W):SUBWATERSHED #10
       2       2
    1.60    6.00    0.10    1.00
       1       1
       1
       1
     0.0     0.0     0.0
       1       1       1       1       1
  1492.5    81.0   0.851     0.0     0.0     0.0     1.0     2.0     0.0
```

JAN 31 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ********************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #10

          ********************************************


  ********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       1.60   INCHES
```

JAN 31 1989

```
* * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	******	81.00	0.851	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	277.03	0.37

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	45.7516	ACRE-FT
PEAK DISCHARGE	=	277.0286	CFS
AREA	=	1492.5000	ACRES
TIME OF PEAK DISCHARGE	=	3.50	HRS

```
* * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1980

GENERIC WATERSHED DESIGN EXAMPLE

100-Year, 6-Hour Storm Event

Input and Output

JAN 31 1989

```
GENERIC WATERSHED(N14-4W):SUBWATERSHED #1
       2       2
    2.40    6.00    0.10    1.00
       1       1
       1
       1
     0.0     0.0     0.0
       1       1       1       1       1
   902.8    81.0   0.587     0.0     0.0     0.0     1.0     2.0     0.0
```

JAN 31 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ********************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #1

          ********************************************


  ********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       2.40   INCHES
```

JAN 31 1989

```
* * * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	902.80	81.00	0.587	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	543.45	0.87

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	65.5874	ACRE-FT
PEAK DISCHARGE	=	543.4497	CFS
AREA	=	902.8000	ACRES
TIME OF PEAK DISCHARGE	=	3.30	HRS

```
* * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

```
GENERIC WATERSHED(N14-4W):SUBWATERSHED #2
       2       2
    2.40    6.00    0.10    1.00
       1       1
       1
       1
     0.0     0.0     0.0
       1       1       1       1       1
   971.9    81.0   0.635     0.0     0.0     0.0     1.0     2.0     0.0
```

JAN 3 1 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ********************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #2

          ********************************************


  ********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       2.40   INCHES
```

JAN 31 1989

```
* * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	971.90	81.00	0.635	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	557.84	0.87

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	70.6074	ACRE-FT
PEAK DISCHARGE	=	557.8386	CFS
AREA	=	971.8999	ACRES
TIME OF PEAK DISCHARGE	=	3.40	HRS

```
* * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * *
```

**** RUN COMPLETED ****

JAN 31 1989

GENERIC WATERSHED(N14-4W):SUBWATERSHED #3

2	2							
2.40	6.00	0.10	1.00					
1	1							
1								
1								
0.0	0.0	0.0						
1	1	1	1	1				
52.9	81.0	0.175	0.0	0.0	0.0	1.0	2.0	0.0

JAN 31 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ********************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #3

          ********************************************


  ********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       2.40   INCHES
```

JAN 21 1980

```
* * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	52.90	81.00	0.175	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	55.76	0.87

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	3.8431	ACRE-FT
PEAK DISCHARGE	=	55.7560	CFS
AREA	=	52.9000	ACRES
TIME OF PEAK DISCHARGE	=	3.10	HRS

```
* * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

```
GENERIC WATERSHED(N14-4W):SUBWATERSHED #4
       2       2
    2.40    6.00    0.10    1.00
       1       1
       1
       1
     0.0     0.0     0.0
       1       1       1       1       1
  1048.9    81.0   0.725     0.0     0.0     0.0     1.0     2.0     0.0
```

JAN 31 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ******************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #4

          ******************************************


  ********************INPUT VALUES********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       2.40   INCHES
```

MAR 31 1990

```
* * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	******	81.00	0.725	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	554.54	0.87

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	76.2014	ACRE-FT
PEAK DISCHARGE	=	554.5439	CFS
AREA	=	1048.8999	ACRES
TIME OF PEAK DISCHARGE	=	3.40	HRS

```
* * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

GENERIC WATERSHED(N14-4W):SUBWATERSHED #5

2	2							
2.40	6.00	0.10	1.00					
1	1							
1								
1								
0.0	0.0	0.0						
1	1	1	1	1				
76.1	81.0	0.302	0.0	0.0	0.0	1.0	2.0	0.0

JAN 31 1994

```
*************************************************************
*************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*************************************************************
*************************************************************


          ******************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #5

          ******************************************


  ********************INPUT VALUES********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       2.40   INCHES
```

JAN 31 1989

```
* * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	76.10	81.00	0.302	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	64.19	0.87

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	5.5286	ACRE-FT
PEAK DISCHARGE	=	64.1866	CFS
AREA	=	76.1000	ACRES
TIME OF PEAK DISCHARGE	=	3.20	HRS

```
* * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

```
GENERIC WATERSHED(N14-4W):SUBWATERSHED #6
      2       2
   2.40    6.00    0.10    1.00
      1       1
      1
      1
    0.0     0.0     0.0
      1       1       1       1       1
   82.0    81.0   0.380     0.0     0.0     0.0     1.0     2.0     0.0
```

JAN 3 1 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ********************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #6

          ********************************************


  ********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       2.40   INCHES
```

JAN 31 1989

```
* * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	82.00	81.00	0.380	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	62.19	0.87

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	5.9572	ACRE-FT
PEAK DISCHARGE	=	62.1950	CFS
AREA	=	82.0000	ACRES
TIME OF PEAK DISCHARGE	=	3.20	HRS

```
* * * * * * * * * * * *
     NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

MAR 31 2000

```
GENERIC WATERSHED(N14-4W):SUBWATERSHED #7
      2       2
   2.40    6.00    0.10    1.00
      1       1
      1
      1
    0.0     0.0     0.0
      1       1       1       1       1
   57.9    81.0   0.284     0.0     0.0     0.0     1.0     2.0     0.0
```

JUN 8 1 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


           ********************************************

                WATERSHED IDENTIFICATION CODE
                -----------------------------
                GENERIC WATERSHED(N14-4W):SUBWATERSHED #7

           ********************************************


  ********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       2.40   INCHES
```

MAR 31 1989

```
* * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	57.90	81.00	0.284	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	50.16	0.87

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	4.2064	ACRE-FT
PEAK DISCHARGE	=	50.1589	CFS
AREA	=	57.9000	ACRES
TIME OF PEAK DISCHARGE	=	3.10	HRS

```
* * * * * * * * * * * *
     NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 3 1 1989

GENERIC WATERSHED(N14-4W):SUBWATERSHED #8

2	2							
2.40	6.00	0.10	1.00					
1	1							
1								
1								
0.0	0.0	0.0						
1	1	1	1	1				
188.0	81.0	0.430	0.0	0.0	0.0	1.0	2.0	0.0

JAN 31 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ********************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #8

          ********************************************


  ********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       2.40   INCHES
```

JAN 31 1985

```
* * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	188.00	81.00	0.430	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	134.35	0.87

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	13.6580	ACRE-FT
PEAK DISCHARGE	=	134.3468	CFS
AREA	=	188.0000	ACRES
TIME OF PEAK DISCHARGE	=	3.20	HRS

```
* * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

3 1 1989

```
GENERIC WATERSHED(N14-4W):SUBWATERSHED #9
      2       2
   2.40    6.00    0.10    1.00
      1       1
      1
      1
    0.0     0.0     0.0
      1       1       1       1       1
  200.9    81.0   0.425     0.0     0.0     0.0     1.0     2.0     0.0
```

JAN 31 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ********************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #9

          ********************************************


  *********************INPUT VALUES*********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       2.40   INCHES
```

MAR 31 1989

```
* * * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	200.90	81.00	0.425	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	144.43	0.87

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	14.5952	ACRE-FT
PEAK DISCHARGE	=	144.4300	CFS
AREA	=	200.9000	ACRES
TIME OF PEAK DISCHARGE	=	3.20	HRS

```
* * * * * * * * * * * *
     NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

```
GENERIC WATERSHED(N14-4W):SUBWATERSHED #10
       2       2
    2.40    6.00    0.10    1.00
       1       1
       1
       1
     0.0     0.0     0.0
       1       1       1       1       1
  1492.5    81.0   0.851     0.0     0.0     0.0     1.0     2.0     0.0
```

JAN 31 1989

```
*****************************************************************
*****************************************************************

      UNIVERSITY OF KENTUCKY COMPUTER MODEL
      OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
      FOR MORE INFORMATION CONTACT THE AGRICULTURAL
      ENGINEERING DEPARTMENT

      THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
      THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
      MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

      VERSION DATE 5-25-83

      DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
      ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
      CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

*****************************************************************
*****************************************************************


          ********************************************

              WATERSHED IDENTIFICATION CODE
              -----------------------------
              GENERIC WATERSHED(N14-4W):SUBWATERSHED #10

          ********************************************


  ********************INPUT VALUES********************

  STORM DURATION                    =       6.00   HOURS
  PRECIPITATION DEPTH               =       2.40   INCHES
```

MAR 31 1989

```
* * * * * * * * * * * * * * * * * * * * * * *
    JUNCTION  1, BRANCH  1, STRUCTURE  1
* * * * * * * * * * * * * * * * * * * * * * *
```

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO
1	******	81.00	0.851	0.000	0.000	0.00	2.0

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)
1	712.15	0.87

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	108.4285	ACRE-FT
PEAK DISCHARGE	=	712.1514	CFS
AREA	=	1492.5000	ACRES
TIME OF PEAK DISCHARGE	=	3.50	HRS

```
* * * * * * * * * * * *
    NULL STRUCTURE
* * * * * * * * * * * *
```

*** RUN COMPLETED ****

JAN 31 1989

GENERIC WATERSHED DESIGN EXAMPLE

Hydraulic Design Calculations

JAN 3

N14-4W

Subwatershed No. 1S

Reclamation Channel 1C

JAN 3 1 1989

RECLAMATION CHANNEL 1C

100-YEAR, 6-HOUR STORM EVENT

CRITICAL SLOPE CALCULATIONS

TRAPEZOIDAL CHANNEL ANALYSIS
CRITICAL DEPTH COMPUTATION

Flow Rate (cubic feet per second)	543.4
Manning's Roughness Coefficient (n-value)	0.03
Channel Side Slope - Left Side (horizontal/vertical)	3
Channel Side Slope - Right Side (horizontal/vertical)	3
Channel Bottom Width (feet)	40

*** RESULTS ***

CRITICAL DEPTH (FEET)	1.71
Critical Slope (feet per foot)	0.0115
Flow Velocity (feet per second)	7.03
Froude Number	1.000
Velocity Head (feet)	0.77
Energy Head (feet)	2.48
Cross-Sectional Area of Flow (square feet)	77.25
Top Width of Flow (feet)	90.27

<Enter>: Repeat, <R>eport, or <Esc>: End

JAN 31 1989

RECLAMATION CHANNEL 1C

10-YEAR, 6-HOUR STORM EVENT
HYDRAULIC CALCULATIONS

JAN 31 1989

RECLAMATION CHANNEL 1C

10-YEAR, 6-HOUR STORM

HYDRAULIC CALCULATIONS

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL

```
                    T
*****************************************  ----------------
 *                                     *
  *                                   *
   *                                 Z*
    *                                *              D
     *                              *
      *                            *
       *          b               *
        ******************************  ----------------------
```

Discharge	=	210.40 cfs	Depth (D)	=	0.99 feet
Bottom (b)	=	40.00 feet	Top width (T)	=	45.94 feet
Side slopes (Z)	=	3.0:1	Velocity	=	4.93 ft/sec
Bed Slope	=	1.100 %	Hydraulic Radius	=	0.92 feet
Manning's n	=	0.030			

JAN 31 1989

RECLAMATION CHANNEL 1C

100-YEAR, 6-HOUR STORM
HYDRAULIC CALCULATIONS

JAN 3 1 1989

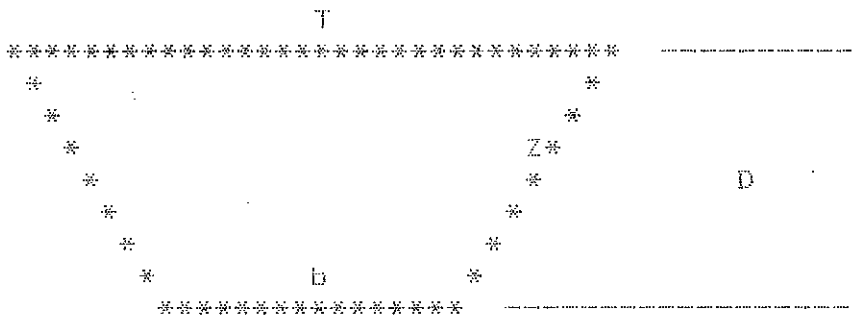
RECLAMATION CHANNEL 1C

100-YEAR, 6-HOUR STORM EVENT

HYDRAULIC CALCULATIONS

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL



Discharge	=	543.40 cfs	Depth (D)	=	1.76 feet
Bottom (b)	=	40.00 feet	Top width (T)	=	50.58 feet
Side slopes (Z)	=	3.0:1	Velocity	=	7.01 ft/sec
Bed Slope	=	1.100 %	Hydraulic Radius	=	1.56 feet
Manning's n	=	0.030			

JAN 31 1989

N14-4W

Subwatershed No. IIS

Reclamation Channel 2C

Gradient Terrace 24T

JAN 31 1989

RECLAMATION CHANNEL 2C

100-YEAR, 6-HOUR STORM EVENT

CRITICAL SLOPE CALCULATIONS

TRAPEZOIDAL CHANNEL ANALYSIS
CRITICAL DEPTH COMPUTATION

Flow Rate (cubic feet per second)	557.8
Manning's Roughness Coefficient (n-value)	0.03
Channel Side Slope - Left Side (horizontal/vertical)	3
Channel Side Slope - Right Side (horizontal/vertical)	3
Channel Bottom Width (feet)	40

*** RESULTS ***

CRITICAL DEPTH (FEET)	1.74
Critical Slope (feet per foot)	0.0115
Flow Velocity (feet per second)	7.09
Froude Number	1.000
Velocity Head (feet)	0.78
Energy Head (feet)	2.52
Cross-Sectional Area of Flow (square feet)	78.70
Top Width of Flow (feet)	50.44

<Enter>: Repeat, <R>eport, or <Esc>: End

JAN 31 1989

RECLAMATION CHANNEL 2C

10-YEAR, 6-HOUR STORM EVENT

&

100-YEAR, 6-HOUR STORM EVENT

HYDRAULIC CALCULATIONS

AT

1.1% AND 7.0% SLOPES

JAN 31 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL

```
                    T
*********************************** ------------
 *                                 *
  *                               *
   *                             Z*
    *                            *            D
     *                          *
      *                        *
       *          b           *
        ****************** ------------------------
```

Discharge	=	216.00 cfs	Depth (D)	=	1.01 feet
Bottom (b)	=	40.00 feet	Top width (T)	=	46.04 feet
Side slopes (Z)	=	3.0:1	Velocity	=	4.98 ft/sec
Bed Slope	=	1.100 %	Hydraulic Radius	=	0.93 feet
Manning's n	=	0.030			

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL

```
                    T
*********************************  ------------
 *                                 *
  *                               *
   *                             Z*
    *                            *            D
     *                          *
      *                        *
       *          b           *
        *****************  ----------------------
```

Discharge	=	557.80 cfs	Depth (D)	=	1.79 feet
Bottom (b)	=	40.00 feet	Top width (T)	=	50.76 feet
Side slopes (Z)	=	3.0:1	Velocity	=	7.08 ft/sec
Bed Slope	=	1.100 %	Hydraulic Radius	=	1.58 feet
Manning's n	=	0.030			

JAN 31 1989

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL

```
                    T
*********************************  ----------------
 *                                *
  *                              *
   *                            Z*
    *                           *          D
     *                         *
      *                       *
       *         b           *
        ****************  ----------------------
```

Discharge	=	216.00 cfs	Depth (D)	=	0.68 feet
Bottom (b)	=	40.00 feet	Top width (T)	=	44.10 feet
Side slopes (Z)	=	3.0:1	Velocity	=	7.43 ft/sec
Bed Slope	=	7.000 %	Hydraulic Radius	=	0.63 feet
Manning's n	=	0.040			
Specific Gravity	=	2.30	Bottom D50	=	1.04 feet
Safety Factor	=	1.20	Bank D50	=	0.98 feet

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL

```
                 :      T
*****************************************  ----------
 *                                     *
  *                                   *
   *                                Z*
    *                               *            D
     *                             *
      *                           *
       *          b              *
        *****************        ----------------------
```

Discharge	=	557.00 cfs	Depth (D)	=	1.27 feet
Bottom (b)	=	40.00 feet	Top width (T)	=	47.64 feet
Side slopes (Z)	=	3.0:1	Velocity	=	9.87 ft/sec
Bed Slope	=	7.000 %	Hydraulic Radius	=	1.16 feet
Manning's n	=	0.044			
Specific Gravity	=	2.30	Bottom D50	=	1.94 feet
Safety Factor	=	1.20	Bank D50	=	1.79 feet

3 1 1989

N14-4W

Subwatershed No. IIIS

Reclamation Downdrain 1D

Gradient Terraces 18T, 20T, 21T

JAN 3 1 1989

RECLAMATION DOWNDRAIN 1D

100-YEAR, 6-HOUR STORM EVENT

CRITICAL SLOPE CALCULATIONS

TRAPEZOIDAL CHANNEL ANALYSIS
CRITICAL DEPTH COMPUTATION

Flow Rate (cubic feet per second)	55.8
Manning's Roughness Coefficient (n-value)	0.03
Channel Side Slope - Left Side (horizontal/vertical)	3
Channel Side Slope - Right Side (horizontal/vertical)	3
Channel Bottom Width (feet)	15

*** RESULTS ***

CRITICAL DEPTH (FEET)	0.72
Critical Slope (feet per foot)	0.0155
Flow Velocity (feet per second)	4.53
Froude Number	1.000
Velocity Head (feet)	0.32
Energy Head (feet)	1.04
Cross-Sectional Area of Flow (square feet)	12.31
Top Width of Flow (feet)	19.31

<Enter>: Repeat, <R>eport, or <Esc>: End

JAN 31 1989

RECLAMATION DOWNDRAIN 1D

10-YEAR, 6-HOUR STORM EVENT

&

100-YEAR, 6-HOUR STORM EVENT

HYDRAULIC CALCULATIONS

AT

1.5% AND 8.5% SLOPES

JAN 31 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL

```
                    T
*********************************  ------------
 *                                 *
  *                               *
   *                             Z*
    *                            *            D
     *                          *
      *                        *
       *                      *
        *         b          *
         ****************  ------------------
```

Discharge	=	22.70 cfs	Depth (D)	=	0.41 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	17.47 feet
Side slopes (Z)	=	3.0:1	Velocity	=	3.19 ft/sec
Bed Slope	=	1.500 %	Hydraulic Radius	=	0.38 feet
Manning's n	=	0.030			

JAN 31 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL

Discharge	=	55.00 cfs	Depth (D)	=	0.70 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	19.23 feet
Side slopes (Z)	=	3.0:1	Velocity	=	4.42 ft/sec
Bed Slope	=	1.500 %	Hydraulic Radius	=	0.62 feet
Manning's n	=	0.030			

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL

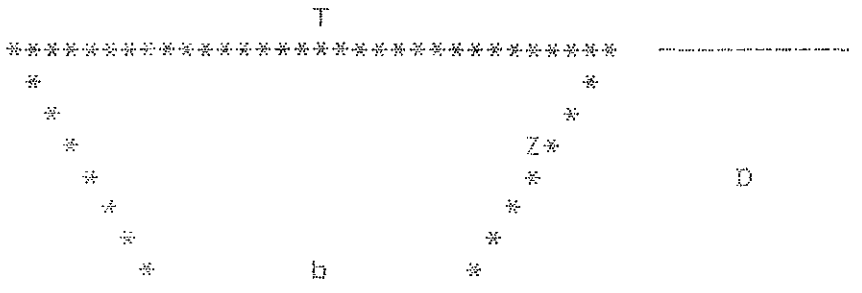
```
                    T
*********************************  ------------
 *                              *
  *                            *
   *                          Z*
    *                         *          D
     *                       *
      *                     *
       *         b         *
        ****************  ------------------------
```

Discharge	=	22.70 cfs	Depth (D)	=	0.28 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	16.68 feet
Side slopes (Z)	=	3.0:1	Velocity	=	3.04 ft/sec
Bed Slope	=	8.500 %	Hydraulic Radius	=	0.26 feet
Manning's n	=	0.036			
Specific Gravity	=	2.30	Bottom D50	=	0.53 feet
Safety Factor	=	1.20	Bank D50	=	0.49 feet

JAN 31 1989

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL



Discharge	=	55.80 cfs	Depth (D)	=	0.50 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	18.03 feet
Side slopes (Z)	=	3.0:1	Velocity	=	6.58 ft/sec
Bed Slope	=	8.500 %	Hydraulic Radius	=	0.46 feet
Manning's n	=	0.039			
Specific Gravity	=	2.30	Bottom D50	=	0.96 feet
Safety Factor	=	1.20	Bank D50	=	0.88 feet

JAN 3 1 1989

N14-4W

Subwatershed No. IVS

Reclamation Channel 3C

Gradient Terraces 19T, 22T, 23T

JAN 3 1 198

RECLAMATION CHANNEL 3C

100-YEAR, 6-HOUR STORM EVENT

CRITICAL SLOPE CALCULATIONS

TRAPEZOIDAL CHANNEL ANALYSIS
CRITICAL DEPTH COMPUTATION

Flow Rate (cubic feet per second)	554.5
Manning's Roughness Coefficient (n-value)	0.03
Channel Side Slope - Left Side (horizontal/vertical)	3
Channel Side Slope - Right Side (horizontal/vertical)	3
Channel Bottom Width (feet)	40

*** RESULTS ***

CRITICAL DEPTH (FEET)	1.73
Critical Slope (feet per foot)	0.0115
Flow Velocity (feet per second)	7.08
Froude Number	1.000
Velocity Head (feet)	0.76
Energy Head (feet)	2.51
Cross-Sectional Area of Flow (square feet)	78.37
Top Width of Flow (feet)	50.40

<Enter>: Repeat, <R>eport, or <Esc>: End

JAN 31 1989

RECLAMATION CHANNEL 3C

10-YEAR, 6-HOUR STORM EVENT

&

100-YEAR, 6-HOUR STORM EVENT

HYDRAULIC CALCULATIONS

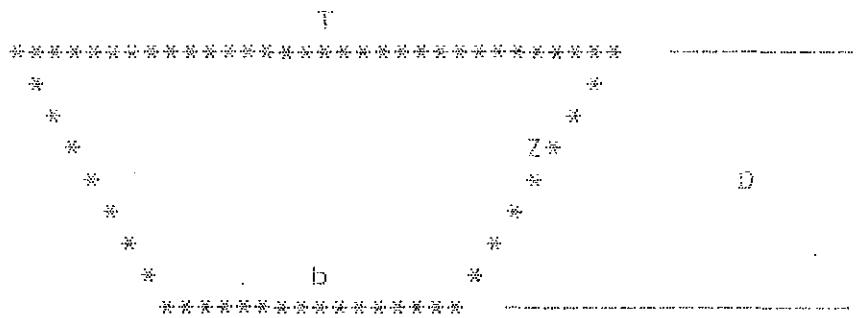
AT

1.1% AND 7.0% SLOPES

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL



Discharge	=	215.00 cfs	Depth (D)	=	1.00 feet
Bottom (b)	=	40.00 feet	Top width (T)	=	46.02 feet
Side slopes (Z)	=	3.0:1	Velocity	=	4.97 ft/sec
Bed Slope	=	1.100 %	Hydraulic Radius	=	0.93 feet
Manning's n	=	0.030			

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL

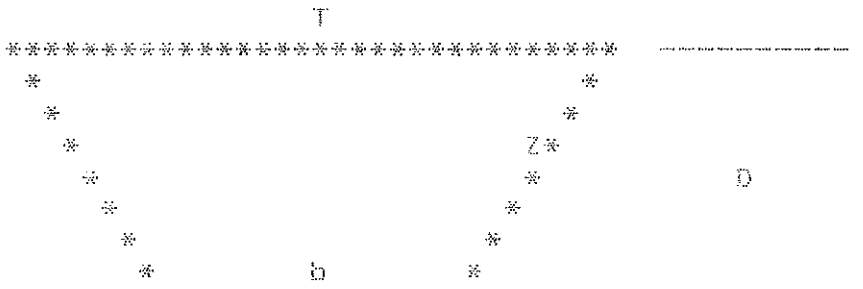
```
                    T
*********************************  ------------
 *                                 *
  *                               *
   *                            Z*
    *                           *          D
     *                         *
      *                       *
       *         b           *
        ****************  ----------------------
```

Discharge	=	554.50 cfs	Depth (D)	=	1.79 feet
Bottom (b)	=	40.00 feet	Top width (T)	=	50.72 feet
Side slopes (Z)	=	3.0:1	Velocity	=	7.06 ft/sec
Bed Slope	=	1.100 %	Hydraulic Radius	=	1.58 feet
Manning's n	=	0.030			

JAN 31 1989

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL

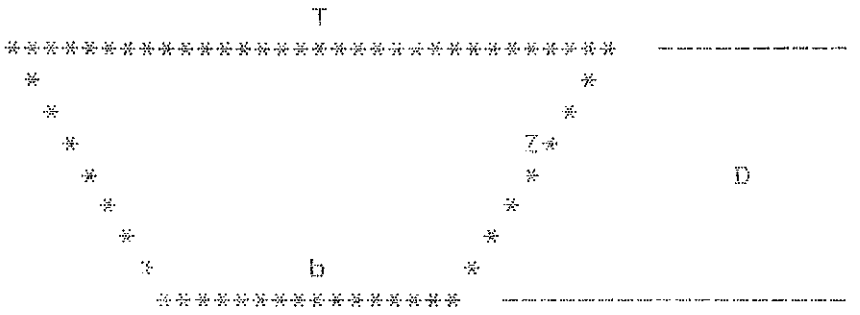


Discharge	=	215.00 cfs	Depth (D)	=	0.68 feet
Bottom (b)	=	40.00 feet	Top width (T)	=	44.09 feet
Side slopes (Z)	=	3.0:1	Velocity	=	7.42 ft/sec
Bed Slope	=	7.000 %	Hydraulic Radius	=	0.65 feet
Manning's n	=	0.040			
Specific Gravity	=	2.30	Bottom D50	=	1.04 feet
Safety Factor	=	1.20	Bank D50	=	0.97 feet

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL



Discharge	=	554.50 cfs	Depth (D)	=	1.27 feet
Bottom (b)	=	40.00 feet	Top width (T)	=	47.61 feet
Side slopes (Z)	=	3.0:1	Velocity	=	9.85 ft/sec
Bed Slope	=	7.000 %	Hydraulic Radius	=	1.16 feet
Manning's n	=	0.044			
Specific Gravity	=	2.30	Bottom D50	=	1.93 feet
Safety Factor	=	1.20	Bank D50	=	1.79 feet

JAN 31 1989

N14-4W

Subwatershed No. VS

Reclamation Downdrain 2D

Gradient Terraces 1T, 2T, 9T, 11T, 13T

JAN 3 1 1989

RECLAMATION DOWNDRAINS 2D

100-YEAR, 6-HOUR STORM EVENT

CRITICAL SLOPE CALCULATIONS

TRAPEZOIDAL CHANNEL ANALYSIS
CRITICAL DEPTH COMPUTATION

Flow Rate (cubic feet per second)	64.2
Manning's Roughness Coefficient (n-value)	0.03
Channel Side Slope - Left Side (horizontal/vertical)	3
Channel Side Slope - Right Side (horizontal/vertical)	3
Channel Bottom Width (feet)	15

*** RESULTS ***

CRITICAL DEPTH (FEET)	0.78
Critical Slope (feet per foot)	0.0151
Flow Velocity (feet per second)	4.72
Froude Number	1.000
Velocity Head (feet)	0.35
Energy Head (feet)	1.13
Cross-Sectional Area of Flow (square feet)	13.61
Top Width of Flow (feet)	19.71

<Enter>: Repeat, <R>eport, or <Esc>: End

JAN 31 1989

RECLAMATION DOWNDRAIN 2D

10-YEAR, 6-HOUR STORM EVENT

&

100-YEAR, 6-HOUR STORM EVENT

HYDRAULIC CALCULATIONS

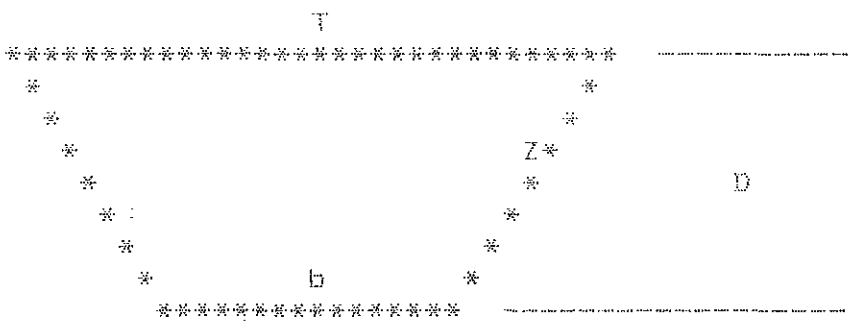
AT

1.5% AND 5.0% SLOPES

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL



Discharge	=	25.70 cfs	Depth (D)	=	0.44 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	17.66 feet
Side slopes (Z)	=	3.0:1	Velocity	=	3.34 ft/sec
Bed Slope	=	1.500 %	Hydraulic Radius	=	0.41 feet
Manning's n	=	0.030			

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL

```
                    T
*****************************************  ------------
 *                                     *
  *                                   *
   *                                 Z*
    *                                *            D
     *                              *
      *                            *
       *          b               *
        *****************  ------------------------
```

Discharge	=	64.20 cfs	Depth (D)	=	0.77 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	19.60 feet
Side slopes (Z)	=	3.0:1	Velocity	=	4.65 ft/sec
Bed Slope	=	1.500 %	Hydraulic Radius	=	0.67 feet
Manning's n	=	0.030			

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL

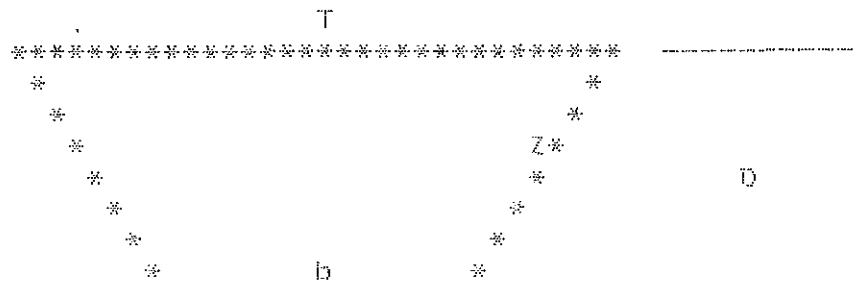
```
                    T
*********************************  ------------
 *                              *
  *                            *
   *                          *
    *                        Z*
     *                       *          D
      *                     *
       *                   *
        *        b        *
         ****************  ----------------------
```

Discharge	=	25.70 cfs	Depth (D)	=	0.34 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	17.05 feet
Side slopes (Z)	=	3.0:1	Velocity	=	4.67 ft/sec
Bed Slope	=	5.000 %	Hydraulic Radius	=	0.32 feet
Manning's n	=	0.033			
Specific Gravity	=	2.30	Bottom D50	=	0.36 feet
Safety Factor	=	1.20	Bank D50	=	0.35 feet

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL



Discharge	=	64.20 cfs	Depth (D)	=	0.62 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	18.72 feet
Side slopes (Z)	=	3.0:1	Velocity	=	6.10 ft/sec
Sed Slope	=	5.000 %	Hydraulic Radius	=	0.55 feet
Manning's n	=	0.037			
Specific Gravity	=	2.30	Bottom D50	=	0.65 feet
Safety Factor	=	1.20	Bank D50	=	0.63 feet

JAN 31 1989

N14-4W

Subwatershed No. VIS

Reclamation Downdrain 3D

JAN 31 1989

RECLAMATION DOWNDRAIN 3D

100-YEAR, 6-HOUR STORM EVENT

CRITICAL SLOPE CALCULATIONS

TRAPEZOIDAL CHANNEL ANALYSIS
CRITICAL DEPTH COMPUTATION

Flow Rate (cubic feet per second)	62.2
Manning's Roughness Coefficient (n-value)	0.03
Channel Side Slope - Left Side (horizontal/vertical)	3
Channel Side Slope - Right Side (horizontal/vertical)	3
Channel Bottom Width (feet)	15

*** RESULTS ***

CRITICAL DEPTH (FEET)	0.77
Critical Slope (feet per foot)	0.0152
Flow Velocity (feet per second)	4.67
Froude Number	1.000
Velocity Head (feet)	0.34
Energy Head (feet)	1.11
Cross-Sectional Area of Flow (square feet)	13.31
Top Width of Flow (feet)	19.61

<Enter>: Repeat, <R>eport, or <Esc>: End

JAN 31 1989

RECLAMATION DOWNDRAIN 3D

10-YEAR, 6-HOUR STORM EVENT

&

100-YEAR, 6-HOUR STORM EVENT

HYDRAULIC CALCULATIONS

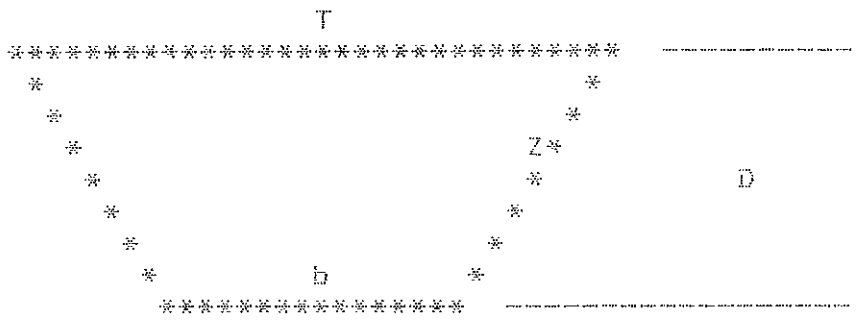
AT

1.5% AND 3.3% SLOPES

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL



Discharge	=	24.60 cfs	Depth (D)	=	0.43 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	17.59 feet
Side slopes (Z)	=	3.0:1	Velocity	=	3.28 ft/sec
Bed Slope	=	1.500 %	Hydraulic Radius	=	0.40 feet
Manning's n	=	0.030			

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL

```
                    T
*********************************** ------------
*                                 *
 *                               *
  *                             Z*
   *                            *          D
    *                          *
     *                        *
      *         b            *
       ****************** ------------------------
```

Discharge	=	62.20 cfs	Depth (D)	=	0.75 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	19.51 feet
Side slopes (Z)	=	3.0:1	Velocity	=	4.60 ft/sec
Bed Slope	=	1.500 %	Hydraulic Radius	=	0.66 feet
Manning's n	=	0.030			

JAN 3 1 1989

ROCKPRO- CHANNEL UTILITY

ROCK RIPRAP CHANNEL

```
                    T
 ******************************************  ----------------
 *                                        *
  *                                      *
   *                                   Z*
    *                                  *            D
     *                                *
      *                              *
       *          b                 *
        ****************************  ----------------------
```

Discharge	=	24.60 cfs	Depth (D)	=	0.36 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	17.18 feet
Side slopes (Z)	=	3.0:1	Velocity	=	4.21 ft/sec
Bed Slope	=	3.300 %	Hydraulic Radius	=	0.34 feet
Manning's n	=	0.031			
Specific Gravity	=	2.30	Bottom D50	=	0.24 feet
Safety Factor	=	1.20	Bank D50	=	0.24 feet

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

ROCK'RIPRAP CHANNEL

```
                    T
*********************************  ------------
 *                                *
  *                              *
   *                            Z*
    *                           *            D
     *                         *
      *                       *
       *                     *
        *         b         *
         *****************  ----------------------
```

Discharge	=	62.20 cfs	Depth (D)	=	0.66 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	18.99 feet
Side slopes (Z)	=	3.0:1	Velocity	=	5.50 ft/sec
Bed Slope	=	3.300 %	Hydraulic Radius	=	0.59 feet
Manning's n	=	0.035			
Specific Gravity	=	2.30	Bottom D50	=	0.45 feet
Safety Factor	=	1.20	Bank D50	=	0.44 feet

JAN 3 1 1989

N14-4W

Subwatershed No. VIIS

Reclamation Downdrain 4D

Gradient Terraces 10T, 12T, 14T,

15T, 16T, 17T

JAN 3 1 1989

RECLAMATION DOWNDRAIN 4D

100-YEAR, 6-HOUR STORM EVENT

CRITICAL SLOPE CALCULATIONS

TRAPEZOIDAL CHANNEL ANALYSIS
CRITICAL DEPTH COMPUTATION

Flow Rate (cubic feet per second)	50.2
Manning's Roughness Coefficient (n-value)	0.03
Channel Side Slope - Left Side (horizontal/vertical)	3
Channel Side Slope - Right Side (horizontal/vertical)	3
Channel Bottom Width (feet)	15

*** RESULTS ***

CRITICAL DEPTH (FEET)	0.67
Critical Slope (feet per foot)	0.0158
Flow Velocity (feet per second)	4.10
Froude Number	1.000
Velocity Head (feet)	0.30
Energy Head (feet)	0.97
Cross-Sectional Area of Flow (square feet)	11.43
Top Width of Flow (feet)	19.03

<Enter>: Repeat, <R>eport, or <Esc>: End

JAN 31 1989

RECLAMATION DOWNDRAIN 4D

10-YEAR, 6-HOUR STORM EVENT

&

100-YEAR, 6-HOUR STORM EVENT

HYDRAULIC CALCULATIONS

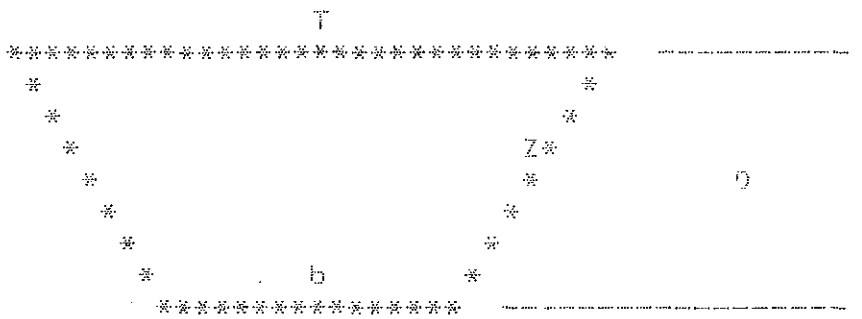
AT

1.6% AND 5.5% SLOPES

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL



Discharge	=	20.20 cfs	Depth (D)	=	0.38 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	17.26 feet
Side slopes (Z)	=	3.0:1	Velocity	=	3.12 ft/sec
Bed Slope	=	1.600 %	Hydraulic Radius	=	0.35 feet
Manning's n	=	0.030			

JAN 31 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL

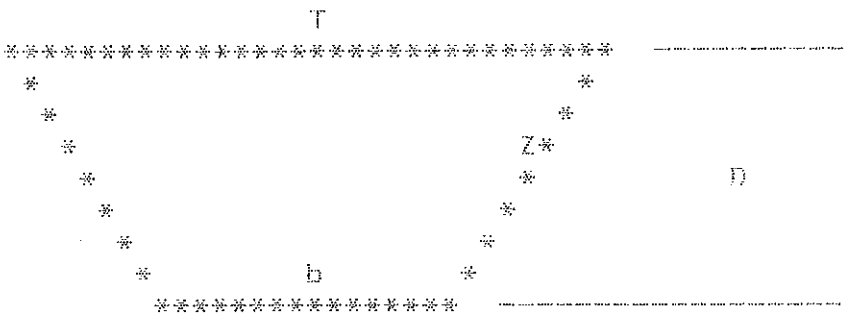
```
                    T
*********************************  ------------
 *                                 *
  *                                *
   *                             Z*
    *                            *          D
     *                          *
      *                        *
       *          b           *
        ****************  ----------------------
```

Discharge	=	50.20 cfs	Depth (D)	=	0.65 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	18.89 feet
Side slopes (Z)	=	3.0:1	Velocity	=	4.35 ft/sec
Bed Slope	=	1.600 %	Hydraulic Radius	=	0.58 feet
Manning's n	=	0.030			

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL

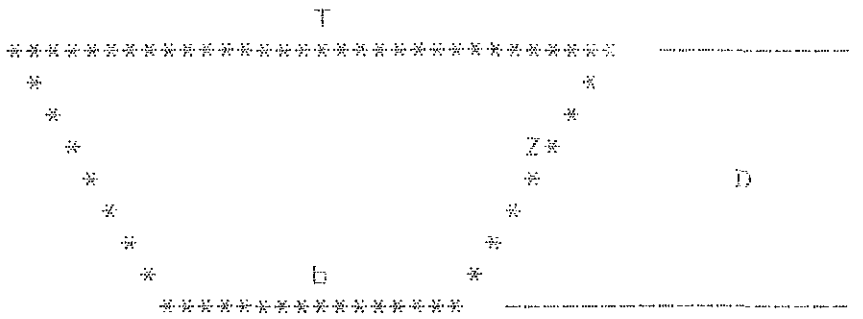


Discharge	=	20.20 cfs	Depth (D)	=	0.29 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	16.71 feet
Side slopes (Z)	=	3.0:1	Velocity	=	4.43 ft/sec
Bed Slope	=	5.500 %	Hydraulic Radius	=	0.27 feet
Manning's n	=	0.033			
Specific Gravity	=	2.30	Bottom D50	=	0.33 feet
Safety Factor	=	1.20	Bank D50	=	0.32 feet

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL



Discharge	=	50.20 cfs	Depth (D)	=	0.52 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	18.11 feet
Side slopes (Z)	=	3.0:1	Velocity	=	5.80 ft/sec
Bed Slope	=	5.500 %	Hydraulic Radius	=	0.47 feet
Manning's n	=	0.036			
Specific Gravity	=	2.30	Bottom D50	=	0.61 feet
Safety Factor	=	1.20	Bank D50	=	0.56 feet

JAN 31 1989

N14-4W

Subwatershed No. VIIIS

Reclamation Downdrain 5D

Gradient Terraces 3T, 4T, 5T, 6T

JAN 3 1 1989

RECLAMATION DOWNDRAIN 5D

100-YEAR, 6-HOUR STORM EVENT

CRITICAL SLOPE CALCULATIONS

TRAPEZOIDAL CHANNEL ANALYSIS
CRITICAL DEPTH COMPUTATION

Flow Rate (cubic feet per second)	154.3
Manning's Roughness Coefficient (n-value)	0.03
Channel Side Slope - Left Side (horizontal/vertical)	3
Channel Side Slope - Right Side (horizontal/vertical)	3
Channel Bottom Width (feet)	15
*** RESULTS ***	
CRITICAL DEPTH (FEET)	1.24
Critical Slope (feet per foot)	0.0133
Flow Velocity (feet per second)	3.78
Froude Number	1.000
Velocity Head (feet)	0.02
Energy Head (feet)	1.26
Cross-Sectional Area of Flow (square feet)	23.25
Top Width of Flow (feet)	22.45

<Enter>: Repeat, <R>eport, or <Esc>: End

JAN 31 1989

RECLAMATION DOWNDRAIN 5D

10-YEAR, 6-HOUR STORM EVENT

&

100-YEAR, 6-HOUR STORM EVENT

HYDRAULIC CALCULATIONS

AT

1.3% AND 6.5% SLOPES

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL

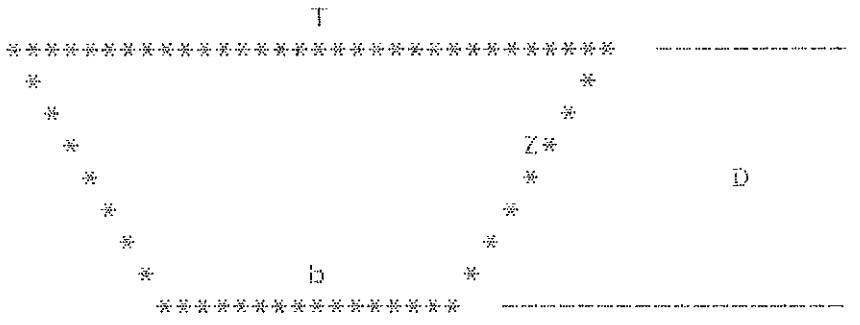
```
                    T
*********************************  ------------
 *                              *
  *                            *
   *                          Z*
    *                         *          D
     *                       *
      *                     *
       *        b          *
        ****************  ----------------------
```

Discharge	=	32.70 cfs	Depth (D)	=	0.71 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	19.27 feet
Side slopes (Z)	=	3.0:1	Velocity	=	4.14 ft/sec
Bed Slope	=	1.300 %	Hydraulic Radius	=	0.62 feet
Manning's n	=	0.030			

JAN 3 1 1989

SEDCAD+: CHANNEL UTILITY

NONERODIBLE CHANNEL

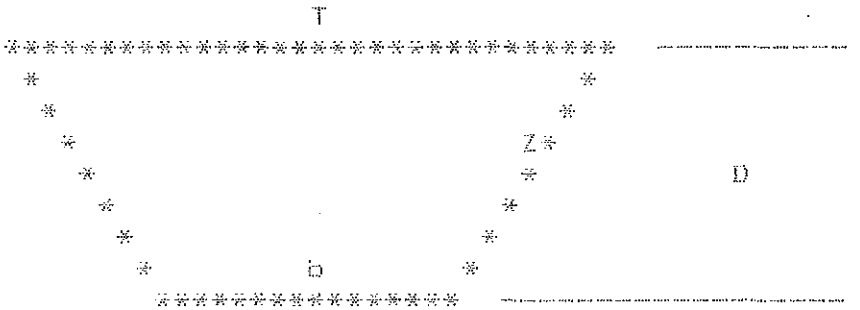


Discharge	=	134.30 cfs	Depth (D)	=	1.25 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	22.50 feet
Side slopes (Z)	=	3.0:1	Velocity	=	5.75 ft/sec
Bed Slope	=	1.300 %	Hydraulic Radius	=	1.02 feet
Manning's n	=	0.030			

JAN 31 1989

GEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL

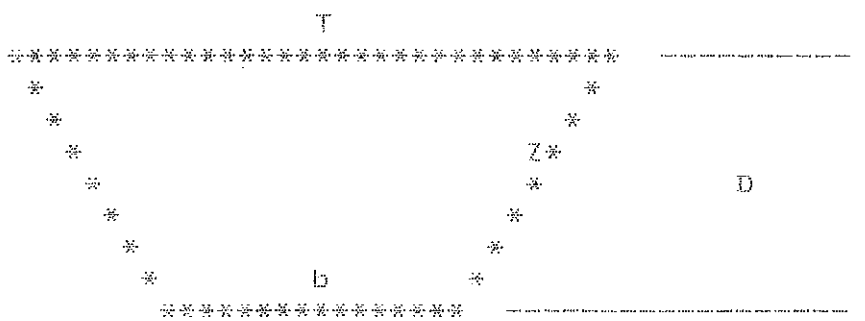


Discharge	=	52.70 cfs	Depth (D)	=	0.52 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	18.09 feet
Side slopes (Z)	=	3.0:1	Velocity	=	6.12 ft/sec
Bed Slope	=	6.500 %	Hydraulic Radius	=	0.47 feet
Manning's n	=	0.037			
Specific Gravity	=	2.30	Bottom D50	=	0.72 feet
Safety Factor	=	1.20	Bank D50	=	0.68 feet

JAN 31 1989

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL



Discharge	=	134.30 cfs	Depth (D)	=	0.94 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	20.65 feet
Side slopes (Z)	=	3.0:1	Velocity	=	7.92 ft/sec
Bed Slope	=	6.500 %	Hydraulic Radius	=	0.80 feet
Manning's n	=	0.041			
Specific Gravity	=	2.30	Bottom D50	=	1.32 feet
Safety Factor	=	1.20	Bank D50	=	1.24 feet

JAN 31 1989

N14-4W

Subwatershed No. IXS

Reclamation Downdrain 6D

Gradient Terraces 25T, 26T, 27T, 28T, 29T,

30T, 31T, 33T, 34T, 35T, 36T, 37T,

38T, 39T, 40T, 41T, 42T

JAN 3 1 1989

RECLAMATION DOWNDRAIN 6D

100-YEAR, 6-HOUR STORM EVENT

CRITICAL SLOPE CALCULATIONS

TRAPEZOIDAL CHANNEL ANALYSIS
CRITICAL DEPTH COMPUTATION

Flow Rate (cubic feet per second)	144.4
Manning's Roughness Coefficient (n-value)	0.03
Channel Side Slope - Left Side (horizontal/vertical)	3
Channel Side Slope - Right Side (horizontal/vertical)	3
Channel Bottom Width (feet)	15

*** RESULTS ***

CRITICAL DEPTH (FEET)	1.30
Critical Slope (feet per foot)	0.0131
Flow Velocity (feet per second)	3.39
Froude Number	1.000
Velocity Head (feet)	0.09
Energy Head (feet)	1.04
Cross-Sectional Area of Flow (square feet)	42.53
Top Width of Flow (feet)	32.79

'Enter': Repeat, <R>eport, or <Esc>: End

JAN 3 1 1989

RECLAMATION DOWNDRAIN 6D

10-YEAR, 6-HOUR STORM EVENT

&

100-YEAR, 6-HOUR STORM EVENT

HYDRAULIC CALCULATIONS

AT

1.3% AND 5.5% SLOPES

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL

```
                    T
*********************************  ------------
 *                                 *
  *                               *
   *                             Z*
    *                            *            D
     *                          *
      *                        *
       *          b           *
        ****************  ----------------------
```

Discharge	=	56.70 cfs	Depth (D)	=	0.74 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	19.45 feet
Side slopes (Z)	=	3.0:1	Velocity	=	4.25 ft/sec
Bed Slope	=	1.300 %	Hydraulic Radius	=	0.65 feet
Manning's n	=	0.030			

JAN 31 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL

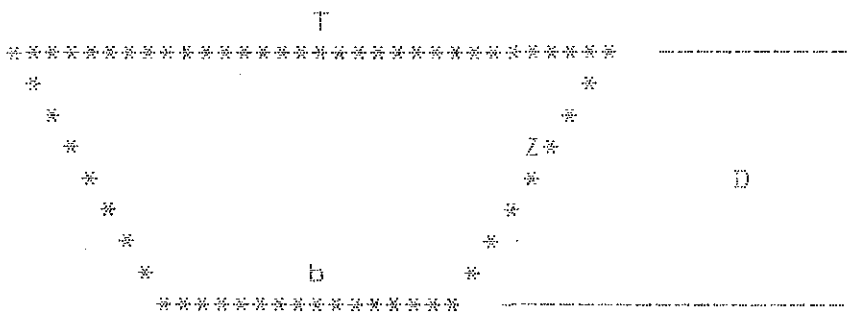
```
                    T
*********************************  ------------
 *                              *
  *                            *
   *                          Z*
    *                         *          D
     *                       *
      *                     *
       *        b          *
        ****************  ------------------------
```

Discharge	=	144.40 cfs	Depth (D)	=	1.31 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	22.84 feet
Side slopes (Z)	=	3.0:1	Velocity	=	5.90 ft/sec
Bed Slope	=	1.300 %	Hydraulic Radius	=	1.06 feet
Manning's n	=	0.030			

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL

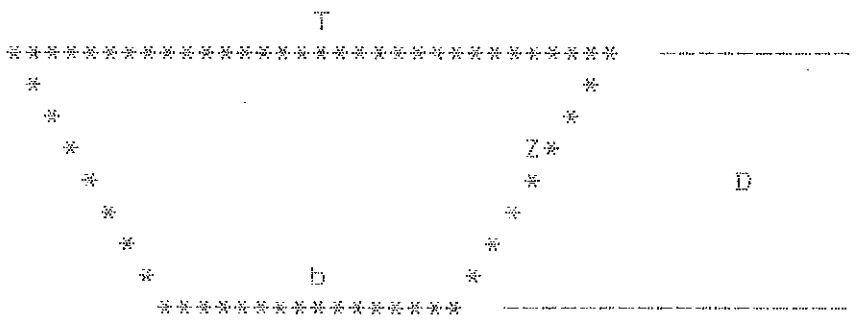


Discharge	=	56.70 cfs	Depth (D)	=	0.56 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	18.36 feet
Side slopes (Z)	=	3.0:1	Velocity	=	6.01 ft/sec
Bed Slope	=	5.500 %	Hydraulic Radius	=	0.50 feet
Manning's n	=	0.037			
Specific Gravity	=	2.30	Bottom D50	=	0.66 feet
Safety Factor	=	1.20	Bank D50	=	0.63 feet

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL



Discharge	=	144.40 cfs	Depth (D)	=	1.02 feet
Bottom (b)	=	15.00 feet	Top width (T)	=	21.12 feet
Side slopes (Z)	=	3.0:1	Velocity	=	7.77 ft/sec
Bed Slope	=	5.500 %	Hydraulic Radius	=	0.86 feet
Manning's n	=	0.041			
Specific Gravity	=	2.30	Bottom D50	=	1.19 feet
Safety Factor	=	1.20	Bank D50	=	1.13 feet

JAN 3 1 198

N14-4W

Subwatershed No. XS

Reclamation Channel 4C

Gradient Terraces 7T, 8T

JAN 31 1989

RECLAMATION CHANNEL 4C

100-YEAR, 6-HOUR STORM EVENT

CRITICAL SLOPE CALCULATIONS

TRAPEZOIDAL CHANNEL ANALYSIS
CRITICAL DEPTH COMPUTATION

Flow Rate (cubic feet per second)	712.2
Manning's Roughness Coefficient (n-value)	0.03
Channel Side Slope - Left Side (horizontal/vertical)	3
Channel Side Slope - Right Side (horizontal/vertical)	3
Channel Bottom Width (feet)	40

*** RESULTS ***

CRITICAL DEPTH (FEET)	2.03
Critical Slope (feet per foot)	0.0110
Flow Velocity (feet per second)	7.60
Froude Number	1.000
Velocity Head (feet)	0.90
Energy Head (feet)	2.93
Cross-Sectional Area of Flow (square feet)	93.68
Top Width of Flow (feet)	52.19

<Enter>: Repeat, <R>eport, or <Esc>: End

JAN 3 1 1989

RECLAMATION CHANNEL 4C

10-YEAR, 6-HOUR STORM EVENT

&

100-YEAR, 6-HOUR STORM EVENT

HYDRAULIC CALCULATIONS

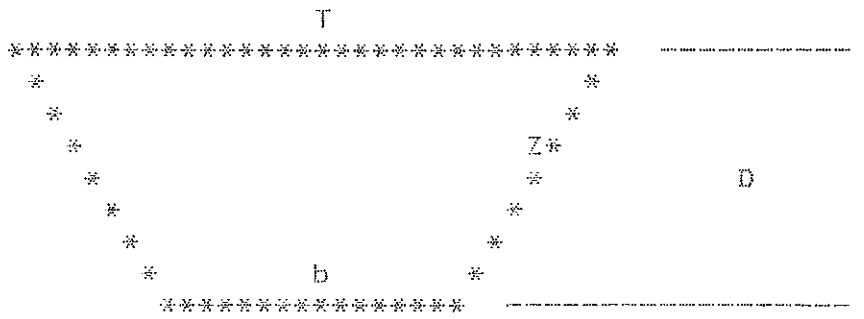
AT

1.1% AND 5.0% SLOPES

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

NONERODIBLE CHANNEL



Discharge	=	277.00 cfs	Depth (D)	=	1.17 feet
Bottom (b)	=	40.00 feet	Top width (T)	=	47.02 feet
Side slopes (Z)	=	3.0:1	Velocity	=	5.46 ft/sec
Bed Slope	=	1.100 %	Hydraulic Radius	=	1.07 feet
Manning's n	=	0.030			

JAN 31 1989

SEDCAD+ CHANNEL UTILITY

:

NONERODIBLE CHANNEL

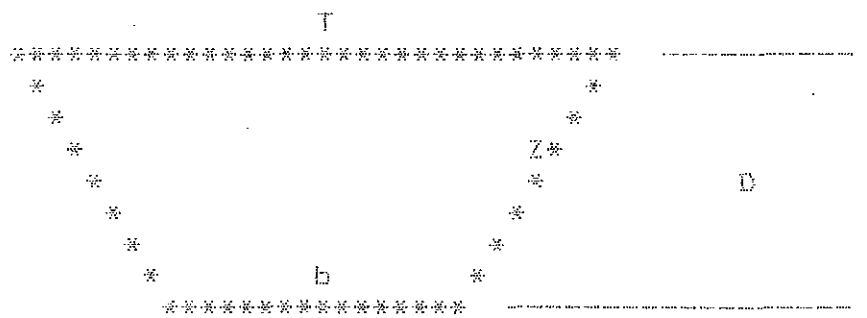
```
                    T
*********************************  ------------
 *                              *
  *                            *
   *                          Z*
    *                         *          D
     *                       *
      *                     *
       *         b         *
        ****************  ------------------------
```

Discharge	=	712.20 cfs	Depth (D)	=	2.08 feet
Bottom (b)	=	40.00 feet	Top width (T)	=	52.49 feet
Side slopes (Z)	=	3.0:1	Velocity	=	7.74 ft/sec
Bed Slope	=	1.100 %	Hydraulic Radius	=	1.81 feet
Manning's n	=	0.030			

JAN 3 1 1989

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL



Discharge	=	277.00 cfs	Depth (D)	=	0.87 feet
Bottom (b)	=	40.00 feet	Top width (T)	=	45.20 feet
Side slopes (Z)	=	3.0:1	Velocity	=	7.45 ft/sec
Bed slope	=	5.000 %	Hydraulic Radius	=	0.81 feet
Manning's n	=	0.039			
Specific Gravity	=	2.30	Bottom D50	=	0.91 feet
Safety Factor	=	1.20	Bank D50	=	0.87 feet

JAN 3 1 1990

SEDCAD+ CHANNEL UTILITY

ROCK RIPRAP CHANNEL

```
                    T
*********************************  ------------
*                                 *
 *                               *
  *                             Z*
   *                            *          D
    *                          *
     *                        *
      *          b           *
       ****************  ------------------
```

Discharge	=	712.20 cfs	Depth (D)	=	1.60 feet
Bottom (b)	=	40.00 feet	Top width (T)	=	49.62 feet
Side slopes (Z)	=	3.0:1	Velocity	=	9.84 ft/sec
Bed Slope	=	5.000 %	Hydraulic Radius	=	1.43 feet
Manning's n	=	0.043			
Specific Gravity	=	2.30	Bottom D50	=	1.68 feet
Safety Factor	=	1.20	Bank D50	=	1.61 feet

JAN 31 1989

ATTACHMENT B-2

BLANK FORMS

JAN 3 1 1989

CONVEYANCE STRUCTURE DESIGN SUMMARY

JAN 3 1 1989

Date:_____

Conveyance Structure Design Summary

Watershed ID:_____

Structure ID:_____

Location:_____

Map Number:_____

Structure Type:_____

Design Rainfall Depth (In):_____

Drainage Area (Ac):_____

Curve Number:_____

Time of Concentration (Hr):_____

Peak Discharge (cfs):_____

(Attach input and output printouts)

Channel Bottom Slope (%):_____

Manning's Roughness Coefficient:_____

Channel Side Slope: (L)_____ (R)_____

Channel Bottom Width (Ft):_____

Flow Depth (Ft):_____

(Attach channel analysis input and output printouts)

Flow Velocity (Fps):_____

Froude Number:_____

Is Channel Lining Requied? (Y)_____ (N)_____

Channel Lining Type:_____

Optional:

Riprap Specific Gravity:_____

Riprap Safety Factor:_____

Riprap Bottom D_{50}:_____

Riprap Bank D_{50}:_____

JAN 5 1 1988

TYPICAL HYDROLOGIC CALCULATION FORMS

JAN 3 1 1989

Typical SEDIMOT II Input File

(Gradient Terrace Sizing)

Card Code 1	Watershed Identification Code
Card Code 2	Storm Type
	I Type: SCS's Type II =
	NRPIV : No. of Depth Time Values =
Card Code 3	Storm Data
	P_{100}: Rainfall Depth (inch) =
	(or) P_{10} : Rainfall Depth (inch) =
	SDUR: Storm Duration (hr) =
	DELTSW: Storm Time Increment =
	P30INT: Max 30 Min. Intensity =
Card Code 4	Number of Junctions
	NOJ: Number of Junctions =
	IHYDR: Hydrology only =
Card Code 5	Number of Branches/Junctions
	NOB(I): Number of Branches per Junction =
Card Code 10	Number of Structures per Branch
	NOS (I,J): Number of Structures per Branch (I) for each Junction (J) =
Card Code 11	Between Structure Routing Parameters
	Time (I,J,K): Travel Time Between Structures =
	RK (I,J,K): Muskingum's K Between Structures (hr) =
	RX (I,J,K): Muskingum's X Between Structures (hr) =
Card Code 12	Subwatershed/Structure Information
	NSWS: Number of Subwatersheds per Structure =
	CNTROL: Type of Sediment Control Structure =
	IPRINT: Print Control Variable =
	ISUBSP: Print Control Variable for the Drainage Area Between Previous Structure or Junction =
	IPRINZ: Print Option for Subwatershed Inputs =
Card Code 13	Subwatershed Data
	PARAH (I,1): Subwatershed Area (acres) =

JAN 3 1 1999

Typical SEDIMOT II Input File

(Gradient Terrace Sizing)

PARAH (1,2): Curve Number (Reclaimed) =

PARAH (1,3): Time of Concentration (hr) =

PARAH (1,4): Travel Time (to Structure) =

PARAH (1,5): Muskingum's K (to Structure) =

PARAH (1,6): Muskingum's X (to Structure) =

PARAH (1,7): Hydrology Print Option =

PARAH (1,8): Hydraulic Surface Condition =

PARAH (1,9): Number of Flow Segments =

Typical SEDIMOT II Input File

(Downdrain Sizing)

Card Code 1	Watershed Identification Code
Card Code 2	Storm Type
	I Type: SCS's Type II =
	NRPIV : No. of Depth Time Values =
Card Code 3	Storm Data
	P_{100}: Rainfall Depth (inch) =
	(or) P_{10} : Rainfall Depth (inch) =
	SDUR: Storm Duration (hr) =
	DELTSW: Storm Time Increment =
	P30INT: Max 30 Min. Intensity =
Card Code 4	Number of Junctions
	NOJ: Number of Junctions =
	IHYDR: Hydrology only =
Card Code 5	Number of Branches/Junctions
	NOB(I): Number of Branches per Junction =
Card Code 10	Number of Structures per Branch
	NOS (I,J): Number of Structures per Branch (I) for each Junction (J) =
Card Code 11	Between Structure Routing Parameters
	Time (I,J,K): Travel Time Between Structures =
	RK (I,J,K): Muskingum's K Between Structures (hr) =
	RX (I,J,K): Muskingum's X Between Structures (hr) =
Card Code 12	Subwatershed/Structure Information
	NSWS: Number of Subwatersheds per Structure =
	CNTROL: Type of Sediment Control Structure =
	IPRINT: Print Control Variable =
	ISUBSP: Print Control Variable for the Drainage Area Between Previous Structure or Junction =
	IPRINZ: Print Option for Subwatershed Inputs =
Card Code 13	Subwatershed Data
	PARAH (I,1): Subwatershed Area (acres) =

JAN 3 1 1989

Typical SEDIMOT II Input File

(Downdrain Sizing)

PARAH (1,2): Curve Number (Reclaimed) =

PARAH (1,3): Time of Concentration (hr) =

PARAH (1,4): Travel Time (to Structure) =

PARAH (1,5): Muskingum's K (to Structure) =

PARAH (1,6): Muskingum's X (to Structure) =

PARAH (1,7): Hydrology Print Option =

PARAH (1,8): Hydraulic Surface Condition =

PARAH (1,9): Number of Flow Segments =

Typical SEDIMOT II Input File

(Primary Reclamation Channel Sizing)

Card Code 1	Watershed Identification Code
Card Code 2	Storm Type
	I Type: SCS's Type II =
	NRPIV: No. of Depth Time Values =
Card Code 3	Storm Data
	P_{100}: Rainfall Depth (inch) =
	(or) P_{10} : Rainfall Depth (inch) =
	SDUR: Storm Duration (hr) =
	DELTSW: Storm Time Increment =
	P30INT: Max 30 Min. Intensity =
Card Code 4	Number of Junctions
	NOJ: Number of Junctions =
	IHYDR: Hydrology only =
Card Code 5	Number of Branches/Junctions
	NOB(I):Number of Branches per Junction =
Card Code 10	Number of Structures per Branch
	NOS (I,J): Number of Structures per Branch (I) for each Junction (J) =
Card Code 11	Between Structure Routing Parameters
	Time (I,J,K): Travel Time Between Structures =
	RK (I,J,K): Muskingum's K Between Structures (hr) =
	RX (I,J,K): Muskingum's X Between Structures (hr) =
Card Code 12	Subwatershed/Structure Information
	NSWS: Number of Subwatersheds per Structure =
	CNTROL: Type of Sediment Control Structure =
	IPRINT: Print Control Variable =
	ISUBSP: Print Control Variable for the Drainage Area Between Previous Structure or Junction =
	IPRINZ: Print Option for Subwatershed Inputs =

JAN 3 1 1989

Typical SEDIMOT II Input File

(Primary Reclamation Channel Sizing)

Card Code 13

Subwatershed Data

PARAH (I,1): Subwatershed Area (acres) =

PARAH (I,2): Curve Number (Reclaimed) =

PARAH (I,3): Time of Concentration (hr) =

PARAH (I,4): Travel Time (to Structure) =

PARAH (I,5): Muskingum's K (to Structure) =

PARAH (I,6): Muskingum's X (to Structure) =

PARAH (I,7): Hydrology Print Option =

PARAH (I,8): Hydraulic Surface Condition =

PARAH (I,9): Number of Flow Segments =

WORK SHEET I

for
Routing Hydrographs
Between Junctions and/or Structures

From Junction or Structure _____ to Structure _____

(1) Segment	(2) Surf. Cond.	(3) Horizontal Distance (ft.)	(4) Vertical Distance (ft.)	(5) Diagonal Distance (ft.)	(6) Slope (%)	(7) Velocity (ft./sec.)	(8) Travel Time (hr.)
1							
2							
3							
		Σ _____		Σ _____			Σ _____

$\overline{V}_w$ = _____ , X = _____ , K = _____

From Junction or Structure _____ to Structure _____

Segment	Surf. Cond.	Horizontal Distance (ft.)	Vertical Distance (ft.)	Diagonal Distance (ft.)	Slope (%)	Velocity (ft./sec.)	Travel Time (hr.)
1							
2							
3							
		Σ _____		Σ _____			Σ _____

$\overline{V}_w$ = _____ , X = _____ , K = _____

From Junction or Structure _____ to Structure _____

Segment	Surf. Cond.	Horizontal Distance (ft.)	Vertical Distance (ft.)	Diagonal Distance (ft.)	Slope (%)	Velocity (ft./sec.)	Travel Time (hr.)
1							
2							
3							
		Σ _____		Σ _____			Σ _____

$\overline{V}_w$ = _____ , X = _____ , K = _____

$$\overline{V}_w = \sum_{i=1}^{N} \frac{\text{col. } 3_{(i)} \times \text{col. } 7_{(i)}}{\Sigma \text{ col. } 3}, \quad \text{OR} \quad \overline{V}_w = \sum_{i=1}^{N} \frac{\text{col. } 5_{(i)} \times \text{col. } 7_{(i)}}{\Sigma \text{ col. } 5}; \quad \text{where } N = \text{segment numbers}$$

$$X = \frac{.5\,\overline{V}_w}{1.7 + \overline{V}_w} \qquad K = \Sigma \text{ col. } 8$$

JAN 3 1 1989

TYPICAL SEDIMOT II

OUTPUT FILE

JAN 3 1 1989

****
****

UNIVERSITY OF KENTUCKY COMPUTER MODEL
OF SURFACE MINE HYDROLOGY AND SEDIMENTOLOGY
FOR MORE INFORMATION CONTACT THE AGRICULTURAL
ENGINEERING DEPARTMENT

THE UK MODEL IS A DESIGN MODEL DEVELOPED TO PREDICT
THE HYDRAULIC AND SEDIMENT RESPONSE FROM SURFACE
MINED LANDS FOR A SPECIFIED RAINFALL EVENT (SINGLE STORM)

VERSION DATE 5-25-83

DISCLAIMER: NEITHER THE UNIVERSITY NOR ANY OF ITS EMPLOYEES
ACCEPT ANY RESPONSIBILITY OR LEGAL LIABILITY FOR THE
CONCLUSIONS DRAWN FROM THE RESULTS OF THIS MODEL

****
****

****

WATERSHED IDENTIFICATION CODE

****

**********INPUT VALUES**********

STORM DURATION	=	HOURS
PRECIPITATION DEPTH	=	INCHES

JAN 3 1 1989

* *

JUNCTION BRANCH STRUCTURE

* *

*** HYDRAULIC INPUT VALUES FOR SUBWATERSHEDS ***

WATER SHED	AREA ACRES	CURVE NUMBER	TC HR	TT HR	ROUTING COEFFICIENTS K-HRS	X	UNIT HYDRO

* * * COMPUTED VALUES FOR INDIVIDUAL WATERSHEDS * * *

WATERSHED	PEAK FLOW (CFS)	RUNOFF (INCHES)

NOTE: SEDIMENT DOES NOT INCLUDE POSSIBLE DEPOSITION BY DELIVERY RATIO 2

***** SUMMARY TABLE FOR TOTAL WATERSHED *****

RUNOFF VOLUME	=	ACRE-FT
PEAK DISCHARGE	=	CFS
AREA	=	ACRES
TIME OF PEAK DISCHARGE	=	HRS

* * * * * * * * * * * * *

NULL STRUCTURE

* * * * * * * * * * * * *

*** RUN COMPLETED ****

JAN 31 1989

TYPICAL HYDRAULIC CALCULATION FORMS

JAN 3 1 1989

TRAPEZOIDAL CHANNEL ANALYSIS
NORMAL DEPTH COMPUTATION

Flow Rate (cubic feet per second)
Channel Bottom Slope (feet per foot)
Manning`s Roughness Coefficient (n-value)
Channel Side Slope - Left Side (horizontal/vertical)
Channel Side Slope - Right Side (horizontal/vertical)
Channel Bottom Width (feet)

*** RESULTS ***

NORMAL DEPTH (FEET)
Flow Velocity (feet per second)
Froude Number
Velocity Head (feet)
Energy Head (feet)
Cross-Sectional Area of Flow (square feet)
Top Width of Flow (feet)

<Enter>: Repeat, <R>eport, or <Esc>: End

JAN 3 1 1989

TRAPEZOIDAL CHANNEL ANALYSIS
CRITICAL DEPTH COMPUTATION

Flow Rate (cubic feet per second)
Manning's Roughness Coefficient (n-value)
Channel Side Slope - Left Side (horizontal/vertical)
Channel Side Slope - Right Side (horizontal/vertical)
Channel Bottom Width (feet)

*** RESULTS ***

CRITICAL DEPTH (FEET)
Critical Slope (feet per foot)
Flow Velocity (feet per second)
Froude Number
Velocity Head (feet)
Energy Head (feet)
Cross-Sectional Area of Flow (square feet)
Top Width of Flow (feet)

<Enter>: Repeat, <R>eport, or <Esc>: End

JAN 31 1989

TRAPEZOIDAL CHANNEL ANALYSIS
RATING CURVE COMPUTATION

Channel Bottom Slope (feet per foot)
Manning's Roughness Coefficient (n-value)
Channel Side Slope - Left Side (horizontal/vertical)
Channel Side Slope - Right Side (horizontal/vertical)
Channel Bottom Width (feet)

*** RESULTS ***

Depth (ft)	Flow Rate (cfs)	Velocity (fps)	Froude Number	Velocity Head(ft)	Energy Head(ft)	Flow Area (sq ft)	Top Width (ft)

Enter Depth of Flow, or Press the <Esc> Key to End

JAN 3 1 1989

NONERODIBLE CHANNEL DESIGN

What shape channel will you be designing for?
1 - TRAPEZOIDAL
2 - PARABOLIC
3 - TRIANGULAR
? 1

Will you INPUT:
1 - DISCHARGE
2 - DEPTH OF FLOW
? 1

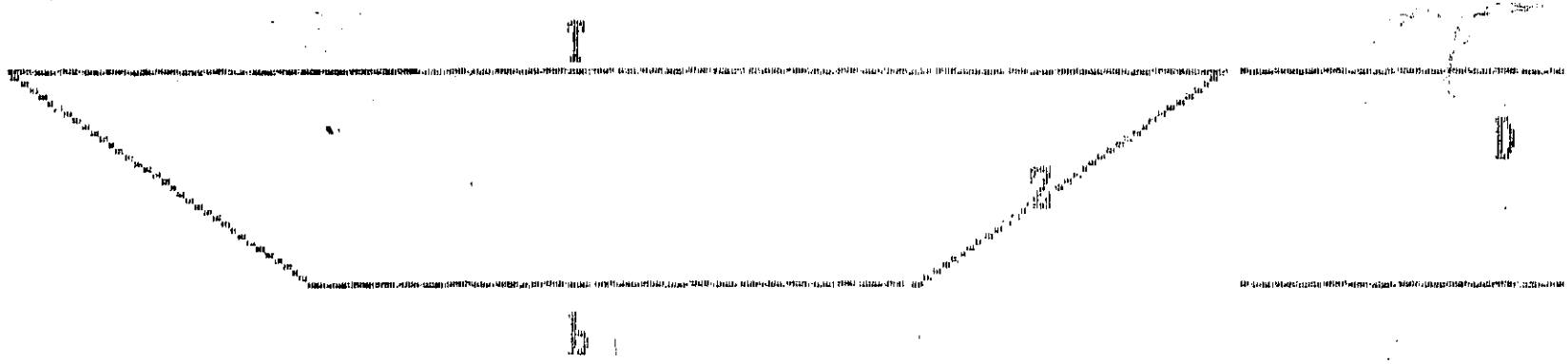
What is the Design Discharge (cfs) ?
What is the average channel bed slope (%) ?
What are the side slopes (Z:1 - enter Z)?
What is the bottom width (in feet)?

CHANNEL MATERIAL	MANNING'S N	RANGE MIN.	RANGE MAX
1 - ASPHALTIC CONCRETE, MACHINE PLACED	[.014]	***	***
2 - ASPHALT, EXPOSED PREFABRICATED	[.015]	***	***
3 - CONCRETE	[.015]	.012	.018
4 - CONCRETE, RUBBLE	[.022]	.016	.029
5 - METAL, SMOOTH (FLUMES)	[.013]	.011	.015
6 - METAL, CORRUGATED	[.024]	.021	.026
7 - PLASTIC	[.013]	.012	.014
8 - SHOTCRETE	[.017]	.016	.017
9 - OTHER	????		

Enter Number Corresponding to Channel Material Used
[Brackets indicate default Manning's n value used]? 9
Enter the Manning's n value?

JAN 31 1989

NONERODIBLE CHANNEL



TRAPEZOIDAL SECTION

Discharge	=	cfs	Depth (D)	=	feet
Bottom (b)	=	feet	Top width (T)	=	feet
Side slopes (Z)	=		Velocity	=	ft/sec
Bed Slope	=	%	Hydraulic Radius	=	feet
Manning's n	=				

JAN 31 1989

ERODIBLE CHANNEL DESIGN

What shape channel will you be designing for?
1 - TRAPEZOIDAL
2 - PARABOLIC
3 - TRIANGULAR
? 1
What is the design discharge (cfs)?
What is the average channel bed slope (%) ?
What are the side slopes (Z:1 - enter Z)?
What is the bottom width (in feet)?
Are you designing for:
1 - CLEAR WATER
2 - WATER TRANSPORTING COLLODIAL SILTS
? 2
Enter the method:
1 - LIMITING VELOCITY
2 - TRACTIVE FORCE
? 1

Enter the number corresponding to channel material:

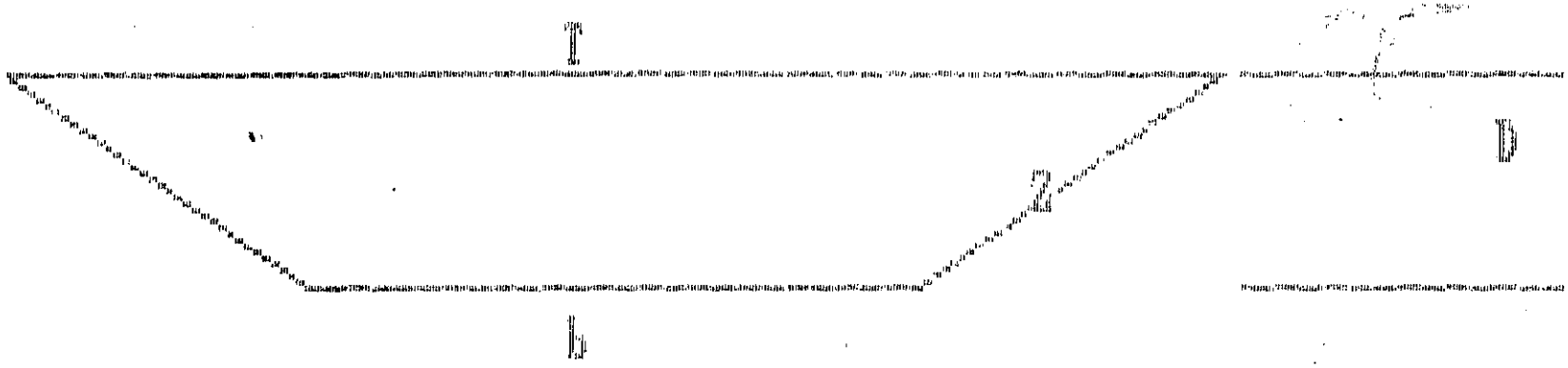
LIMITING VELOCITIES AND TRACTIVE FORCES FOR OPEN CHANNELS

			For Clear Water		Water Transporting Colloidal Silts	
N	Material	(n)	Velocity (fps)	Tractive Force (psf)	Velocity (fps)	Tractive Force (psf)
1	FINE SAND COLLOIDAL	0.020	1.50	0.027	2.50	0.075
2	SANDY LOAM NONCOLLOIDAL	0.020	1.75	0.037	2.50	0.075
3	SILT LOAM NONCOLLOIDAL	0.020	2.00	0.037	3.00	0.075
4	ALLUVIAL SILTS NONCOLLOIDAL	0.020	2.00	0.048	3.50	0.150
5	ORDINARY FIRM LOAM	0.020	2.50	0.075	3.50	0.150
6	VOLCANIC ASH	0.020	2.50	0.075	3.50	0.150
7	STIFF CLAY VERY COLLOIDAL	0.025	3.75	0.260	5.00	0.460
8	ALLUVIAL SILTS COLLOIDAL	0.025	3.75	0.260	5.00	0.460
9	SHALES AND HARDPANS	0.025	6.00	0.670	6.00	0.670
10	FINE GRAVEL	0.020	2.50	0.075	5.00	0.320
11	GRADED LOAM-COBBLES NONCOLLOIDAL	0.030	3.75	0.380	5.00	0.660
12	GRADED SILTS-COBBLES COLLOIDAL	0.030	4.00	0.430	5.50	0
13	COARSE GRAVEL NONCOLLOIDAL	0.025	4.00	0.300	6.00	0
14	COBBLES AND SHINGLES	0.035	5.00	0.910	5.50	1.100

?

JAN 31 1989

ERODIBLE CHANNEL



TRAPEZOIDAL SECTION

Discharge	=	cfs	Depth (D)	=	feet
Bottom (b)	=	feet	Top width (T)	=	feet
Side slopes (Z)	=		Velocity	=	ft/sec
Bed Slope	=	%	Hydraulic Radius	=	feet
Manning's n	=				

JAN 31 1989

ROCK RIPRAP DESIGN

What is the design discharge (cfs)?
What is the average channel bed slope (%) ?
What are the side slopes (Z:1 - enter Z)?
What is the bottom width (in feet)?
What is the Specific Gravity of the rock [2.65]?
What is the design Safety Factor [1.5]?

SEDCAD+ CHANNEL UTILITY

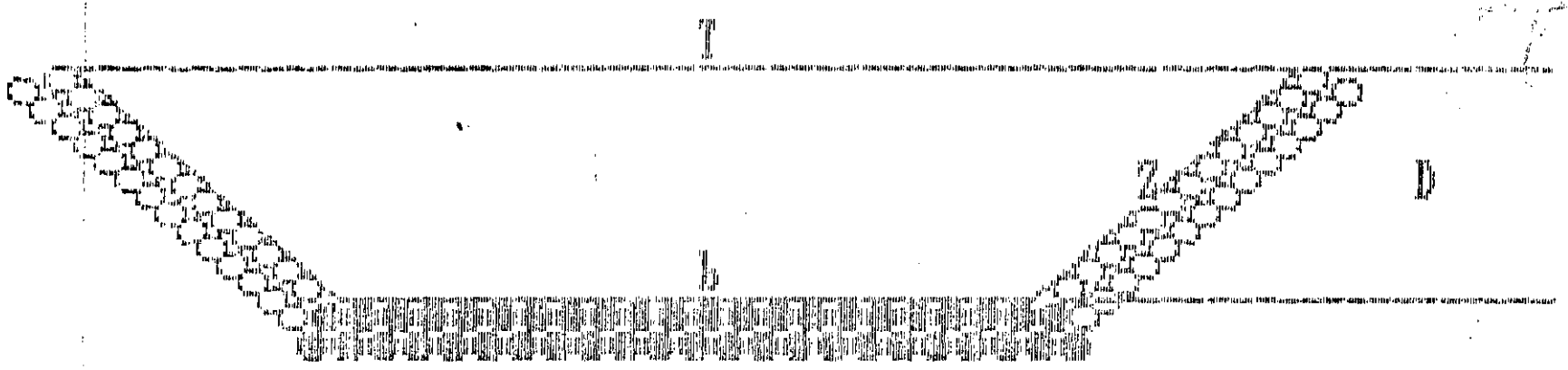
ROCK RIPRAP CHANNEL

```
                    T
*********************************  ----------
 *                              *
  *                            *
   *                          Z*
    *                         *          D
     *                       *
      *                     *
       *         b         *
        ****************  -----------------
```

Discharge	=	cfs	Depth (D)	=	feet
Bottom (b)	=	feet	Top width (T)	=	feet
Side slopes (Z)	=		Velocity	=	ft/
Bed Slope	=	%	Hydraulic Radius	=	feet
Manning's n	=				
Specific Gravity	=		Bottom D50	=	feet
Safety Factor	=		Bank D50	=	feet

JAN 31 1989

ROCK RIPRAP CHANNEL



TRAPEZOIDAL SECTION

Discharge	=	cfs	Depth (D)	=	feet
Bottom (b)	=	feet	Top width (T)	=	feet
Side slopes (Z)	=		Velocity	=	ft/sec
Bed Slope	=	%	Hydraulic Radius	=	feet
Manning's n	=		Bottom D50	=	feet
Specific Gravity	=		Bank D50	=	feet
Safety Factor	=				

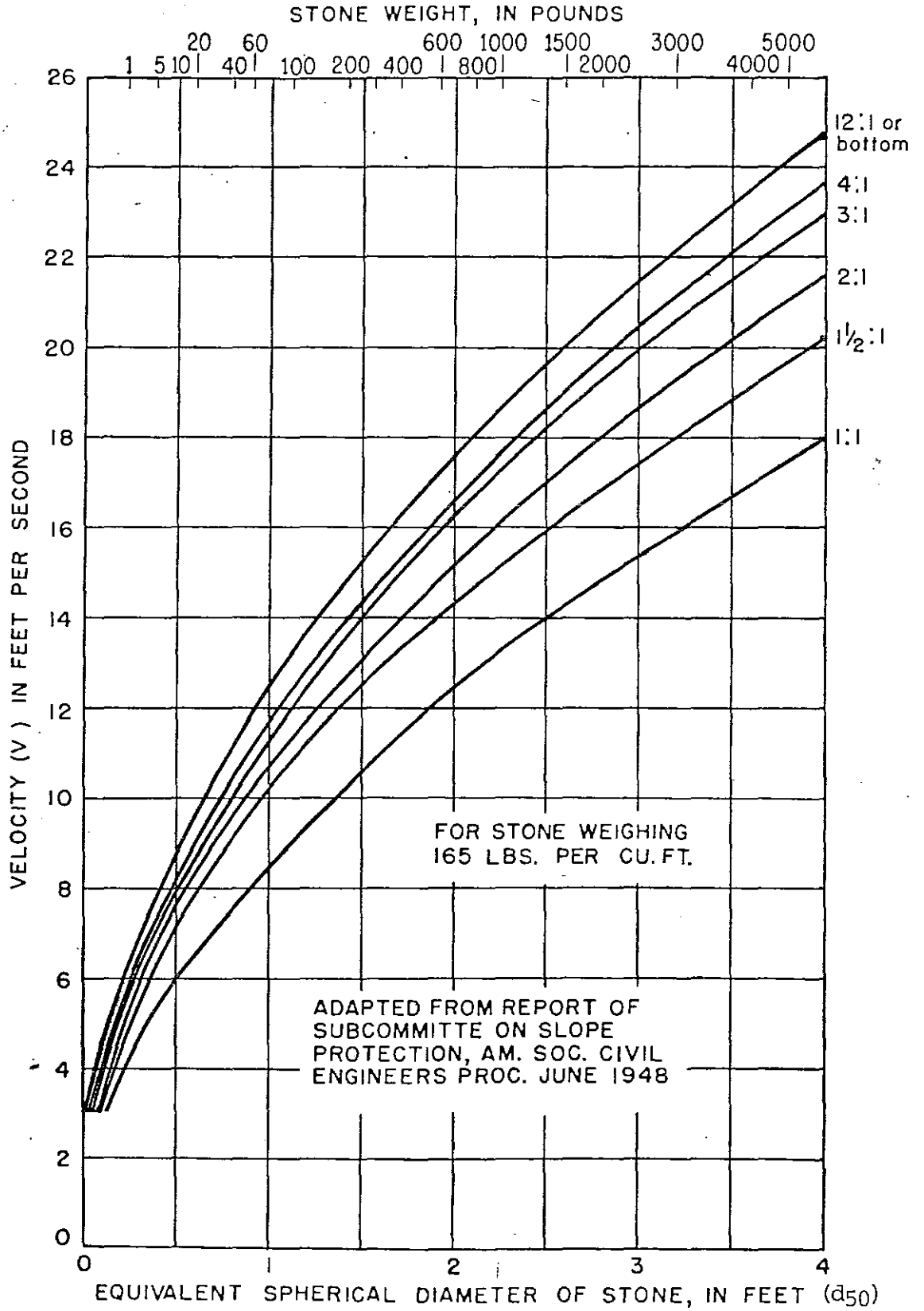
JAN 31 1989

AM. SOC. CIVIL ENGINEERS

PROC. JUNE, 1984

RIPRAP SIZING CHART

JAN 3 1 1989



SIZE OF STONE THAT WILL RESIST DISPLACEMENT FOR VARIOUS VELOCITIES AND SIDE SLOPES

JAN 5 1 1989

DESIGN COMMENTS

Date:_____

Watershed ID:_____

Structure ID:_____

Designer:_____

JAN 3 1 1989

FIELD MONITORING AND MAINTENANCE INSPECTION FORM

JAN 3 1 1989

Peabody

INSPECTION FORM

PEABODY COAL COMPANY
Western Division

DATE _____

DAY	S	M	T	W	TH	F	S

PROJECT _____
JOB NO. _____
CLIENT _____
CONTRACTOR _____
PROJECT MANAGER _____

WEATHER	Brite Sun	Clear	Overcast	Rain	Snow
TEMP.	To 32	32-50	50-70	70-85	85 up
WIND	Still	Moder	High	Report No	
HUMIDITY	Dry	Moder	Humid		

AVERAGE FIELD FORCE

Name of Contractor	Non-manual	Manual	Remarks

VISITORS

Time	Representing	Representing	Remarks

EQUIPMENT AT THE SITE

CONSTRUCTION ACTIVITIES

DISTRIBUTION:
1. Proj. Mgr.
2. Field Office
3. File
4. Client

PAGE 1 OF _____ PAGES

BY _____ TITLE _____

Wiley-Fisk Form 8-1

JAN 3 1 1989

Peabody

PEABODY COAL COMPANY
Western Division

INSPECTION FO 1
(Continua eet)

PROJECT _____ REPORT NO. _____

JOB NO. _____ DATE _____

CONSTRUCTION ACTIVITIES (Continued)

Discussions

Inspectors Comments

DISTRIBUTION:
1. Proj. Mgr.
2. Field Office
3. File
4. Client

SHEET _____ OF _____

BY _____ TITLE _____ JAN 3 1 1989

ATTACHMENT C

RECLAMATION SURFACE STABILIZATION DESIGN PROCESS

MAR 2012
APPROVED

ATTACHMENT C
Reclamation Surface Stabilization Design Process

Evaluated Existing Plan – Assemble Estimated PMT Design for Approval

↓

Obtain Latest Existing Topographic Data and Site Parameters. Determine Existing Premine Drainage Density. Attach Existing Coal Crop Boundary. (See Figure 1.)

↓

PMT Design Considerations using latest "Life-of-Mine" Mine Plan, Pond Locations, Ramps/Roads, Facilities, Topsoil Pile Locations, Environmental Sites (TCP, Archaeological Sites, etc..), External Dumpsite Locations and Any Other Existing Obstructions. (See Figures 2 and 3)

↓

Determine Excavating Machines and Parameters. (See Figure 4)

↓

Determine Cross-Section Locations on Existing Topographic Map to be used with Range Diagram Software. Develop Mined Out Spoil Cross-Sections for use in Geomorphology Design Software. (See Figures 5 and 6)

↓

Develop Mined Out Spoil Topography Contours with Final Ramps, Haul Roads, Permanent Features and Drainages. (See Figures 7 and 8)

↓

Develop Bottom of Coal Surface Topography to Determine Cut/Fill Balance of PMT Surface (See Figure 9)

↓

Design Postmine Topography Contours using Latest Available Computer Aided Design Software. Design PMT Channels Similar to Existing Premine Surface Drainage Density (ft/ac.). Design Geomorphic Surface using Side Board Guidelines in Attachment A . Develop 1st Order Channels and Spacing using Guidelines in Attachment B. Adjust PMT Outer Edge Boundary to Incorporate Permanent Structures (Ponds, Roads, Streams, Lease Boundary, Environmental Sites and Undisturbed Areas. (See Figure 10)

↓

Does Postmine Topography Cut/Fill Balance come within +/- 5% ? or are Slopes less than/equal to 4:1?

→ No → Re-Adjust Spoil Topography Contours. → (back to Design Postmine Topography Contours)

↓

Yes

↓

Update 85352 "Estimated Postmining Topography Map" (See Figure 11)

↓

MAR 2012
APPROVED

Develop PMT Watersheds for each 2nd Order or Higher Channels. 1st Order Channels will use Attachment A or B as Design Guidelines as Appropriate. Design Appropriate Erosion Protection Structure for Estimated Channel Locations. (See Figure 12)

↓

Update "Exhibit #1 Hydrology Parameters" Map with Supporting Channel Profile Sheets where Appropriate. (See Figure 13)

↓

Submit Assemble Estimated PMT Design for Approval

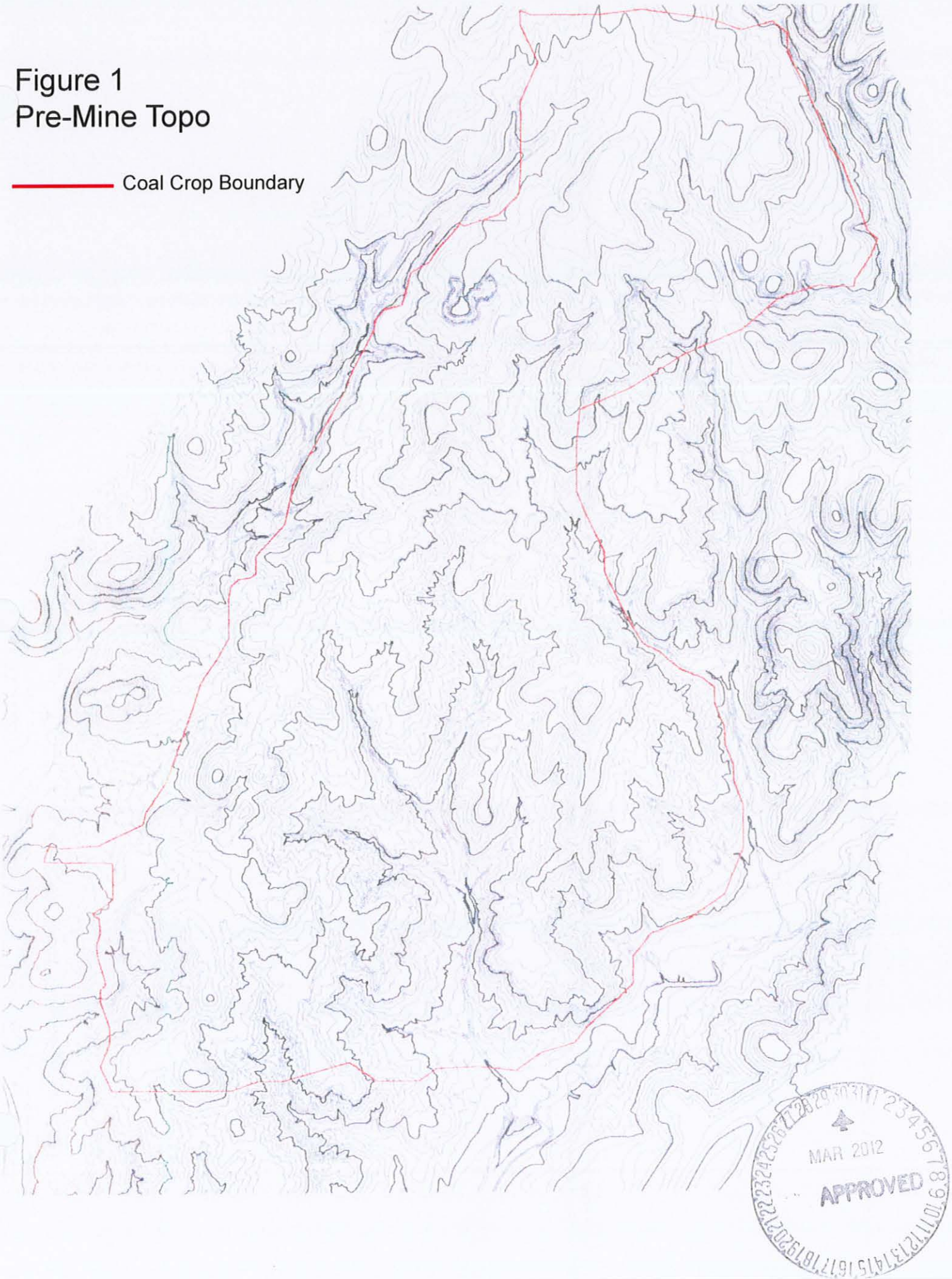
↓

Initiate Rough Grading Activities Using Chapter 26 Side Boards as Guidance

MAR 2012
APPROVED

Figure 1
Pre-Mine Topo

Coal Crop Boundary



MAR 2012
APPROVED

Figure 2
"Life-of-Mine"
Mine Plan

MAR 2012
APPROVED

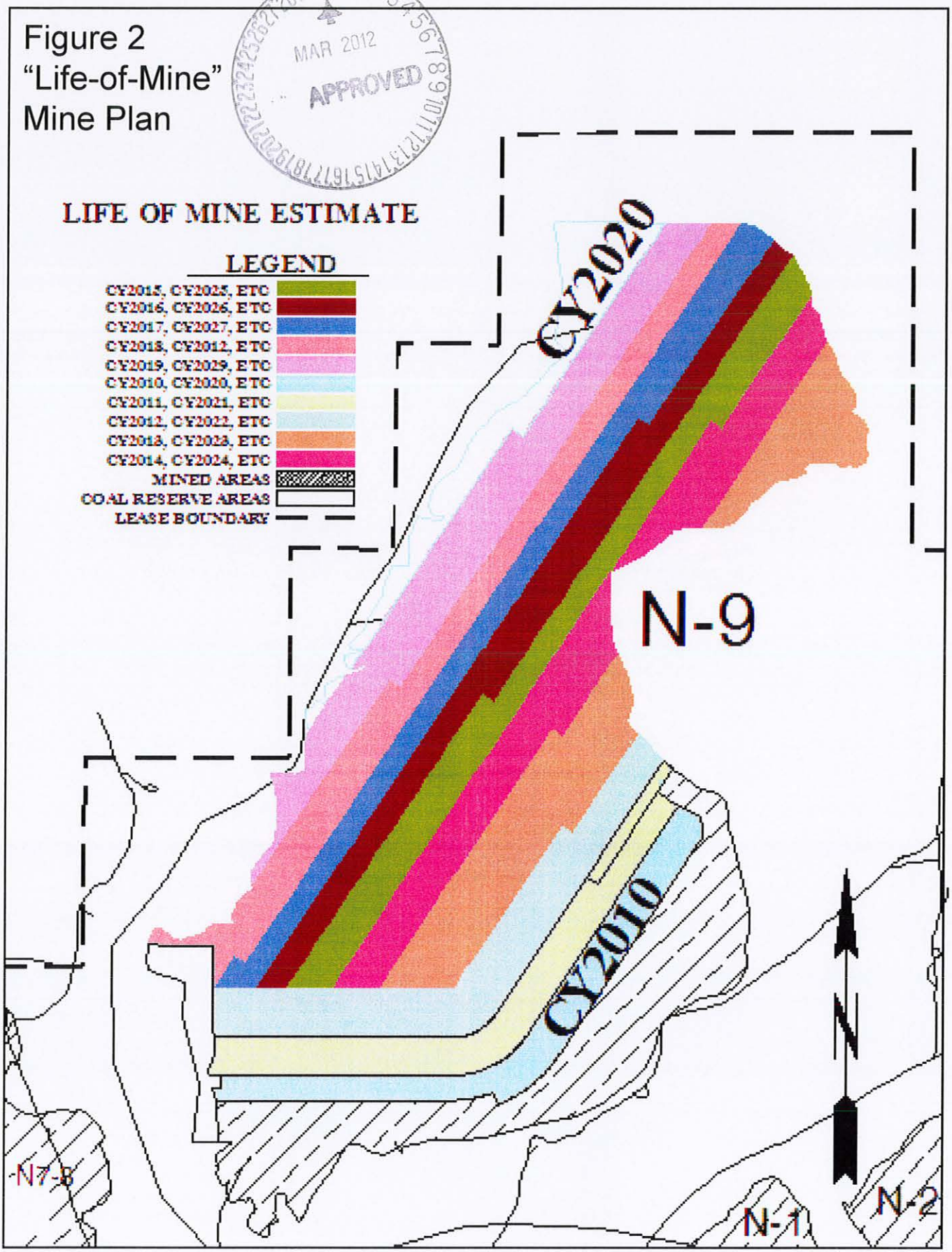


Figure 3
"Life-of-Mine" Mine Plan and Obstructions

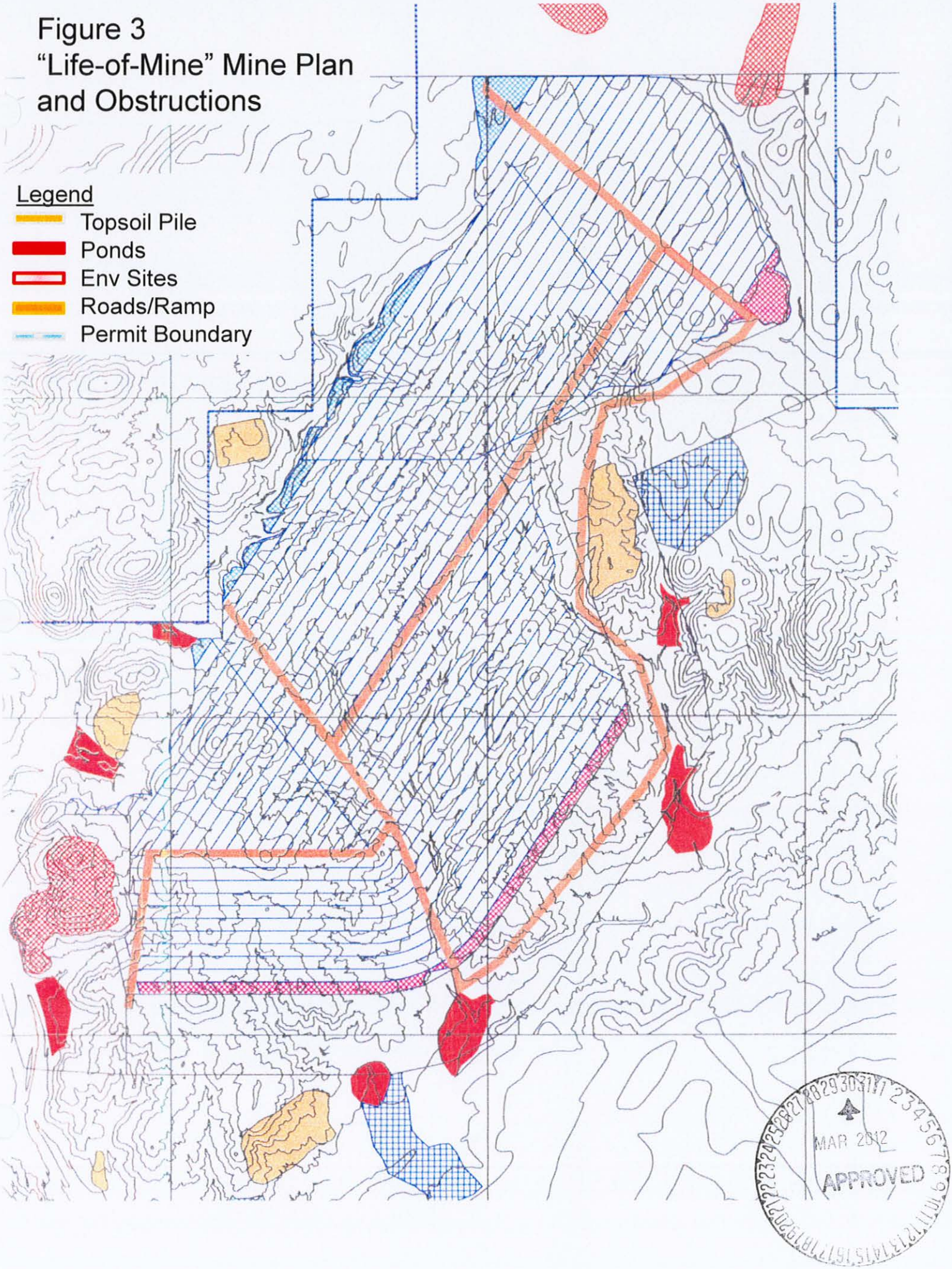
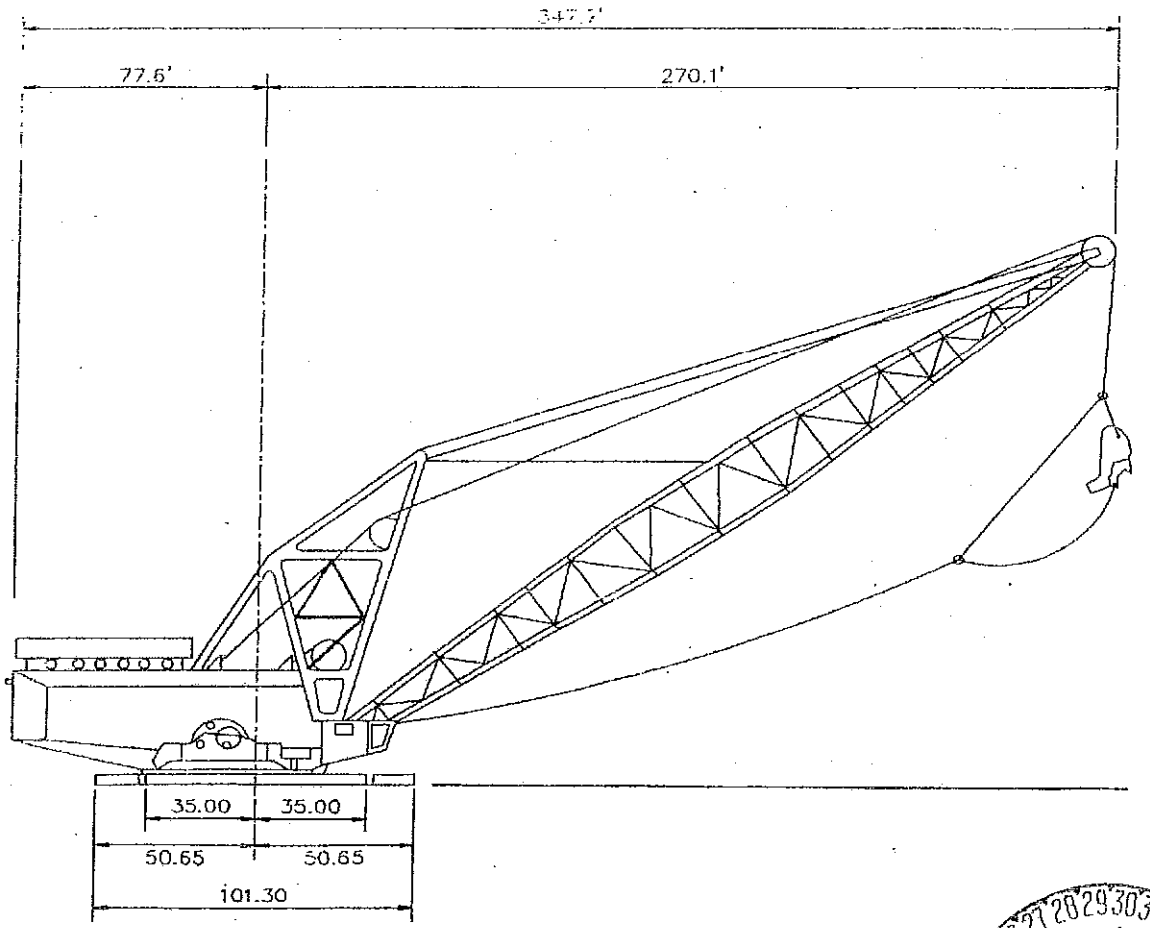


Figure 4
Excavating Machine
Example

Marion 8750
Dragline Dimensions

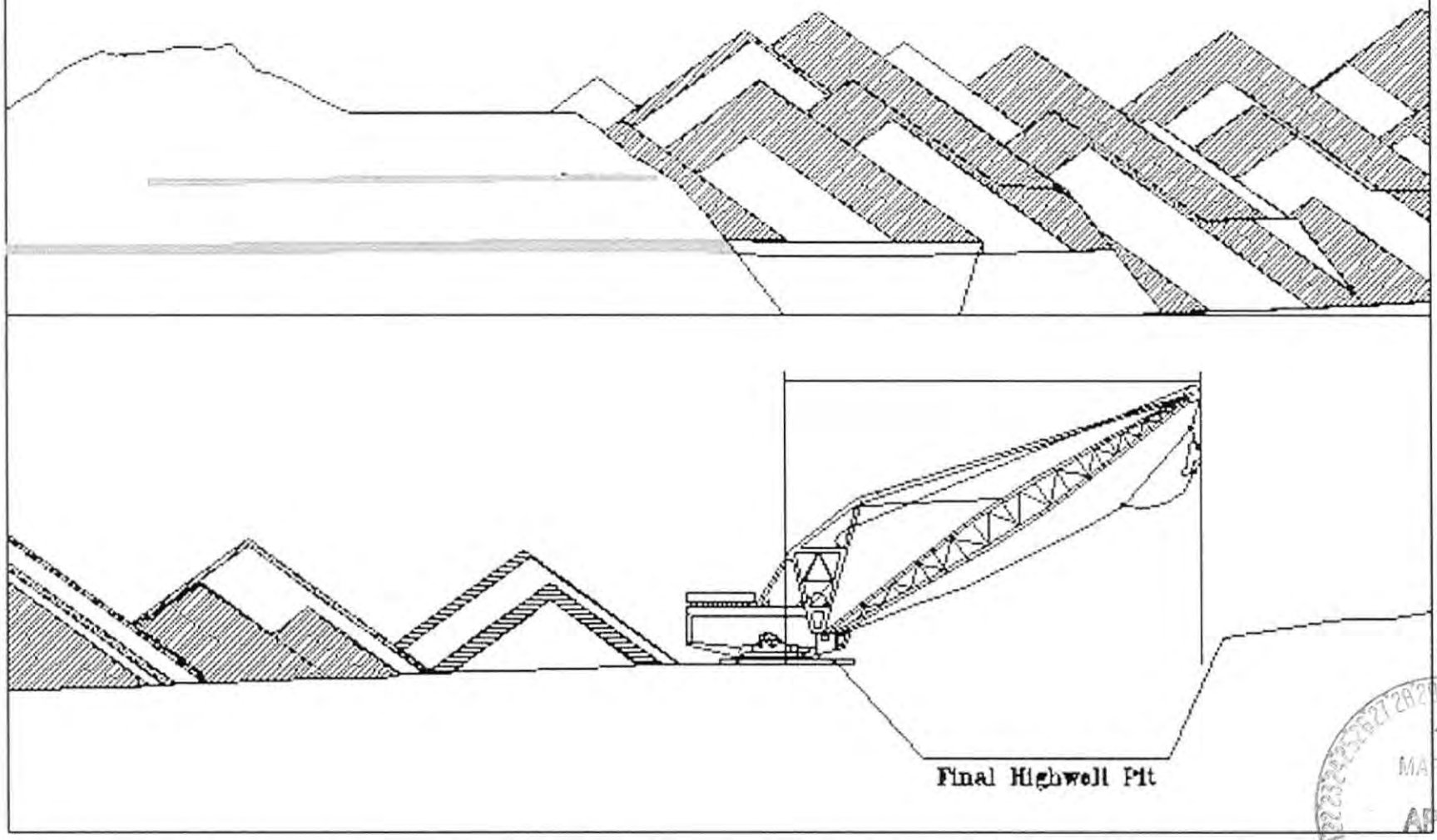


Tub Diameter---- 70 feet
Shoe Width ----- 13.5 feet
Dump Radius ----270.1 feet
Dump Height ----109.1 feet
Boom Angle-----35°45'5.6"
Outside to Outside of Shoe -----101.3 feet
Rear Clearance to Edge of Housing-----77.6 feet

MAR 2012
APPROVED

Figure 5

TYPICAL RANGE DIAGRAM FOR POSTMINING TOPOGRAPHY DESIGN PROCESS



MAR 2012
APPROVED

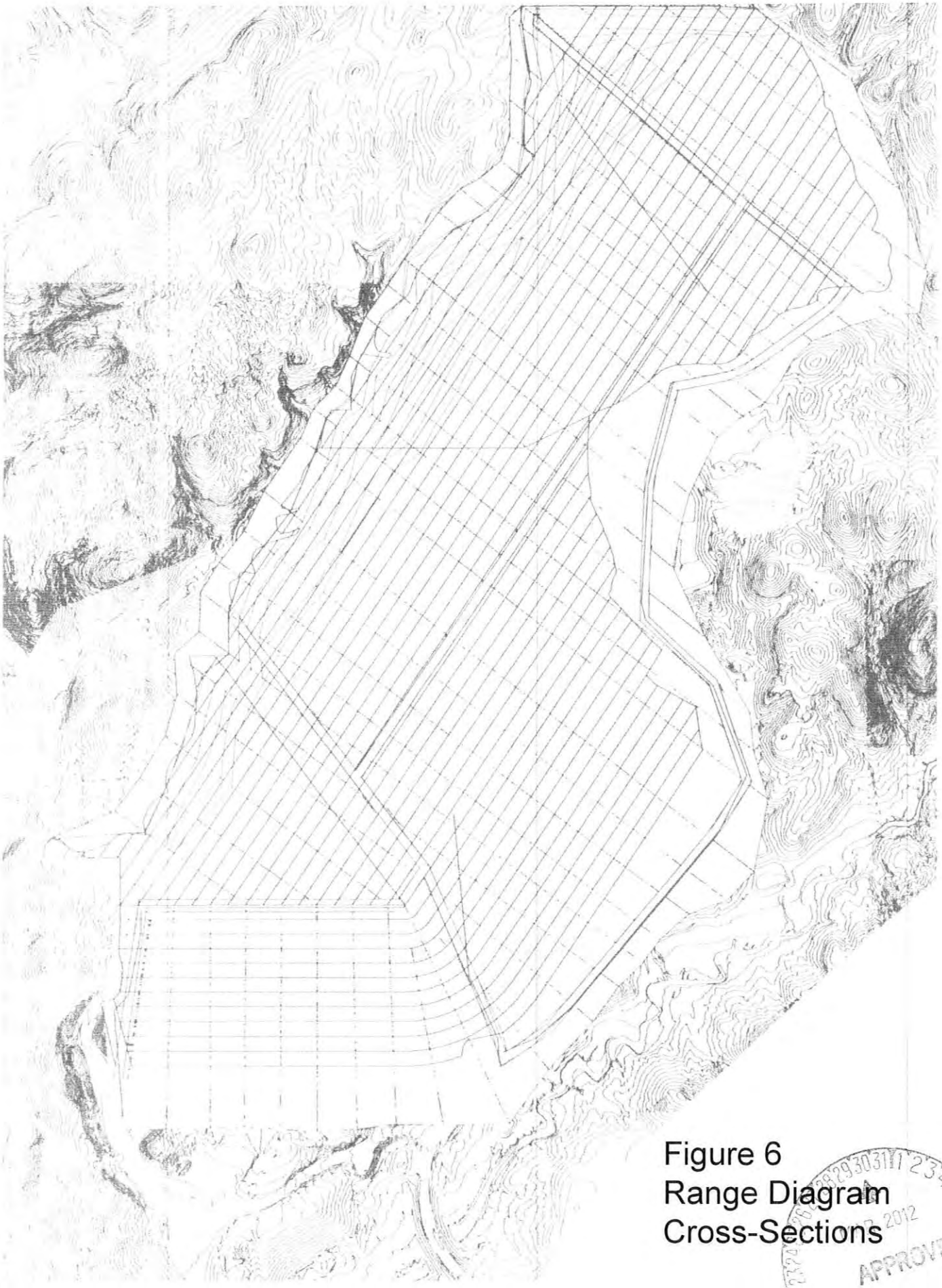
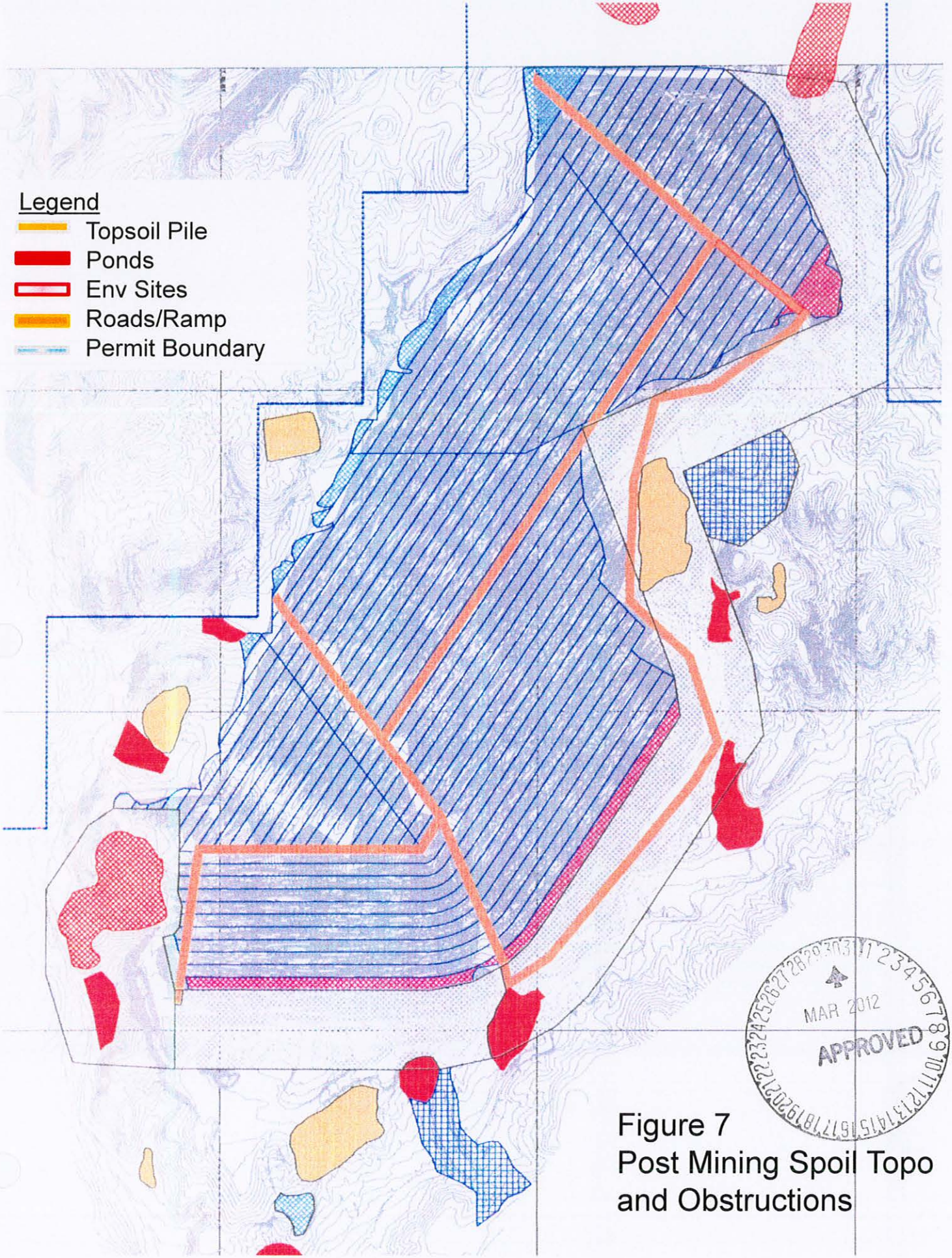


Figure 6
Range Diagram
Cross-Sections

APPROVED



MAR 2012
APPROVED

Figure 7
Post Mining Spoil Topo
and Obstructions

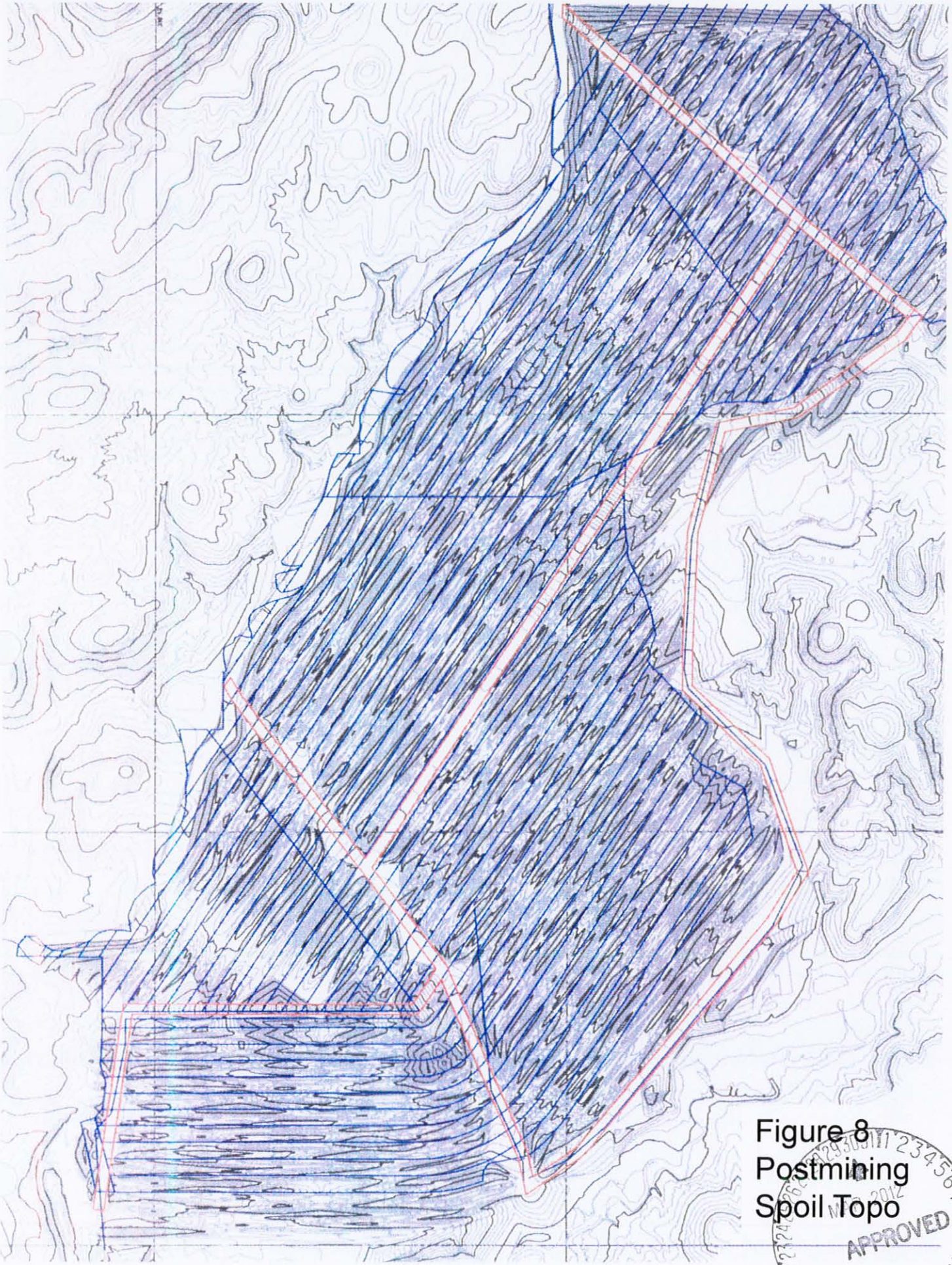


Figure 8
Postmining
Spoil Topo

APPROVED

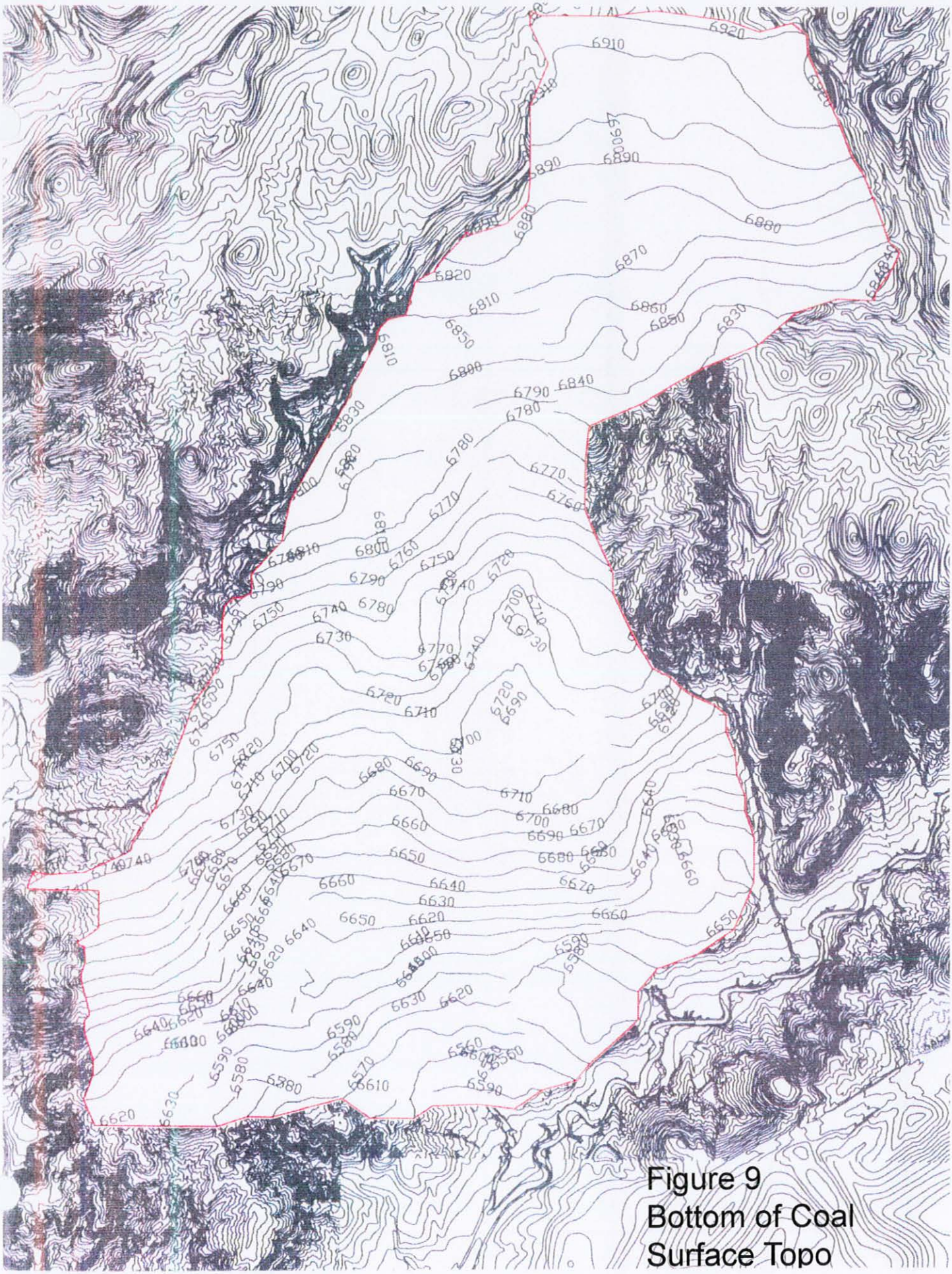
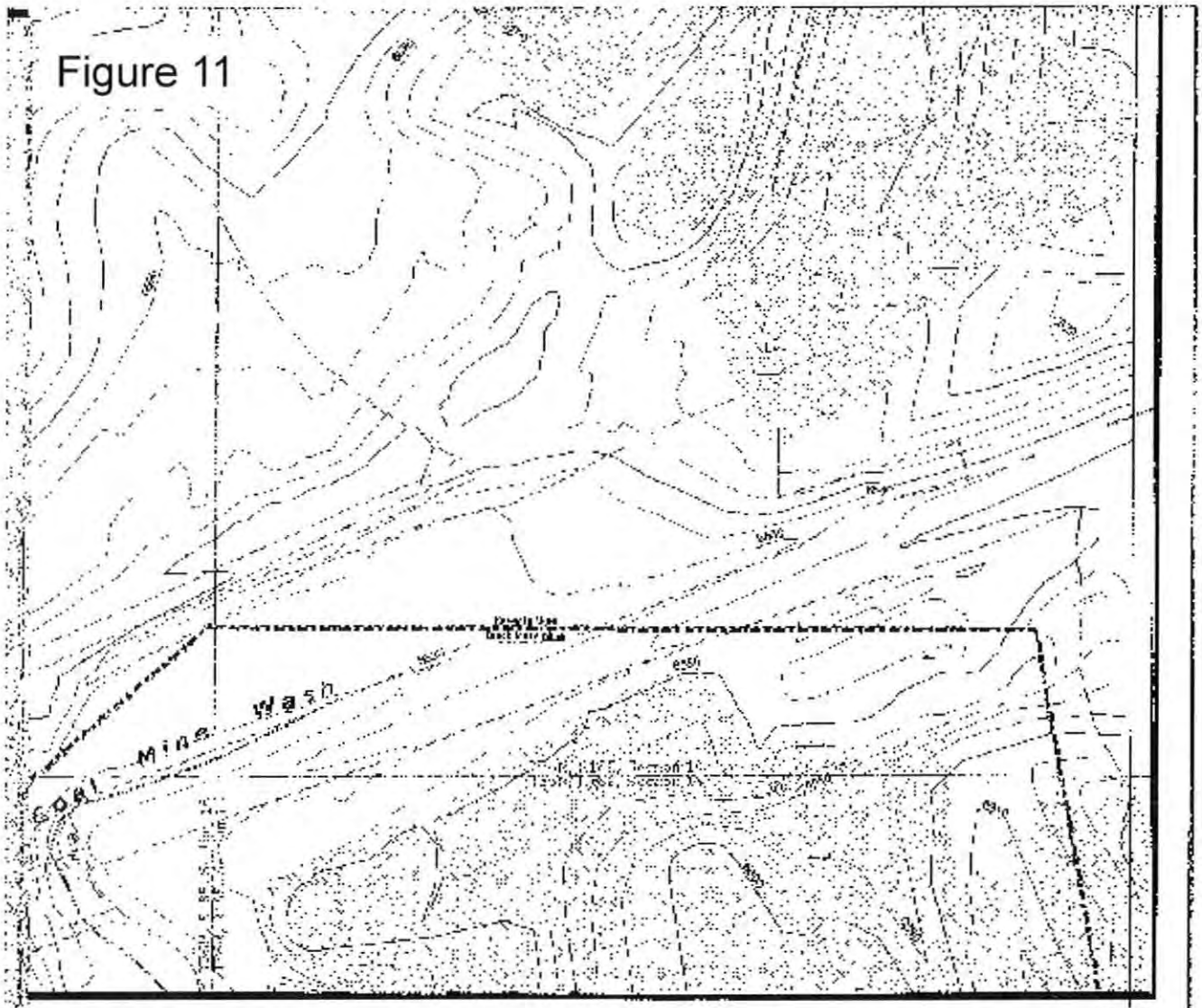


Figure 9
Bottom of Coal
Surface Topo

Figure 10
Final Postmining Topo

Figure 11



pSites

ages

Drawing No. 85352, Estimated Postmining Topographic Map

MD9 South

Produced by PWCC GIS
August 11, 2008

0 100 200 400 Feet
1 inch = 400 Feet

10 foot interval
Indexes at 50 feet

N

PEABODY WESTERN
Black Mesa Complex
PO Box 650
Kayenta, Arizona 86033

MAR 2012
APPROVED

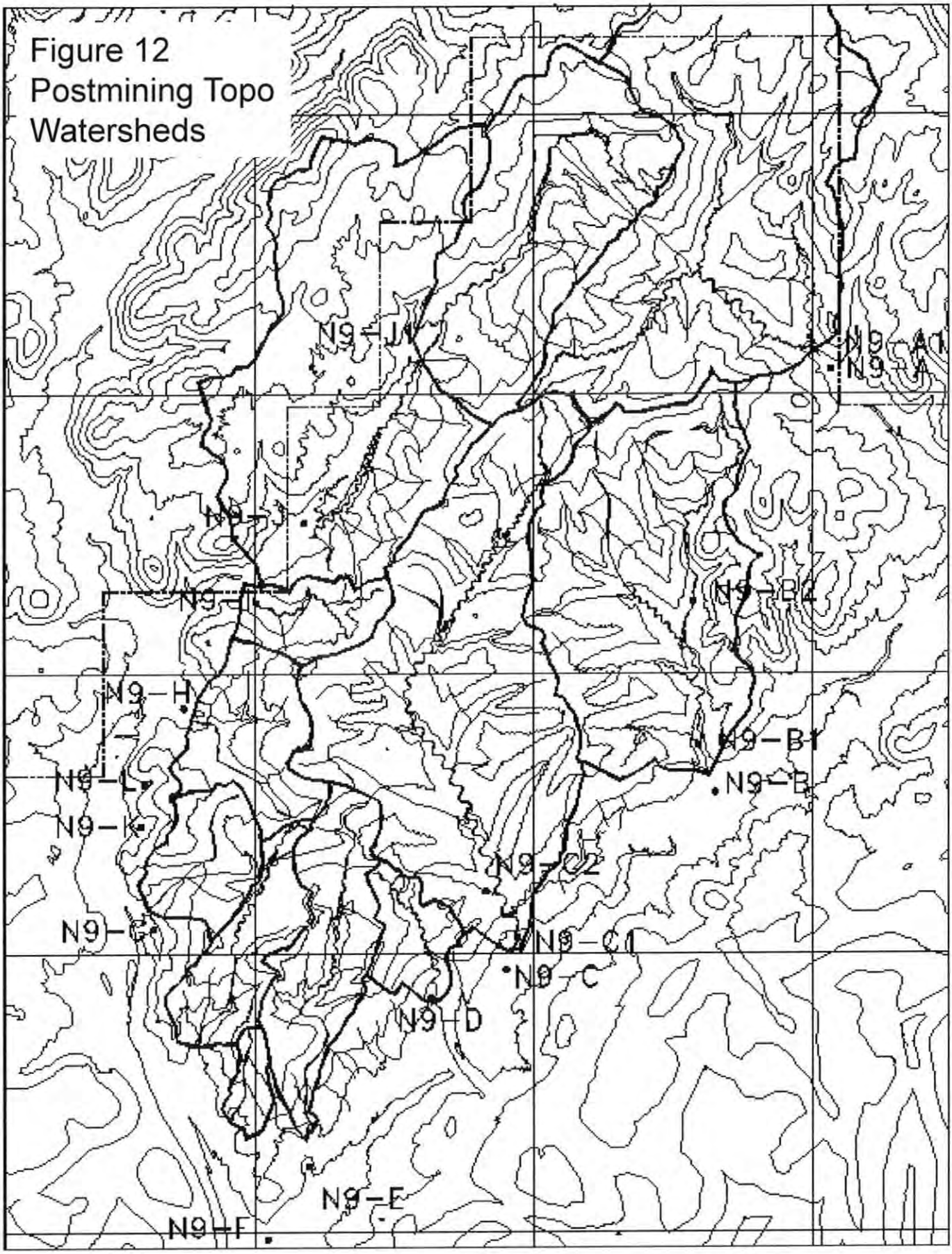
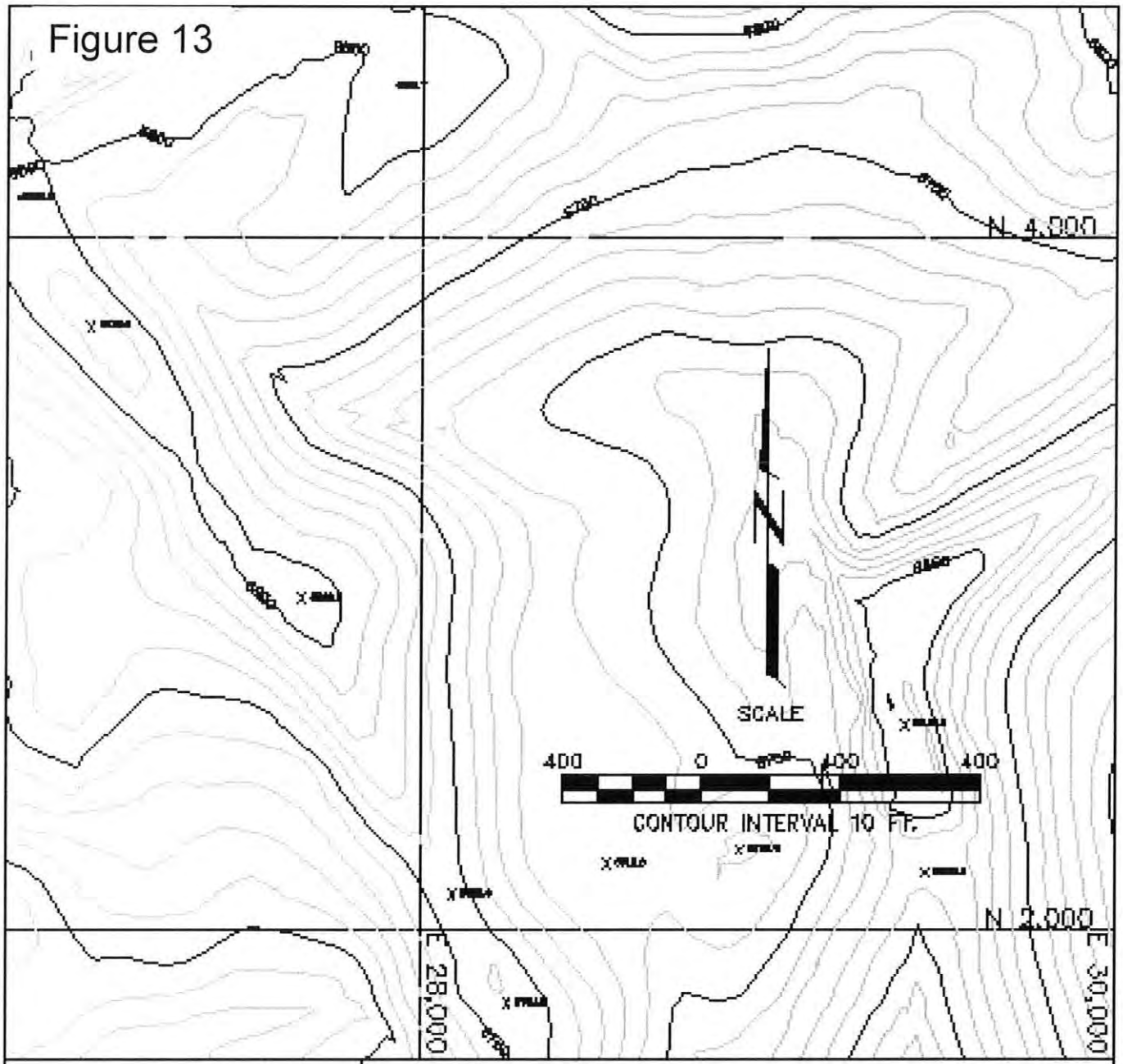


Figure 12
Postmining Topo
Watersheds



PEABODY WESTERN

EXHIBIT #1 (SHEET 1 OF 3)
N-9 HYDROLOGY PARAMETERS

KAYENTA MINE
PEABODY WESTERN COAL COMPANY
P.O. BOX 650 KAYENTA, ARIZONA 86033

DESIGNED BY: GA	SCALE: 1"=400'
DRAWN BY: G.A.	DRAWING DATE: 02-18-10
CHECKED BY: GA	PHOTO DATE: 07-29-09
CONTOUR INT.: 10'	

MAR 2012
APPROVED

Sediment Control Plan

Peabody Western Coal Company

NPDES Permit No. NN0022179
Kayenta Complex Mine Permit AZ-0001E

July 2012

TABLE OF CONTENTS

Section			Page No.
1.0	INTRODUCTION		1
	1.1	Purpose and Need	1
2.0	BEST MANAGEMENT PRACTICES		2
	2.1	Limits of Disturbance	3
	2.2	Postmining Topography	4
	2.3	Postmining Water Conveyance Features	4
	2.4	Topsoil	6
	2.5	Revegetation Practices	6
	2.6	Sediment Ponds and Alternative Sediment Control Methodologies	7
3.0	CRITERIA FOR INSPECTIONS AND MAINTENANCE		8
4.0	WATERSHED MODELING DEMONSTRATIONS		9
5.0	SUMMARY AND CONCLUSIONS		12
6.0	REFERENCES		12

LIST OF APPENDICES

Appendix	Description
1	Surface Water Modeling of the Reclaimed J7-CD, J7-E, and J7-F Watershed Area at the Black Mesa Complex
2	Surface Water Modeling of the Reclaimed N6-C, N6-D, and N6-F Watershed Area at the Black Mesa Complex
3	Surface Water Modeling of the Reclaimed J21-D and J21-E Watershed Area at the Black Mesa Complex
4	Surface Water Modeling of the Reclaimed J16-E and J16-F Watershed Area at Kayenta Mine
5	Surface Water Modeling of the Reclaimed J21-A Watershed Area at Black Mesa Complex
6	Surface Water Modeling of the Reclaimed N6-G Watershed Area at Black Mesa Complex

LIST OF APPENDICES (cont.)

Appendix	Description
7	Surface Water Modeling of the Reclaimed J7-K and J7-M Watershed Area at Black Mesa Complex
8	Surface Water Modeling of the Reclaimed N5-D and N5-E Watershed Area at Black Mesa Complex
9	Surface Water Modeling of the Reclaimed J7-A, J7-B1, J7-G, J7-H, J7-I, J7-J, J7-R1, and J7-R Watershed Area at Black Mesa Mine

LIST OF EXHIBITS

Sediment Control Plan – J7 Area
Sediment Control Plan – N14/J16 Area
Sediment Control Plan – J21 Area
Sediment Control Plan – N6 East Area
Sediment Control Plan – N6 West Area
Sediment Control Plan – J27 Area

1.0 INTRODUCTION

Peabody Western Coal Company (PWCC) has been mining coal in two separate surface-mining operations on Black Mesa, within Navajo County, Arizona, since the 1970s. Mining takes place at the Kayenta Complex (previously designated Black Mesa Complex), which is located on contiguous coal leases within the boundaries of the Hopi and Navajo Indian Reservations. The Kayenta Mine currently operates under the Office of Surface Mining Reclamation and Enforcement (OSMRE) Permanent Program Permit AZ-0001E in accordance with permanent program performance standards at 30 CFR Subchapter K Part 810. The Black Mesa Mine operated historically through 2005 under an OSMRE initial regulatory program (30 CFR Subchapter B Part 710); however, mining operations are temporarily suspended at the Black Mesa Mine. The combined permit and lease area is referred to as the Kayenta Complex.

OSM is charged with the regulation of surface coal mining and reclamation operations on Indian Lands, including the administration and enforcement of the performance standards as set forth in the 1977 Surface Mining Control and Reclamation Act (SMCRA). The performance standards include the General Hydrology Requirements for protecting the hydrologic balance at 30 CFR 816.41, and sediment control measures at 30 CFR 816.45. During mining at both the Kayenta and Black Mesa Mines, PWCC constructed numerous temporary sediment ponds around the perimeter of the mining areas to treat runoff from the disturbance area. Although the Black Mesa Mine was authorized to mine in accordance with the initial regulatory program rules, all temporary ponds built at both mines were designed, constructed and maintained in compliance with 30 CFR 816.42, 816.46, 816.47, and 816.49. The ponds collect runoff that drains from watersheds that are tributary to either Moenkopi Wash or Dinnebito Wash, which in turn both drain to the Little Colorado River.

1.1 Purpose and Need

30 CFR 816.45 requires that sediment control measures, including sediment ponds as best technology currently available (BTCA), be designed, constructed, and maintained to meet the more stringent of applicable state or federal effluent limitations. Consequently, PWCC obtained National Pollutant Discharge Elimination System (NPDES) Permit NN0022179 from the U.S. Environmental Protection Agency (USEPA). As part of the wastewater permitting process, USEPA assigned discharge monitoring locations or outfalls that coincide with the spillways at temporary sediment ponds constructed at the Kayenta Complex where discharges must comply with specific effluent limitations.

The effluent limitations at 40 CFR Part 434 for Subpart H, Western Alkaline Coal Mining are applicable to alkaline drainage from reclaimed areas at western coal mining operations, including permitted outfalls at the Kayenta Complex that have eligible reclaimed areas. The portions of the watersheds that were mined above several temporary ponds have been regraded to achieve an acceptable post-mining topography. These regraded areas have been topsoiled with suitable topsoil in accordance with OSMRE requirements in the permanent program Permit AZ-0001E or

the initial regulatory program. These areas have also been seeded with a permanent seed mix as required in Permit AZ-0001E or the initial regulatory program and have an established vegetative cover at least two years old.

The following sections present the Sediment Control Plan (Plan) for eligible outfalls (temporary sediment ponds) in NPDES Permit No. NN0022179. The plan includes descriptions of the best management practices (BMPs) PWCC has implemented above the ponds to control sediment and erosion, and to minimize disturbance to the prevailing hydrologic balance. The plan also summarizes design specifications, construction specifications, inspection criteria, and maintenance schedules. The information summarized and referenced in the Plan is contained in the approved Kayenta Mine permit application package (PAP) for Permit No. AZ-0001E.

Sediment yield demonstrations were conducted using the Erosion and Sediment Impacts (EASI) computer model (Zevenbergen et al. 1990; WET 1990). This model was calibrated using site-specific data collected at the Kayenta Complex over an eight-year period (RCE, 1993). EASI has been used to predict mean annual runoff and sediment yield from several large areas that were reclaimed under both the initial and permanent regulatory programs. These predictions have been reviewed and approved by OSMRE and other agencies in support of applications for Termination of Jurisdiction (previously described as liability release) for reclaimed parcels located in the N1/N2, J27 and N7/N8 initial program areas. In addition, EASI modeling predictions were included in recently submitted and approved Phase II performance bond release applications for the N14, J19 and J21 permanent program reclaimed areas at the Kayenta Complex. Therefor, PWCC believes the use of the model is appropriate.

Results of the modeling demonstrations for each temporary sediment pond are provided in separate modeling reports in the Appendices to the Plan. This plan also includes 1”=400’ scale map exhibits that show outfall locations, current topography established in outfall watersheds, affected lands boundary within each pond’s watershed, and the BMP’s installed in order to control sediment. The modeling demonstrations show that average annual sediment yields predicted at each outfall location taking into account the postmining, or reclaimed mine-land conditions within the watershed are less than or equal to the average annual sediment yields for the premining, or undisturbed conditions. Average annual sediment yields are provided in each modeling report as tons/acre/yr, which are normalized values that account for differences between premining and postmining acreages and topography. The sediment yield data shows that the BMPs utilized by PWCC at the Kayenta Complex are effective in minimizing erosion and sediment loads from reclaimed mine-lands, and ultimately, protecting the prevailing hydrologic balance.

2.0 BEST MANAGEMENT PRACTICES

PWCC has developed the Plan for temporary sediment ponds that are eligible for coverage under Subpart H (Western Alkaline Coal Mining) of the 40 CFR Part 434 effluent limitations guidelines to prevent an increase in the average annual sediment yield from areas disturbed by mining and

reclamation operations. The Sediment Control Plan utilizes a variety of BMPs to control and minimize erosion and resulting sediment yield that includes, but is not limited to the following:

- Minimize the extent of the disturbance area;
- Stabilize the disturbance area by backfilling and grading to return the land surface to a postmining topography similar to the original landform;
- Develop a postmine drainage configuration that regulates runoff velocities and is designed for the long-term stability of the landscape;
- Regulate runoff velocities of water by collecting runoff in postmine drainage channels, and lining the drainage channels with erosion resistant materials including suitable spoil, as appropriate;
- Salvage and redistribute topsoil material to provide an adequate plant growth medium for revegetation;
- Till and prepare the seedbed to provide initial surface stabilization, prepare the topsoil material for seeding, and enhance seed germination and plant establishment;
- Design and plant reclamation seed mixtures that are permanent and sustainable for rapid and long-term surface stabilization that achieve the postmine land use; and,
- Design and construct sediment ponds to treat and control sediment from the disturbance area.

2.1 Limits of Disturbance

Mining and reclamation operations at the Kayenta Complex were designed and implemented to minimize the extent of disturbance. The operations were designed to disturb only the land necessary to remove the coal resource. The extent of the disturbance area or affected lands includes the mined area, road right-of-ways, topsoil salvage and storage areas, facilities areas (e.g., temporary sediment ponds) and reclamation areas. Drawing No. 85360, Jurisdictional Permit and Affected Lands Map, contained in Volume 20 of the Kayenta Complex Permit Application Package (PAP) show the affected lands boundary within the Kayenta Complex permit areas.

Current watershed areas above each temporary sediment pond are shown on the 1”=400’ map exhibits attached to this plan. The current watershed areas may differ from the premining watershed areas due to the reclaimed topography. The affected lands boundary within the watershed disturbance boundary is also shown on each 1”=400’ map exhibit.

The reclamation operations were designed to complete reclamation and revegetation activities as quickly as possible, site conditions and weather permitting, to restore the disturbed area to the postmine land use and minimize adverse impacts to the environment. The reclamation timetable at the Kayenta Complex is summarized in Chapter 20, Reclamation Schedule of the PAP (Volume 11). The reclamation schedule outlines the sequence and timing of each major phase of the reclamation operations.

2.2 Postmining Topography

Following coal removal, the disturbed area is returned to a postmining topography that is similar to the original landform in accordance with 30 CFR 715.14, Backfilling and Grading, for initial program lands, and with 30 CFR 816.102, Backfilling and Grading: General Requirements, for permanent program lands. OSMRE approved the postmining landforms above the eligible temporary sediment ponds as part of the permit approval process for Permit AZ-0001E or as required by the initial regulatory program.

Chapter 21, Backfilling and Grading in Volume 11 of the PAP describes methods and procedures used by PWCC to develop the postmine landform. The design of the postmining topography required adjusting the original landform elevations for the removed coal seam and the swell of the overburden or spoil material. The postmine topography is designed to blend into the surrounding undisturbed hills and slopes. The approved postmining topography is shown on Drawing No. 85352, Estimated Postmining Topographic Map in Volume 29 of the PAP. PWCC also implemented a Surface Stabilization Program (SSP) beginning in 1990 and recently modified the program to develop postmining landforms (see Chapter 26, Surface Stabilization Plan in Volume 28 of the PAP).

PWCC designed the backfilling and grading sequence to produce a postmining land surface similar to the original landform. Methods used to backfill and grade the mine spoils are also described in Chapter 21, Backfilling and Grading, of the PAP (Volume 11). As the mining sequence progresses, spoil materials from the “active” pit are used to backfill the previous pit. Backfilled materials are placed to minimize adverse affects on groundwater, minimize off-site effects, and to support the approved postmining land use.

Final grading of the spoil material is performed to create surface irregularities to minimize erosion, increase infiltration, improve soil moisture holding characteristics for the revegetation process, and improve range and wildlife habitat. The graded spoil is sampled to insure that there is a minimum of four feet of suitable plant growth material for revegetation.

2.3 Postmining Water Conveyance Features

The postmine drainage configurations for the reclaimed portions above the eligible temporary sediment ponds were developed during the backfilling and grading process to blend with undisturbed drainages above and below the disturbed area. The conveyances were included in the

post-mining topography to provide drainage through the reclaimed areas, restore the premine drainage pattern where practicable, and minimize adverse impacts to the hydrologic balance.

The premining drainage network on Black Mesa typically features high drainage densities and deeply-incised ephemeral channels that convey large runoff events due to heavy localized thunderstorms and regional frontal storms. Most of the events feature supercritical flows that carry very high sediment loads. Utilization of the SSP as outlined in Chapter 26 of the PAP results in creating postmining drainage networks that develop characteristics similar to the premining drainage systems. In order to minimize deeply-incised channels within the postmining drainage network, PWCC utilizes topsoiled and revegetated swales in the flatter interior portions of reclaimed areas. Reclamation meandering downdrain channels and main reclamation channels, and in limited cases gradient terraces, are utilized in steeper reclaimed areas such as outslopes from initial box cuts of the mine pits, and final pit areas. Reclamation channels are also utilized to convey runoff from reclaimed areas into the undisturbed receiving stream channels.

Reclamation meandering downdrain channels are erosion-resistant grade control structures used to convey concentrated flow from steep areas into reclaimed channels. These structures are built with appropriate surface protection to limit velocities, trap sediment, and minimize erosion. Design criteria for constructing reclamation downdrain channels are provided in Attachment A (Reclamation Scale Geomorphology) and Attachment C (Reclamation Surface Stabilization Design Process) of Chapter 26 in the PAP (Volume 28).

Main reclamation channels may vary in size depending on the drainage area. Main reclamation channels that drain less than 640 acres are designed for the 10-year, 6-hour precipitation event, and main reclamation channels that drain more than 1 square mile are designed for the 100-year, 6-hour event. The main reclamation channels are not topsoiled. Rather, four feet of suitable plant growth spoil material form the bottom and sides of the channels. The spoil material is typically comprised of coarse rock fragments that provide an armored surface, minimize erosion and enhance channel stability. In addition, no topsoil is placed for up to 15 feet on each side of the main reclamation channel bottoms adequately containing high flows and confining low meandering flows within the channel area and away from the topsoiled and revegetated areas. Design criteria for the reclamation channels are discussed in Attachment A (Reclamation Scale Geomorphology) and Attachment C (Reclamation Surface Stabilization Design Process) of Chapter 26 in the PAP (Volume 28).

Gradient terraces serve as low-gradient, first order ephemeral channels to break up slope lengths and thereby minimize hillslope erosion, and to convey runoff to reclamation meandering downdrain channels or main reclamation channels. Gradient terraces will be limited to steeper reclaimed slopes greater than ten percent. Criteria for spacing gradient terraces on reclaimed hillslopes are provided in Attachment B (Terrace Spacing) of Chapter 26 in the PAP (Volume 28). Design criteria for constructing gradient terraces are discussed in Attachment A (Reclamation Scale Geomorphology) and Attachment C (Reclamation Surface Stabilization Design Process) of Chapter 26 in the PAP (Volume 28).

2.4 Topsoil

PWCC developed an overburden/spoil handling plan to ensure a minimum of three feet of suitable growth material is placed on backfilled and graded lands prior to topsoiling activities. Overburden was tested to determine suitability as a plant growth material. Chapter 8, Soils Resources and Overburden in the PAP (Volume 8) presents results of the overburden suitability assessment. Chapter 22, Minesoil Reconstruction in the PAP (Volume 11) presents the overburden and spoil handling plan.

Site-specific soil survey data (Chapter 8, Soils Resources and Overburden) is used to ensure the most suitable topsoil is salvaged. Chapter 22, Minesoil Reconstruction also describes topsoil redistribution operations. PWCC uses direct hauling of topsoil material whenever possible. If direct hauling is not possible then the material is stored in approved stockpiles. Except where regraded materials are determined to be suitable as a surface plant growth material, topsoil is replaced after approved postmine contours are achieved, water conveyance structures are identified and preliminary construction initiated, and when no additional disturbance is anticipated. Residual soils with high levels of coarse rock fragments are used in limited areas to support the reestablishment of cultural and woody plants. OSM requires a minimum topsoil depth of 0.5 feet over initial program graded spoil. Assessments of overburden suitability and available topsoil salvaged from each mine pit area prior to mining indicate a minimum average of 1.0 feet of topsoil has been replaced over suitable graded spoil at permanent program areas of the Kayenta Complex (Chapter 22, Minesoil Reconstruction). Upon completion of topsoiling activities, the areas are scarified to a minimum depth of 18 inches to enhance the rooting medium, increase infiltration, and reduce erosion. Following scarification, the replaced soil is disked on contour with a large furrowing disk.

2.5 Revegetation Practices

Following the completion of backfilling and grading activities and topsoil redistribution, the reclaimed areas are revegetated to support the proposed postmining land uses – livestock grazing and wildlife habitat. Chapter 23, Revegetation Plan in the PAP (Volume 11) contains detailed information on methods used to revegetate the postmining areas within the watersheds above the eligible temporary sediment ponds. Across the majority of the reclaimed lands at the Kayenta Complex, the revegetation plan was developed with herbaceous production emphasized over development of large woody plants. Emphasizing herbaceous vegetation ensures the quick establishment of a vegetation community, enhances long-term stability, and minimizes erosion.

PWCC developed several seed mixes for permanent revegetation at the Black Mesa Complex. The most prevalent seed mix used for revegetation is a rangeland mix comprised primarily of grasses and forbs, but also includes fourwing saltbush. This mix establishes a permanent and sustainable vegetative cover that includes shrubs. Other seed mixes have been developed for providing temporary stabilization to minimize erosion, for repairing rills and gullies, and for key

habitat areas along drainages and ridgelines. Seeding is generally accomplished by broadcasting or drilling on the contour. PWCC conducts both qualitative and quantitative revegetation monitoring in order to evaluate seeding success, determine the success of applied reclamation practices and collect data for termination of jurisdiction applications for interim program areas or bond release applications for permanent program areas (see Chapter 23, Revegetation Plan). Qualitative evaluations are carried out at least annually during the growing season, while quantitative measurements and evaluations are conducted on a more periodic basis during May and September of each year through bond release. Revegetation monitoring data is submitted to the OSM in the Annual Reclamation Status and Monitoring Reports. Annual revegetation monitoring at the Kayenta Complex indicates established vegetation on reclaimed mine areas consistently has average total vegetative cover greater than the reference area standard, which represents the premine condition. OSM's approvals of Phase II bond release applications for reclaimed parcels at N14 (approved December 2008), J21 (approved October 2011), and J19 (approved July 2012) further support the findings of comprehensive vegetative cover monitoring efforts. The revegetation will enhance the long-term erosional stability of the site as the revegetated areas are effective and self-sustaining. RUSLE evaluations contained in Attachment B (Terrace Spacing) to Chapter 26 of the AZ-0001E PAP support these conclusions.

2.6 Sediment Ponds and Alternative Sediment Control Methodologies

PWCC designed and constructed numerous temporary sediment ponds in the drainages surrounding the affected lands at the Kayenta Complex to treat disturbed area runoff and to minimize off-site adverse impacts to the hydrologic balance, The ponds were designed, constructed and maintained in compliance with 30 CFR 816.46, 816.47, and 816.49. The eligible temporary sediment ponds that are included with the Plan were designed in accordance with the aforementioned rules.

The 1"=400' maps that are included in each appendix to the plan show the location of the eligible temporary sediment ponds in relation to current topography. Drawing No. 85400, Drainage Area and Facilities Map in Volume 21, and Drawing No. 85405, Sediment and Water Control Structures Map in Volume 22 of the PAP show the location of all temporary sediment ponds constructed at the Kayenta Complex.

Chapter 6, Facilities in the PAP (Volumes 1 through 7F) contains design methodology and as-built certifications for all temporary sediment ponds constructed at the Kayenta Complex, including regulatory requirements. In addition, individual design reports for the eligible temporary sediment ponds in this Plan can be found in Chapter 6, which include details on pond capacities and configurations, spillway designs, and pond-specific calculations of sediment trapping performance.

In addition to using sediment ponds to control sediment, PWCC uses alternative sediment control methodologies (ASCMs) either in conjunction with the sediment ponds or individually. These ASCMs include straw dikes, filtration structures (silt fence), sediment traps, gabions, and check

dams to reduce overland flow velocity, reduce runoff volume, or trap sediment. Most of these are temporary measures, but some may be left as permanent features in the reclaimed landscape. Descriptions of ASCMs along with references to design and construction specifications are provided in Chapter 26, Surface Stabilization Plan in the PAP (Volume 28).

PWCC plans to eventually remove and reclaim the embankments of the eligible temporary sediment ponds. Reclamation will involve removing either a portion (breaching) or all of each embankment to restore the natural stream channel course and gradient in the vicinity of the pond. Breaching involves less disturbance of established vegetation than complete removal of the entire embankment. The area disturbed by the removal of the embankments will be graded to blend in with the surrounding topography, mechanically manipulated as needed, and seeded with an appropriate seed mix. ASCMs will be installed in the vicinity and downstream of the breached structure and will serve as BMPs. ASCMs will be installed in accordance with design and construction specifications referenced in Chapter 26, Surface Stabilization Plan in the PAP (Volume 28). ASCMs that are temporary such as silt fences and/or straw bales may be removed once revegetation in the vicinity becomes established. The BMPs will be maintained until termination of jurisdiction is achieved for initial program lands or final bond release is granted for permanent program lands above each breached embankment. Modifications to this plan and other portions of the PAP as needed to reflect PWCC's plans to remove the embankments will be submitted to OSMRE as a technical revision to Permit AZ-0001E going forward.

3.0 CRITERIA FOR INSPECTIONS AND MAINTENANCE

As an active surface coal mine with ongoing reclamation operations, OSMRE conducts quarterly inspections of all areas of the Kayenta Mine to assure compliance with the 30 CFR performance standards and the provisions of Permit AZ-0001E. OSMRE performs semiannual inspections of all areas of the inactive Black Mesa Mine. The inspections include the BMPs that have been discussed in previous sections of this Plan, such as backfilling and grading to confirm the reclaimed land surface conforms to the approved postmine topography. Reclaimed areas in which topsoiling and revegetation activities have been completed are inspected to identify potential problem areas as indicated by rilling or gullying or other signs of instability or excess erosion. Postmine water conveyance structures and sediment ponds are also inspected to assure these structures are stable and retain the capacity of the approved design(s). If a problem is identified during an inspection, OSMRE may require an immediate fix, request a remedial plan, and/or they may issue a notice of violation which includes a specified time period to solve the problem depending upon the magnitude and severity.

In addition, PWCC is required by Permit AZ-0001E to conduct ongoing inspections of the reclaimed mine-lands including engineered structures to record and monitor the reclamation process and identify any potential problems. If problems are identified by either OSMRE or PWCC in the course of an inspection, then a remedial plan is developed and implemented. After the problem is fixed, the remedial work is monitored to assure the corrective action was successful.

PWCC is required to monitor the salvage, storage and redistribution of topsoil and spoil handling operations. Specific programs include determining spoil suitability of final graded slopes and verifying topsoil redistribution thickness. The topsoil and spoil handling monitoring data collected for each calendar year is reported to OSMRE in the Annual Reclamation Status and Monitoring Report.

PWCC conducts annual vegetation monitoring of permanently revegetated areas to document revegetation success. Revegetated areas are also surveyed for noxious weeds to evaluate potential adverse impacts to adjacent desirable vegetation. The revegetation monitoring data collected for each calendar year is reported to OSMRE in the Annual Reclamation Status and Monitoring Report.

PWCC is required to inspect all temporary sediment ponds on a quarterly basis for embankment stability, inlet and outlet conditions, and sediment storage capacities. The annual sediment pond inspection report is certified by a Professional Engineer and submitted to OSMRE.

Comprehensive Site Inspections and Reporting

PWCC will conduct comprehensive site inspections of the BMPs at the eligible temporary sediment ponds included with this Plan. The inspections will assess the following:

- The accuracy of the area covered by Plan,
- 1”=400’ map exhibits are to be updated or otherwise modified to reflect current conditions,
- Effective implementation of the BMPs identified in the Plan,
- Necessity to maintain existing BMPs or install additional BMPs, and
- Necessity to revise the Plan.

As the Plan is approved by OSMRE and USEPA, inspections will be conducted at the eligible temporary sediment ponds quarterly or semiannually as part of OSMRE’s inspections. If the comprehensive site inspection determines changes to the plan are warranted, PWCC will revise the Plan and submit the revisions to both OSMRE and USEPA for approval within 60 days.

PWCC will develop an Annual Compliance Evaluation Report and submit the report to OSMRE and USEPA by May 31st of each year for the preceding calendar year’s inspections. The report will identify personnel making the inspections, dates of inspections, and summarize observations made and actions taken in accordance with the Plan. The report will identify any incidents of noncompliance, and where a report does not identify any incidents of noncompliance, the report will contain a certification that the facility is in compliance with the Plan. Annual Compliance Evaluation Reports are retained with the Plan kept in the Environmental Manager’s files at the N8 Offices.

4.0 WATERSHED MODELING DEMONSTRATIONS

In accordance with 40 CFR Part 434.82, PWCC has prepared numerous watershed demonstrations that evaluate the performance of BMPs for controlling sediment in the reclaimed watersheds above eligible temporary sediment ponds at the Kayenta Complex. The demonstrations involved using the EASI model to predict average annual sediment yields for the entire watershed area above eligible temporary sediment ponds. Sediment yields predicted for premining conditions reflect natural conditions in the watershed above pond locations prior to mining. Sediment yields predicted for postmining conditions reflect the BMPs that PWCC has implemented within the affected lands in the watershed above the sediment ponds. The modeling demonstrations were conducted to show the BMPs result in average annual sediment yields from the postmining landscape that are less than or equal to the average annual sediment yields from the premining landscape.

As mentioned previously, similar EASI modeling demonstrations have been completed for larger reclaimed parcels as part of termination of jurisdiction or Phase II bond release applications. The first and most comprehensive EASI modeling report was completed in 1993 by Resource Consultants & Engineers, Inc. of Fort Collins, Colorado (RCE, 1993). This report described the EASI model, modeling calibration and validation, modeling assumptions and inputs, and modeling results for the N1/N2 and J27 initial program reclaimed parcels. The combined total reclaimed area modeled was approximately 3,090 acres. Subsequent EASI model demonstrations for large reclaimed parcels were completed by Ayres Associates, Inc of Fort Collins, Colorado for 946 acres in the N7/N8 reclaimed area (Ayres, July 2001), 1,580 acres in the N14 reclaimed area (Ayres, July 2008), 1,533 acres in the J1/N6 reclaimed area (Ayres, September 2009), and 2,832 acres in the J21 reclaimed area (Ayres, September 2010). Most recently, PWCC completed an EASI model demonstration for 943 acres in the J19 reclaimed area (PWCC, 2011). The EASI modeling demonstrations completed for large, multi-watershed reclaimed parcels at the Kayenta Complex totals approximately 10,924 acres as of June 2012.

EASI modeling demonstrations developed for select temporary ponds have also been completed by Ayres Associates, Inc. The reports were developed for eligible temporary sediment ponds (outfalls) that share adjacent watershed boundaries in which similar BMPs have been used for sediment control within the reclaimed portions of each watershed. The reports provide information on the EASI model development and reference previous EASI modeling reports developed for PWCC that were submitted to OSMRE in support of applications for termination of jurisdiction of initial program areas and bond release for permanent program areas. They also discuss data used to develop each model, modeling methodology, and model results. The model results are provided as average annual sediment yields on an acre-unit basis above each pond for both premine and postmine watershed conditions.

The following is a list of the temporary sediment ponds and corresponding NPDES Permit NN0022179 outfall designations at the Kayenta Complex that have been evaluated for eligibility under the effluent limitations at 40 CFR Part 434 for Subpart H. The list also provides the Appendix to the Plan in which the modeling demonstration reports for each pond can be found, or

provides the reference to a large reclaimed area modeling report listed above and in Section 6.0, References that incorporated the watershed above the pond. For some outfalls (e.g., outfall 170 - Pond J7-S), a modeling demonstration report is listed for a reclaimed parcel or specific pond adjacent or proximate to the pond/outfall. In these limited cases, PWCC considers the listed modeling report and predictions to be representative because BMPs established in the pond/outfall are similar enough to those evaluated in the referenced modeling demonstration. The reference to each large reclaimed modeling report also includes the liability release or bond release application and status in which the modeling report was incorporated.

Pond ID	Outfall No.	Appendix No. or Modeling Report Reference
J7-CD	049	Appendix 1
J7-E	050	Appendix 1
J7-F	051	Appendix 1
N6-C	021	Appendix 2
N6-D	022	Appendix 2
N6-F	037	Appendix 2
J21-D	174	Appendix 3
J21-E	175	Appendix 3
J16-E	031	Appendix 4
J16-F	032	Appendix 4
J21-A	079	Appendix 5
N6-G	150	Appendix 6
J7-K	052	Appendix 7
J7-M	071	Appendix 7
N5-E	082	Appendix 8
J7-A	147	Appendix 9
J7-B1	163	Appendix 9
J7-G	048	Appendix 9
J7-I	069	Appendix 9
J7-J	070	Appendix 9
J7-R	169	Appendix 9
J27-RC	178	RCE, 1993
J7-S	170	Appendix 7 and 9
J7-T	171	Appendix 7 and 9
J7-U	172	Appendix 7 and 9
J7-V	173	Appendix 7 and 9
J21-C	148	Ayres, September 2010
N14-F	024	Ayres, July 2008
N14-G	025	Ayres, July 2008
N14-H	039	Ayres, July 2008

5.0 SUMMARY AND CONCLUSIONS

The EASI modeling results indicate that the average annual sediment yield from the watersheds above the eligible temporary sediment ponds at the Kayenta Complex, including the reclaimed areas above each pond, is less than or equal to the average annual sediment yield from the premining watershed that existed prior to building the pond. The sediment yield data demonstrates that the BMPs utilized by PWCC at the Kayenta Complex are successful at minimizing erosion and sediment loads from the reclaimed mine-lands. The results also demonstrate that the ponds no longer serve as the best practicable control technology available for minimizing erosion and sediment, and the sediment ponds could be removed and reclaimed.

6.0 REFERENCES

Ayres Associates, Inc., July 2001. "Surface Water Modeling of Reclaimed Parcels at the Kayenta Mine N7/N8 Coal Resource Area". (Prepared for Peabody Western Coal Company's N7/N8 Liability Release Application submitted August 2001, approved July 2008.)

Ayres Associates, Inc., July 2008. "Surface Water Modeling of the Reclaimed N14 Coal Resource Area at Kayenta Mine". (Prepared for Peabody Western Coal Company's N14 Phase II Bond Release Application submitted August 2007, approved December 2008.)

Ayres Associates, Inc., September 2009. "Surface Water Modeling of the Reclaimed Parcels at Black Mesa Complex J1/N6 and N6 East Central Coal Resource Areas". (Prepared for Peabody Western Coal Company's upcoming Liability Release Application for J1/N6 scheduled for submittal September 2012.)

Ayres Associates, Inc., September 2010. "Surface Water Modeling of Reclaimed Parcels at the J21 Coal Resource Area, Kayenta Mine". (Prepared for Peabody Western Coal Company's J21 Phase II Bond Release Application submitted September 2010, approved January 2012.)

ESCO Associates, Inc., 2008. "2007 Annual Revegetation Monitoring Report, Black Mesa and Kayenta Mines", Prepared for Peabody Western Coal Company, Kayenta, Arizona.

Peabody Western Coal Company, September 2011. "Surface Water Modeling of Reclaimed Parcels at the J19 Coal Resource Area, Kayenta Complex". (Prepared for Peabody Western Coal Company's J19 Phase II Bond Release Application submitted September 2011, approval expected July 2012.)

Resource Consultants & Engineers, Inc. (RCE), 1993. "Surface Water Modeling of Reclaimed Parcels at the Black Mesa Complex", Prepared for Peabody Western Coal Company.

Water Engineering & Technology, Inc. (WET), 1990. "Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control

Technology at Surface Mines in the Semiarid West," Prepared for Office of Surface Mining and the National Coal Association, Fort Collins, CO.

Zevenbergen, L.W., Peterson, M.R., and Watson, C.C., 1990. "Computer Simulation of Watershed Runoff and Sedimentation Processes", Proceedings of the Billings Symposium; Planning, Rehabilitation and Treatment of Disturbed Lands.

Appendix 1

Surface Water Modeling of the Reclaimed J7-CD, J7-E, and J7-F Watershed Area at the Black Mesa Complex

SURFACE WATER MODELING OF THE RECLAIMED J7-CD, J7-E, and J7-F WATERSHED AREA AT BLACK MESA MINE

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES

SURFACE WATER MODELING OF THE RECLAIMED J7-CD, J7-E, and J7-F WATERSHED AREA AT BLACK MESA MINE

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES
P.O. Box 270460
Fort Collins, Colorado 80527
(970) 223-5556, FAX (970) 223-5578

Ayres Project No. 32-1304.00
PEAB-J7.DOC

August 2008

TABLE OF CONTENTS

1. Reclaimed Parcel Modeling 1.1

1.1 Introduction 1.1
1.2 Background 1.1
1.3 Data 1.2

1.3.1 Soils 1.2
1.3.2 Vegetation 1.2
1.3.3 Topography 1.3

1.4 Methodology 1.3

1.4.1 Synthetic Rainfall 1.8
1.4.2 Computation of Average Runoff and Sediment Yield 1.8

1.5 Results 1.8
1.6 Discussion 1.9

2. Comparisons with Measured Sediment Transport 2.1

3. References 3.1

Exhibit 1 – Postmine Topography ..... --
Exhibit 2 – Premine Topography ..... --

LIST OF FIGURES

Figure 1.1. Reclaimed area soils trilinear graph. 1.2

Figure 1.2. Spatial distribution of vegetative cover types for WA J7 premine condition 1.4

Figure 1.3. J7-CD, J7-E, and J7-F postmine basins. 1.6

Figure 1.4. J7-CD, J7-E, and J7-F premine basins. 1.7

Figure 2.1. Observed and modeled sediment and water discharge. 2.2

Figure 2.2. Observed versus modeled sediment concentration and discharge. 2.3

Figure 2.3. Background measured sediment and water discharge with Sen lines. 2.5

Figure 2.4. Reclaimed measured sediment and water discharge with Sen lines. 2.6

Figure 2.5. Modeled premine sediment and water discharge for the J7 WA with Sen lines. 2.7

Figure 2.6. Modeled postmine sediment and water discharge for the J7 WA with Sen lines. .. 2.8

LIST OF TABLES

Table 1.1. Soils Data. 1.3

Table 1.2. Cover Sampling Data. 1.5

Table 1.3. Cover Data for J7-CD, J7-E, and J7-F Watersheds. 1.5

Table 1.4. Average Runoff and Sediment Yield Results. 1.8

Table 1.5. Average Physical Properties of the J7 WA. 1.9

1. RECLAIMED PARCEL MODELING

1.1 Introduction

The objective defined by PWCC for this project is to use a previously calibrated and validated runoff and erosion model (EASI, Zevenbergen et al. 1990; WET 1990) for the Black Mesa and Kayenta Mines to predict mean annual runoff and sediment yields from the reclaimed J7-CD, J7-E, and J7-F watersheds. This objective included computation of runoff and sediment yields under premine conditions for the same area. All soils and rainfall input to the model are to be taken from models calibrated in the previous study (RCE 1993). The input variables that were calibrated to the mine areas and used in this study include soil infiltration parameters, erodibility parameters, and the grain size distribution. Parameters that are specific to this study are vegetative canopy and ground cover percentages from data collected on site.

The model calibration was conducted in a previous study (RCE 1993) using data obtained from instrumented watersheds and small hillslope plots collected under natural rainfall conditions. For a detailed discussion of data collection and model calibration, please refer to the previous study (RCE 1993).

1.2 Background

The J7-CD, J7-E, and J7-F Watershed Area (WA) that is the focus of this project was reclaimed between 1983 and 1990. The fundamental purpose of this study was to quantify the expected behavior and hydrologic response of the reclaimed areas above each pond relative to the conditions that existed prior to the occurrence of mining activities.

Runoff and sediment yield response from the reclaimed lands should be managed by implementing Best Management Practices (BMP's) in conjunction with an OSM approved sediment control plan in order to not adversely impact the prevailing hydrologic balance and to limit additional contributions of suspended sediment to streamflow or runoff outside the mine permit areas. BMP's include regrading, replacing salvaged topsoil, revegetation, and other controls such as riprapped channel bottoms, check dams, and where practicable, contour terraces. The natural watersheds on the mesa contribute significant quantities of sediment to the channel system. It is expected that the postmine condition will also produce comparable amounts of sediment without adverse impact on the hydrologic balance.

This section describes the data and procedures used to evaluate the J7 WA. This area was modeled to determine the average annual hydrologic response following the completion of reclamation activities taking into account BMP's implemented as part of the reclamation process. Infiltration, runoff, and erosion processes from both hillslopes and channels within the J7 WA were modeled using EASI. Results were determined for concentration points at the outlets of the reclaimed watersheds, which correspond to the embankments associated with Ponds J7-CD, J7-E, and J7-F. The locations of these points are shown in **Exhibit 1**. Modeling was also conducted to determine hydrologic response under premine conditions based on the topography, soils, cover, and other conditions that typified the undisturbed watersheds draining to each concentration point. **Exhibit 2** shows the modeling endpoints for the premine J7 WA.

1.3 Data

1.3.1 Soils

Soils data used for the current study (J7 WA) were based on data developed from the calibration of models used in the previous study for Coal Resource Areas (CRAs) N1/N2 and J27 (RCE 1993). The composition of postmine soil in the current study is depicted along with the composition of postmine soils from the previous study in **Figure 1.1**. This figure shows that the soil composition of WA J7 is very similar to soils evaluated during model calibration. Therefore, the soil properties developed in the previous study are valid for this modeling project. These properties include calibrated parameters, such as infiltration and erodibility coefficients, and measured soil size distributions. **Table 1.1** lists the premine and postmine soils data used during EASI modeling of WA J7.

1.3.2 Vegetation

Vegetative cover data representative of both pre- and postmine conditions in WA J7 were supplied by PWCC. For the premine condition, land was characterized as being covered by sagebrush or pinon juniper. The spatial distribution of vegetative cover for the J7 WA premine condition appears in **Figure 1.2**. Average cover properties for CRAs N1/N2 and J27 of the previous study and WA J7 of the current study appear in **Table 1.2**. For the postmine condition, the reclaimed area was assigned the postmine cover type and the unmined area was assigned the same cover type as the premine condition. **Table 1.3** lists the pre- and postmine vegetative cover data used in the EASI model runs generated for the J7 WA. Note that if a unit contained significant portions of both sagebrush and pinon juniper cover types, it was classified as half pinon juniper and half sagebrush.

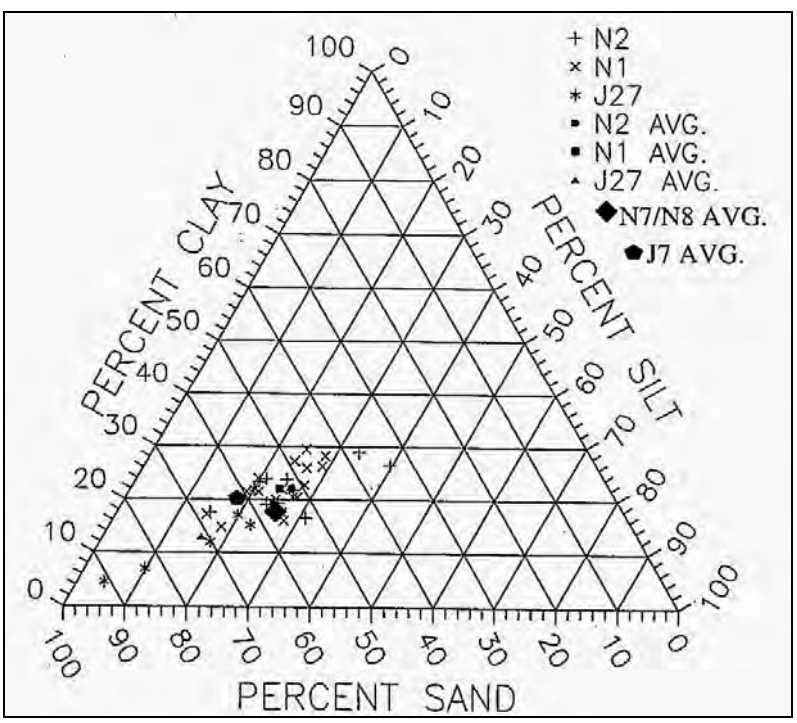


Figure 1.1. Reclaimed area soils trilinear graph.

Table 1.1. Soils Data.			
Condition	Premine	Postmine	Rock Chutes
Rainfall detachment	0.005	0.005	0
Overland flow detachment	0.44	0.44	0
Channel flow detachment	0.5	0.5	0
Initial soil moisture, %	70	70	70
Final soil moisture, %	90	90	90
Soil porosity, %	45	45	46
Temperature, *F	70	70	70
Hydraulic conductivity, in/hr	0.23	0.29	0.3
Capillary suction, in	3.7	2.6	2.6
	Particle Size Distribution (all conditions)		
	Size, mm	% Finer	
	0.001	0	
	0.004	18.0	
	0.016	27.4	
	0.062	36.6	
	0.125	56.2	
	0.250	64.3	
	0.500	72.4	
	1.000	80.5	
	2.000	88.6	
	4.000	92.4	
	16.000	100	

1.3.3 Topography

Pre- and postmine topography was supplied by PWCC in the form of ArcGIS geodatabase. Basin delineations, hillslope delineations, subwatershed delineations, as well as areas, slopes, and lengths of all units of the study area were defined and calculated using ArcGIS software. **Figures 1.3 and 1.4** show the watershed delineation and numbers assigned to the basins used in the EASI model for the post- and premine conditions, respectively. Channel dimensions input to EASI were based on the topography supplied and limited field observations.

1.4 Methodology

Runoff and sediment yield in the semiarid western United States is largely governed by the occurrence of high-intensity, short-duration rainstorms of limited areal extent (Renard and Simaton 1975). Research has indicated that relatively few events may produce the greatest erosion (e.g., Hjelmfelt et al. 1986 reported that only 3 to 4% of rainfall events accounted for 50% of long-term sediment yields). Although there is perhaps a relatively limited physical basis for definition of an "average annual" runoff or sediment yield in a semiarid environment due to the extreme variability in response and importance of single infrequent events, such a term does provide a useful basis for long-term comparison between reclaimed and undisturbed conditions.

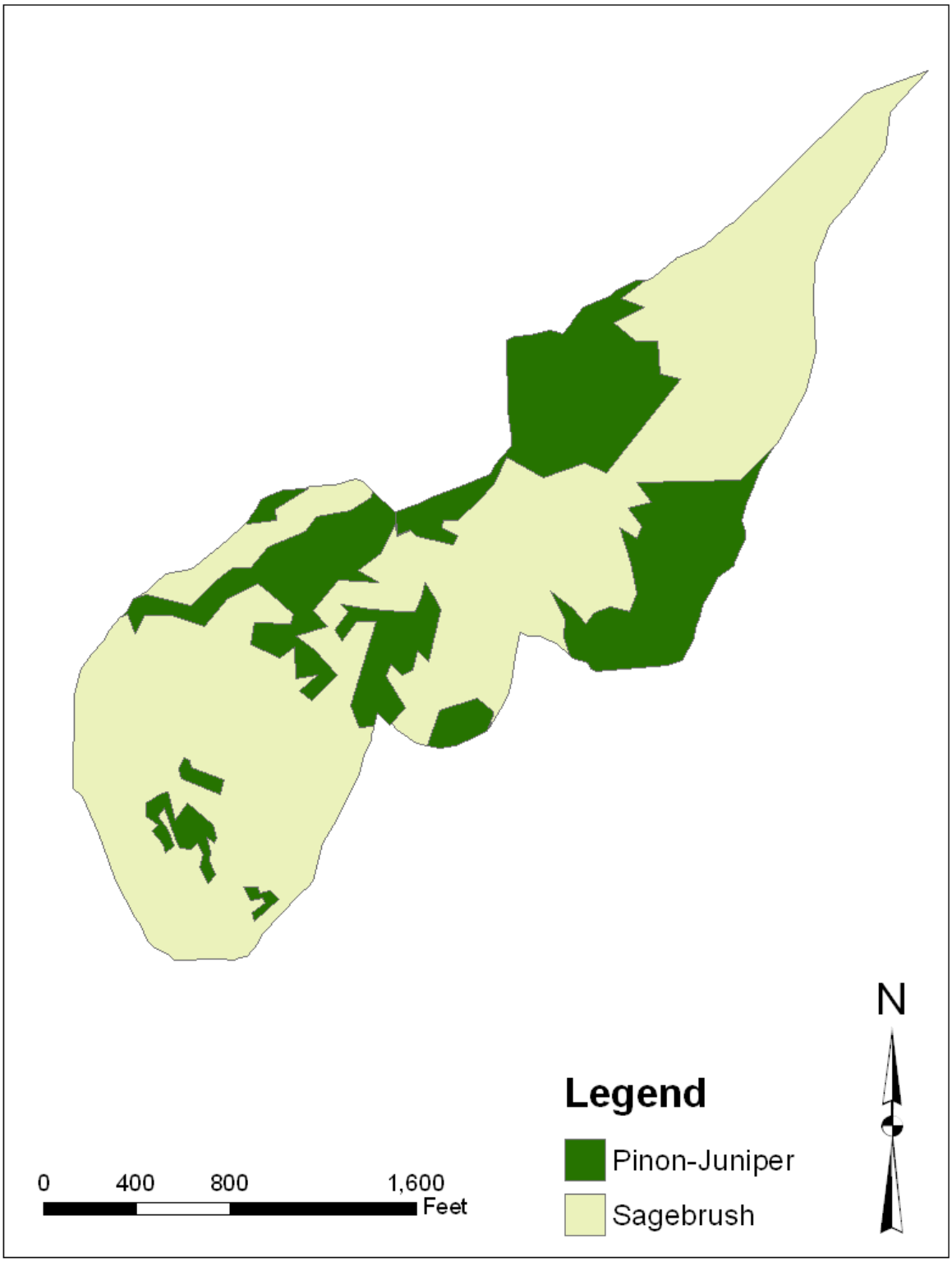


Figure 1.2. Spatial distribution of vegetative cover types for WA J7 premine condition.

Table 1.2. Cover Sampling Data.								
Area	Condition	Cover Type	Nonstratified Vegetation Cover (%)	Vegetation Canopy Cover (%)	Vegetation Ground Cover (%)	Litter* (%)	Rock (%)	Total Ground Cover (%)
N1/N2	Postmine	Postmine	25.6	1.4	24.2	13.6	4.2	41.9
J7 WA	Postmine	Postmine		0.3	20.9	26.2	1.4	48.5
N1/N2/J27	Premine	Pinon Juniper	32.7	31.1	3.0	44.0	19.7	66.7
J7 WA	Premine	Pinon Juniper		11.7	3.2	19.1	18.5	40.8
N1/N2	Premine	Sagebrush	25.1	16.0	10.3	25.3	18.1	53.7
J27	Premine	Sagebrush	30.6	9.7	22.0	24.0	1.6	47.6
J7 WA	Premine	Sagebrush		0.6	7.3	21.7	6.8	35.8
*Including standing dead litter								

Table 1.3. Cover Data for J7-CD, J7-E, and J7-F Watersheds.				
Condition	Pinon Juniper	Sagebrush	Half Pinon Juniper-Half Sagebrush	Postmine
Canopy cover, %	11.7	0.6	6.1	0.3
Ground cover, %	40.8	35.8	38.3	48.5
Canopy storage, in	0.05	0.05	0.05	0.05
Ground storage, in	0.05	0.05	0.05	0.05
Depression storage, in	0.03	0.03	0.03	0.03
Impervious area, %	0	0	0	0
Manning n	0.07	0.07	0.07	0.05

To make comparisons between reclaimed lands and associated undisturbed lands at the Black Mesa Mining Complex on the basis of average annual sediment yield, a procedure was used that considers the importance of infrequent storm events in defining sediment yield in the semiarid west. First, however, the site-specific rainfall data available for the Black Mesa Mining Complex were used to evaluate the frequency and magnitude of the measured events relative to existing predictions for rainfall depth-duration (Miller et al. 1973). The analysis of the rainfall data was performed as part of a previous study of the N1/N2 and J27 CRAs (Resource Consultants and Engineers 1993).

Comparisons between runoff and sediment yield from undisturbed and reclaimed areas in WA J7 were developed for specific modeling endpoints shown in Exhibits 1 and 2. Mining and reclamation activities did not exactly replicate the topography, drainage network, or drainage areas that existed prior to mining. Consequently, direct comparisons of total runoff and sediment yield cannot be made between undisturbed and reclaimed response at a given point in a watershed. Comparisons were made on the basis of unit rates of runoff (inches) and sediment yield (tons/acre) at the various modeling computation endpoints. Although the same disturbance boundary was used to model extents for both pre- and postmine conditions, the topographic differences that resulted after mining and reclamation occurred in the J7 WA dictated that some small areas would be included or excluded from the modeling. The total area modeled (combined area for J7-CD, J7-E, and J7-F watersheds) for premine conditions is 102.2 acres and for postmine conditions is 99.8 acres. The difference in area results from the sediment ponds in postmine conditions. The area bounded by the modeling boundary identified by PWCC as shown in Exhibits 1 and 2 is 102.2 acres.

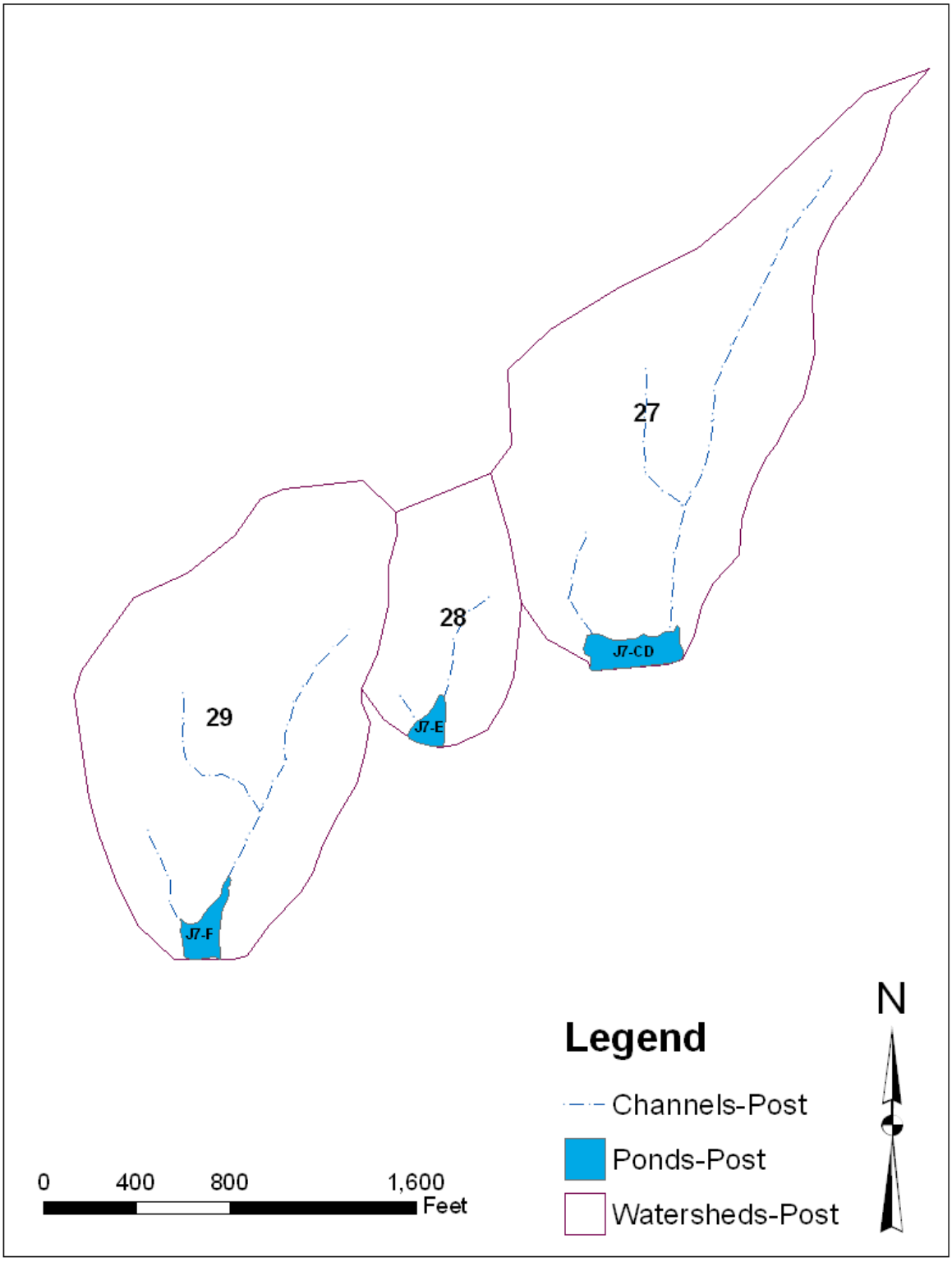


Figure 1.3. J7-CD, J7-E, and J7-F postmine basins.

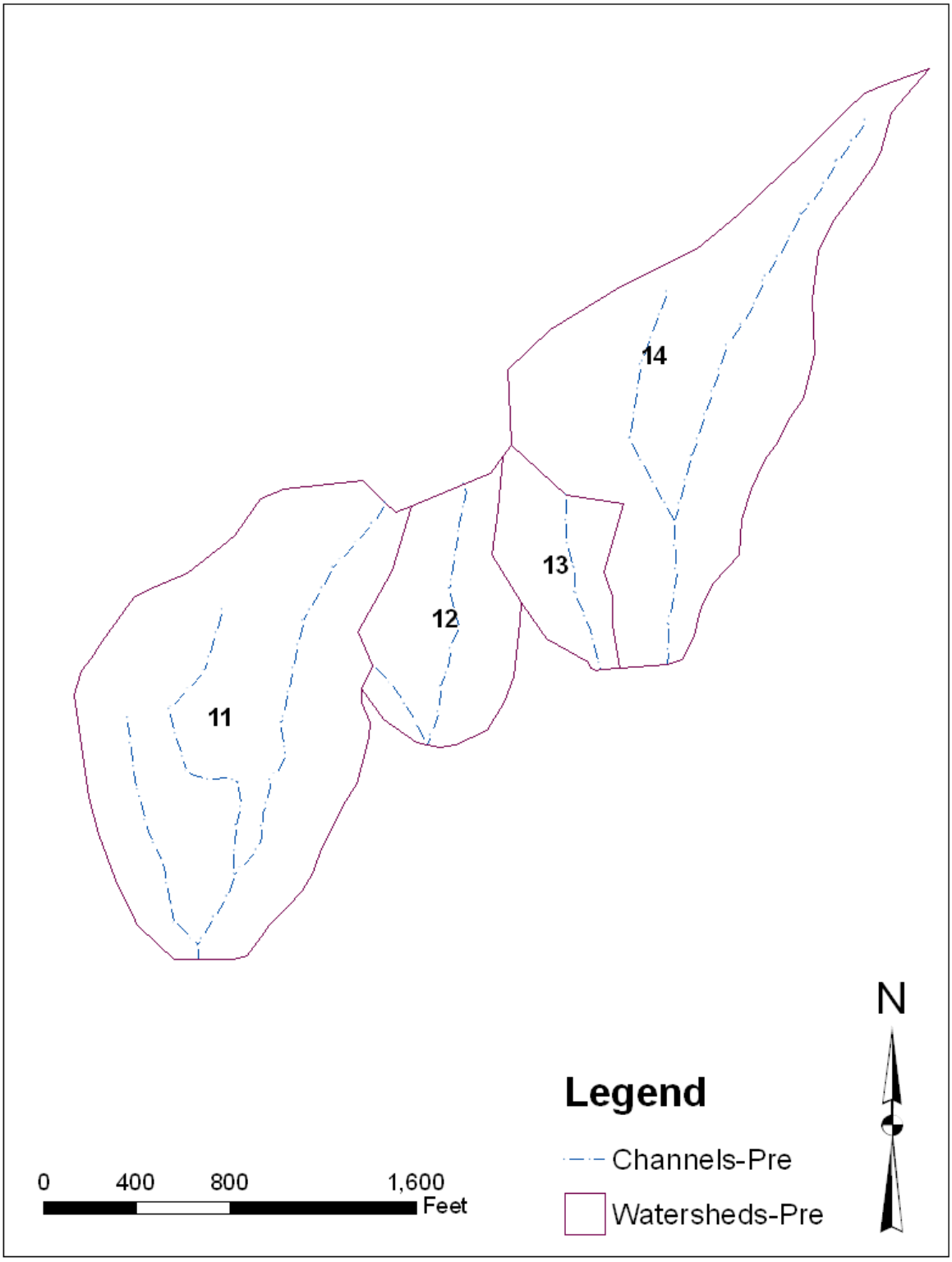


Figure 1.4. J7-CD, J7-E, and J7-F premine basins.

1.4.1 Synthetic Rainfall

Synthetic storms of 2-, 5-, 10-, 25-, 50-, and 100-year return periods were used as input to the EASI model. Actual hyetographs were taken from the previous study (RCE 1993) and are based on both local data collection and the NOAA Atlas (Miller et al. 1973).

1.4.2 Computation of Average Runoff and Sediment Yield

The EASI model was used to evaluate runoff and sediment yield from a series of storm events having recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100 years. To define average annual conditions, the average annual runoff and sediment yield generated from storm events were computed using the commonly used equation of Lagasse et al. (1985).

1.5 Results

Figures 1.3 and 1.4 show the post- and premine basin delineations. Since the individual subareas differ in number, acreage and outlet locations, a direct comparison is not possible on a subarea basis. Therefore, the best way to compare the results is on an average basis for the WA. **Table 1.4** shows pre- and postmine drainage area, runoff, and sediment yield for the J7 WA. To consider the situation of pond removal for the postmine condition, the EASI model replaces a sediment pond with a channel, which lies near the location of the pond and discharges to the basin outlet. The channel is assumed to have a length equal to the pond's length and a slope of 2%. Runoff is defined as the total volume of water leaving the WA on an average annual basis and, therefore, does not include water stored in depression areas and ponds. For the premine condition, this is equal to the amount of water that drains off the hillslopes and subwatersheds because there are no ponds or significant depressions. For the postmine condition, this is equal to the amount of hillslope runoff less the amount stored in ponds. No ponds or significant depressions exist within the reclaimed J7 WA that was modeled. Similarly, the sediment yield is the amount of eroded material that leaves the WA on an average annual basis computed using the equation of Lagasse et al. (1985). The sediment yield is the production from the hillslope areas and erosion from the channels. The amount of erosion is the sediment yield from the hillslopes and subwatersheds only and does not include channel erosion, channel deposition or sediment trapped in ponds. Sediment yield can be greater or less than erosion, depending on the amount of channel erosion and the capacity of the channel network to convey sediment off the leasehold.

Table 1.4. Average Runoff and Sediment Yield Results.

Area	Condition	Drainage Area (ac)	Runoff (in)	Sediment Yield (t/ac/yr)
J7 WA	Premine	102.2	0.42	2.46
J7 WA	Postmine	99.8	0.42	2.02
J7-CD	Premine	45.7	0.42	2.30
J7-CD	Postmine	44.2	0.42	2.05
J7-E	Premine	13	0.42	1.96
J7-E	Postmine	12.6	0.42	1.58
J7-F	Premine	43.6	0.42	2.77
J7-F	Postmine	43.0	0.42	2.12

For the postmine condition, the overall sediment yield is less than those in the premine condition. Sediment yield is approximately 80% of the premine amount, and runoff is the same as the premine amount. The reduction of sediment yield is primarily due to the channel erosion control measures (BMP's) for the postmine condition.

Table 1.4 also shows pre- and postmine drainage area, runoff, and sediment yield for three individual watersheds (J7-CD, J7-E, and J7-F) within the J7 WA. Modeling results of individual watersheds are similar to the overall J7 WA.

1.6 Discussion

Table 1.5 gives an overview of the geometric properties of the pre- and postmine disturbed areas. Postmine hillslopes are gentler than premine hillslopes, while postmine channels are as steep as premine channels. It is because most ridges within the J7 WA were mined and reclaimed and most valleys with the J7 WA were not disturbed. The drainage density of the postmine condition is smaller than that of premine condition because the postmine topography has simple geometric characteristics and the premine topography is highly dissected.

Table 1.5. Average Physical Properties of the J7 WA.

	Premine	Postmine
Total Area (ac)	102.2	99.8
Total Channel Length (ft)	10541	6209
Mean Channel Slope	0.0625	0.0628
Drainage Density (mi/mi^2)	12.5	7.5
Mean Hillslope Length (ft)	213	255
Mean Hillslope Gradient	0.0918	0.0686

2. COMPARISONS WITH MEASURED SEDIMENT TRANSPORT

As discussed in Section 1, PWCC has monitored flow and sediment on the main channels, principal tributaries and small watersheds within the leasehold. These data, along with the runoff plots, were used to calibrate the EASI model soil erodibility and infiltration input variables. **Figures 2.1** and **2.2** show sediment transport and sediment concentration versus discharge for measured unmined (background), measured reclaimed, WA J7's modeled unmined (premine) and modeled reclaimed (postmine) data. Although there is significant scatter shown in the data (as is expected with any sediment transport conditions), there are several conclusions that can be drawn from this data.

The open symbols in both figures depict measured data and whether the data were collected from reclaimed areas (the small watershed study) or from unmined or background surface water monitoring stations. The range of flows is generally greater for the background data but there is significant overlap between the two data sets between 0.1 and 100 cfs. This is because the reclaimed data are from small watersheds and the unmined data are from channels draining larger basins. These data show the same trend for sediment transport and sediment concentration over the entire range of flows and very close agreement in the area of discharge overlap. This, in itself, is strong evidence that (1) the sediment yields are channel transport capacity limited, (2) overlap of model predictions for both pre- and postmine conditions with measured data strongly indicate that EASI model predictions are representative and reasonable, and (3) sediment yields from reclaimed areas will not be additive to yields on the receiving streams.

The closed symbols depict data from WA J7's pre- and postmine EASI model runs. They represent data generated by EASI for both subwatersheds and channels for peak discharges resulting from 2-, 5-, 10-, 25-, 50-, and 100-year storms. Using the peak flows from extreme events results in discharges that generally exceed 10 cfs. The trend of the model-derived data is similar and the ranges of concentration and sediment transport are similar to the measured data and between pre- and postmine conditions.

The sediment discharge plot (Figure 2.1) shows a stronger trend because it is plotting discharge (sediment) against discharge (flow). This is expected because the sediment discharge does depend on flow discharge. The concentration plot (Figure 2.2) shows the two separate variables and, therefore, a less significant trend. PWCC believes that data measurement may have some influence on the scatter (outliers were removed), but the process variability is probably the major influence. The majority of the data, however, fall in a group centered on 100 cfs and 100,000 mg/l, both in the observed data and in the model results. These plots support the use of the EASI model, the results of the modeling, the conclusion that sediment yields from reclaimed areas are not additive to receiving stream sediment loads, and that sediment impacts to the prevailing hydrologic balance have been minimized.

From Figures 2.1 and 2.2 it is apparent that sediment loads and concentrations are dependent on the channel sediment transport capacity for both pre- and postmine conditions. Channel sources of sediment in this arid environment are virtually unlimited. Therefore, channel transport capacity and channel derived sediment limits and governs sediment yields from the small tributaries, large channels and the WA as a whole. The similarity of sediment discharge (or concentration) between pre- and postmine conditions appears to be inconsistent with the lower rates of sediment yield shown in Table 1.4.

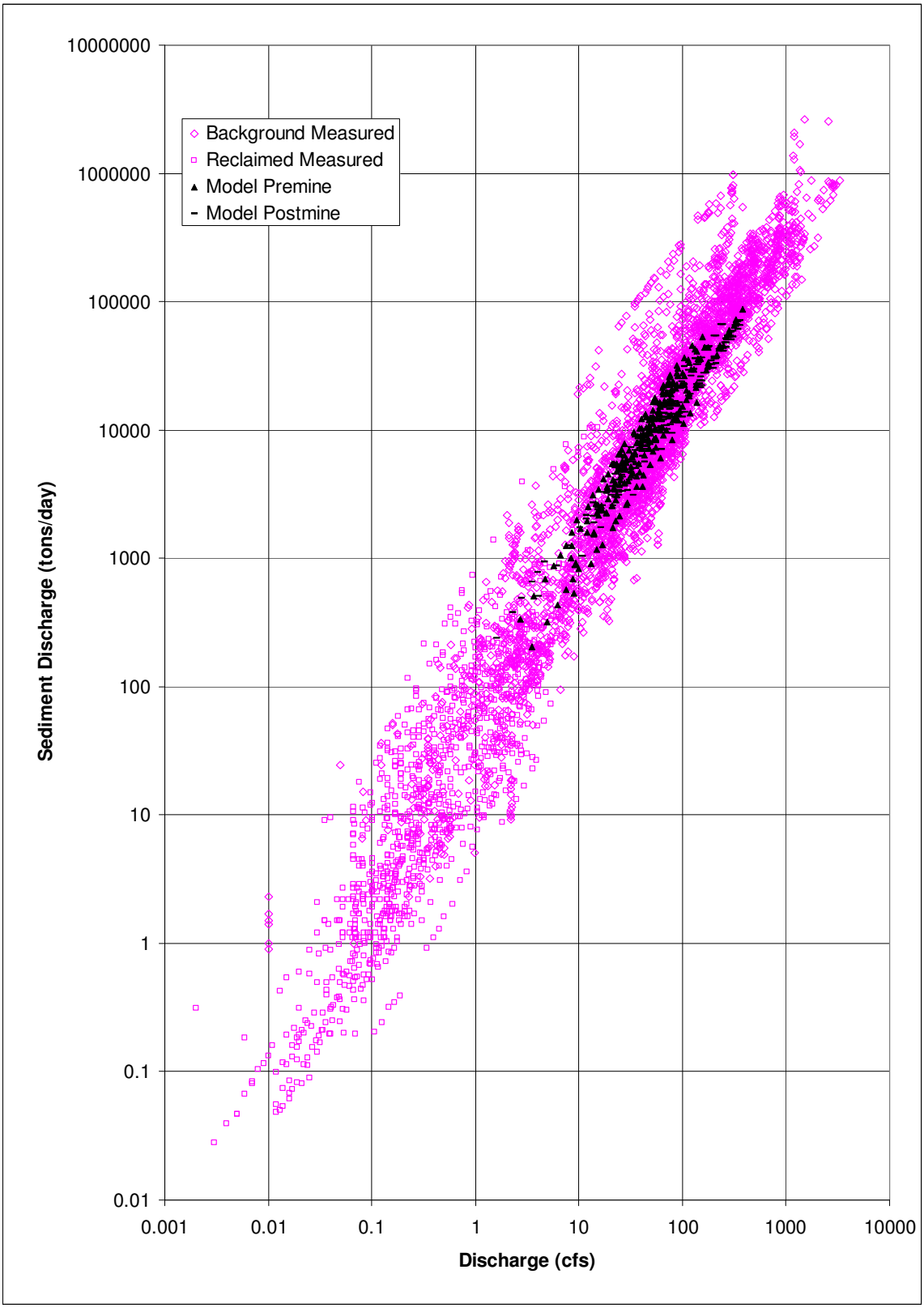


Figure 2.1. Observed and modeled sediment and water discharge.

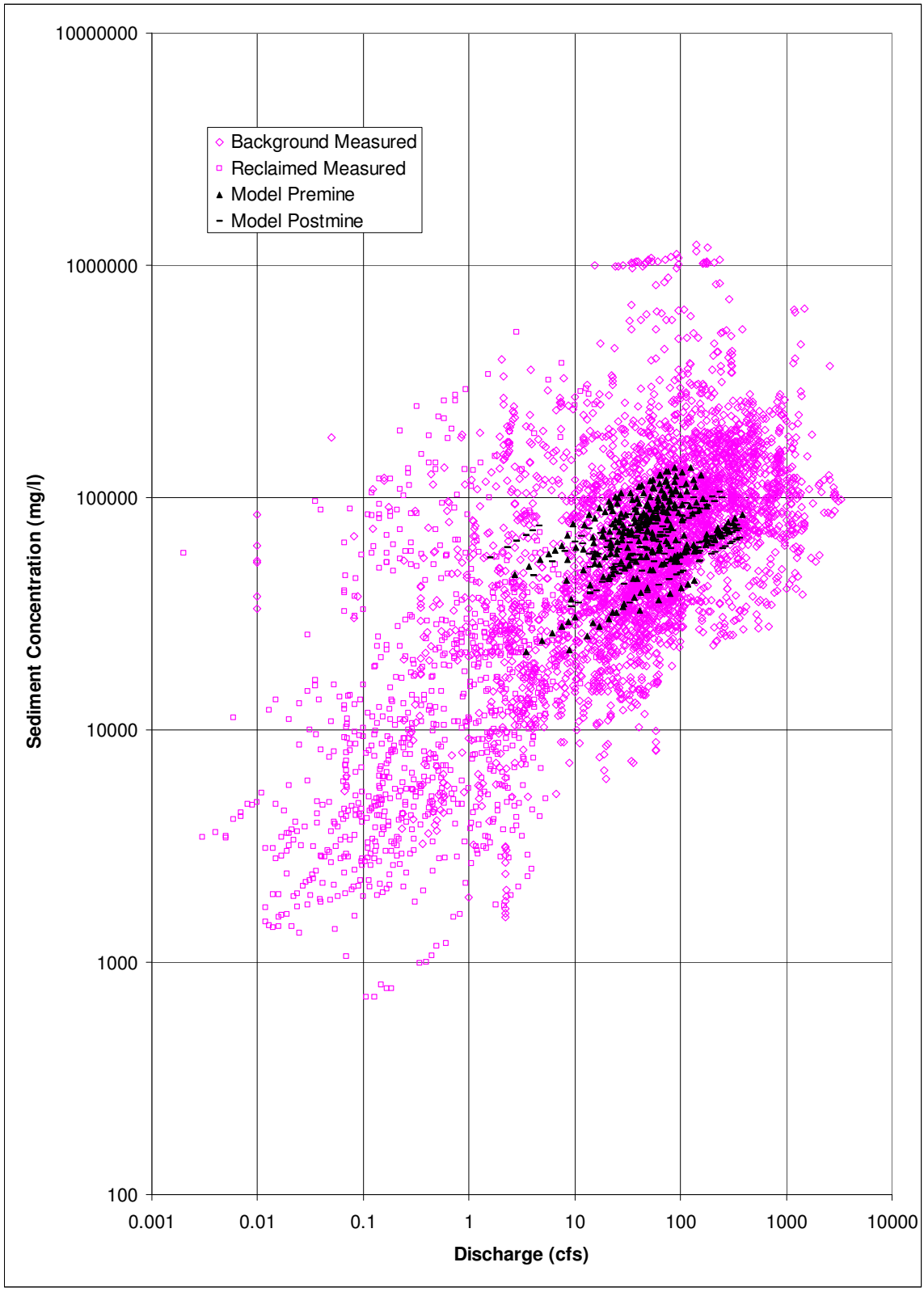


Figure 2.2. Observed versus modeled sediment concentration and discharge.

However, the sediment yield shown in Table 1.4 is the average annual amount of sediment leaving the J7 WA whereas the sediment discharge shown in Figure 2.1 is the peak rate of sediment in transport occurring in any channel represented by the data, whether the channel is located upstream or downstream of a pond. Therefore, it should be concluded that with or without a pond left in the postmine landscape that traps sediment or stores water, the mine reclamation is not contributing additional sediment to the receiving streams and sediment impacts to the prevailing hydrologic balance have been minimized.

Smith and Best (2000) analyzed the measured data (background and reclaimed) shown in Figure 2.1 to develop an approach that can be used to determine if channels in reclaimed areas have similar sediment transport characteristics as background channels. The method that they used was to develop Sen lines (Sen 1968) and confidence intervals around the data. The slope of the Sen line is a non-parametric statistic computed as the median slope of all possible slopes determined from pairing all the data points. The Sen line is drawn through the median coordinate of the data. Smith and Best first showed that the large channel flume data (background) and the small watershed background data could be combined. They concluded that since the data from one data set fall within the Sen line bounds of the other data set then the two data sets are merely extensions of each other and could be combined. Also, because the main channel and background small watershed site data could be combined, it indicated there is an unlimited supply of sediment and the channels are conveying sediment at (or near) capacity. The Sen line and bounds are shown with the background measured data in **Figure 2.3**.

They then plotted the reclaimed measured data (**Figure 2.4**) with the Sen line and bounds from the background data to show that the reclaimed data have the same characteristics even though the flow range of the measurements is lower. The data indicate that channel flows in this environment achieve the sediment transport capacity of the channel, whether in reclaimed or background conditions.

Using the same approach with the modeled data generated for the J7 WA, **Figures 2.5 and 2.6** show the pre- and postmine computed sediment transport rates with the Sen lines and bounds. One difference between the plots is that the measured data occur throughout the flow hydrograph whereas the modeled data are tabulated at the peak of the simulation flow hydrograph. The premine data plot (Figure 2.5) shows the data grouped above the Sen line and well within the bounds. The postmine data (Figure 2.6) plot most densely around the Sen line. On these graphs data plotting above the Sen line indicate that there is more sediment in transport for a given discharge.

Several conclusions can be drawn from these data plots: (1) EASI model well replicates erosion and sediment transport processes at the mine site for background and reclaimed conditions, (2) all data show similar trends and are within the same bounds, (3) data trends indicate that channels are transporting sediment at or near capacity, and (4) amounts of sediment leaving the WA for postmine conditions are similar to premine conditions and within the range expected for the background conditions. Therefore, the overall conclusion is that the postmine reclaimed condition in J7 WA is not contributing additional suspended solids to receiving streams, and related impacts to the hydrologic balance have been minimized.

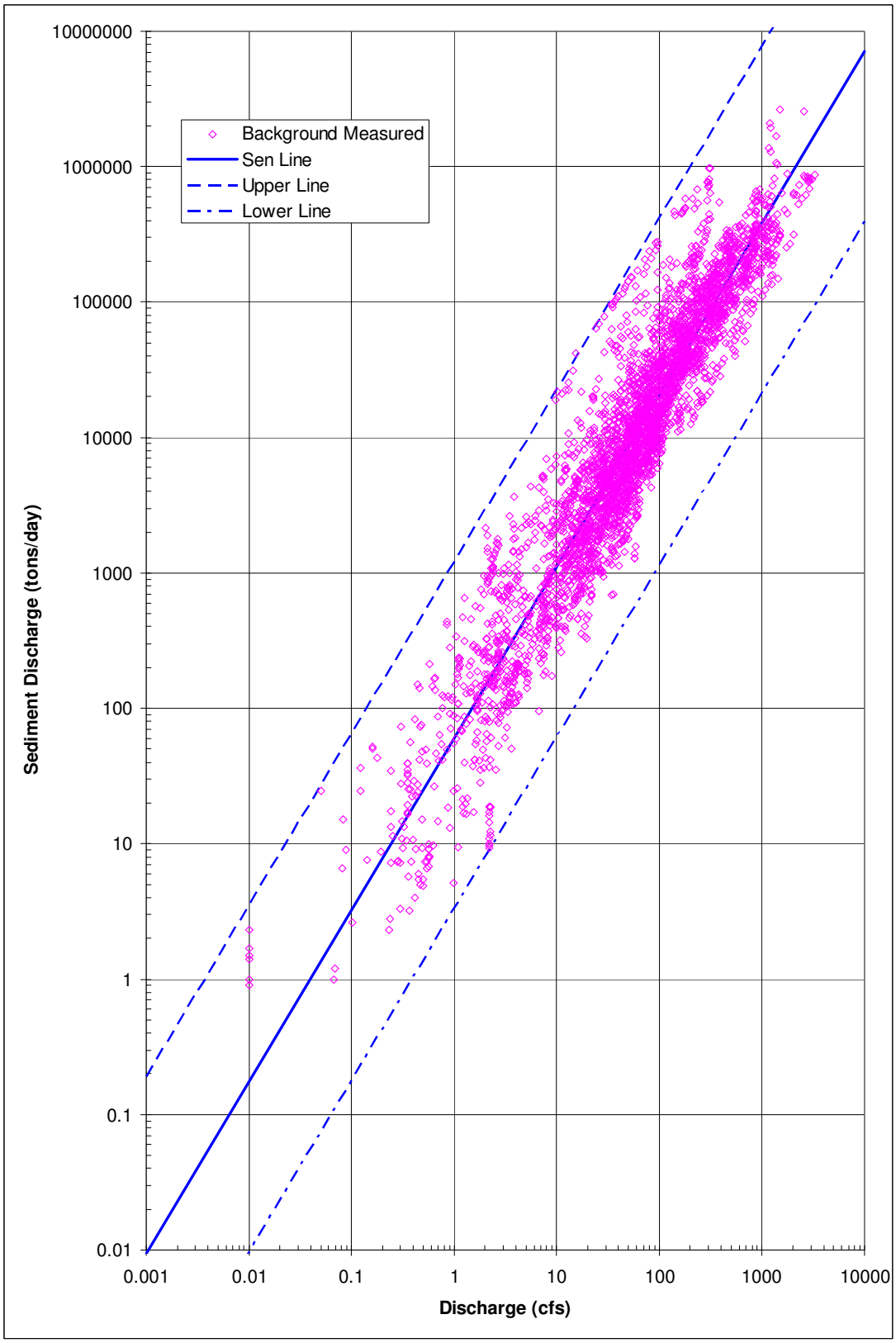


Figure 2.3. Background measured sediment and water discharge with Sen lines.

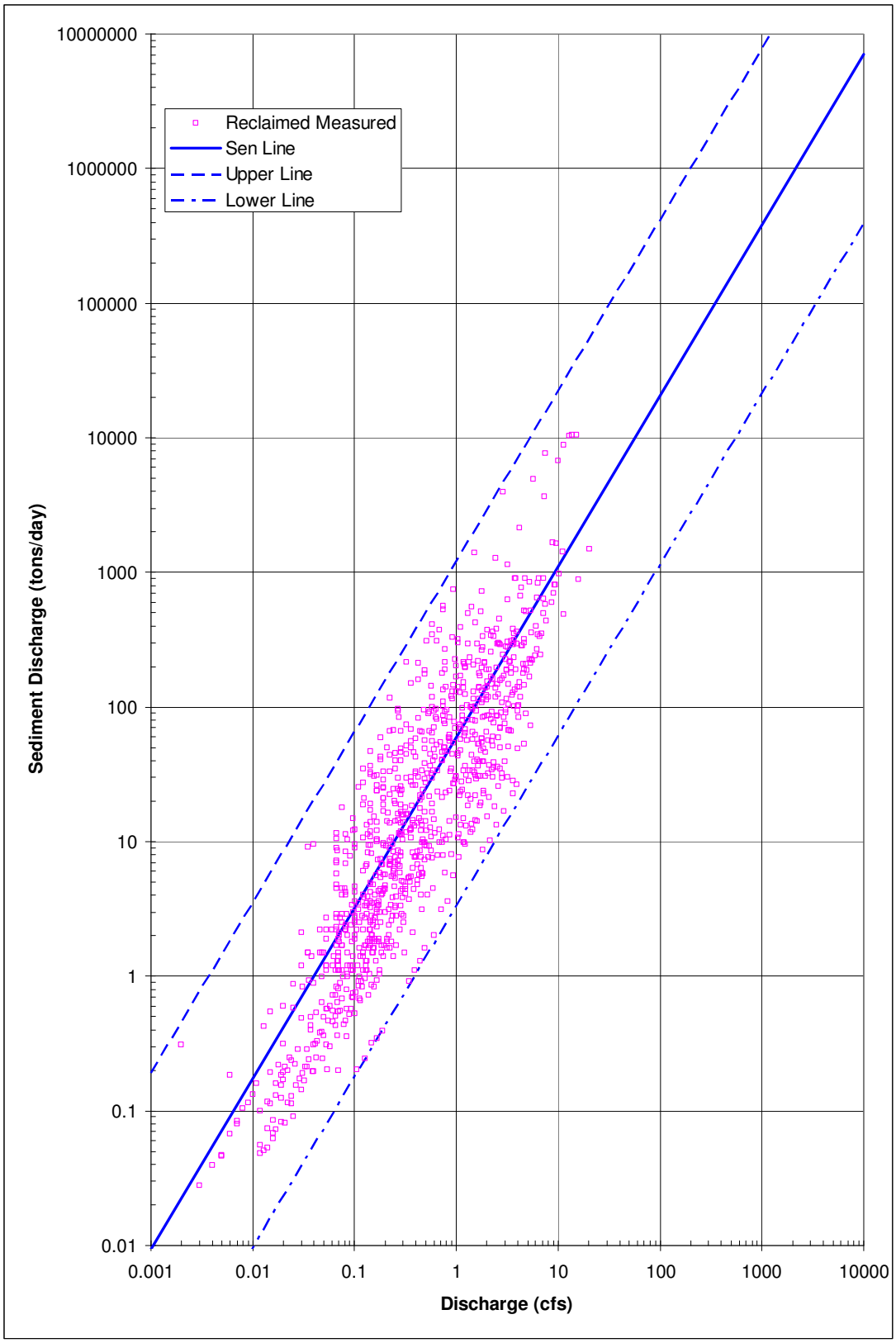


Figure 2.4. Reclaimed measured sediment and water discharge with Sen lines.

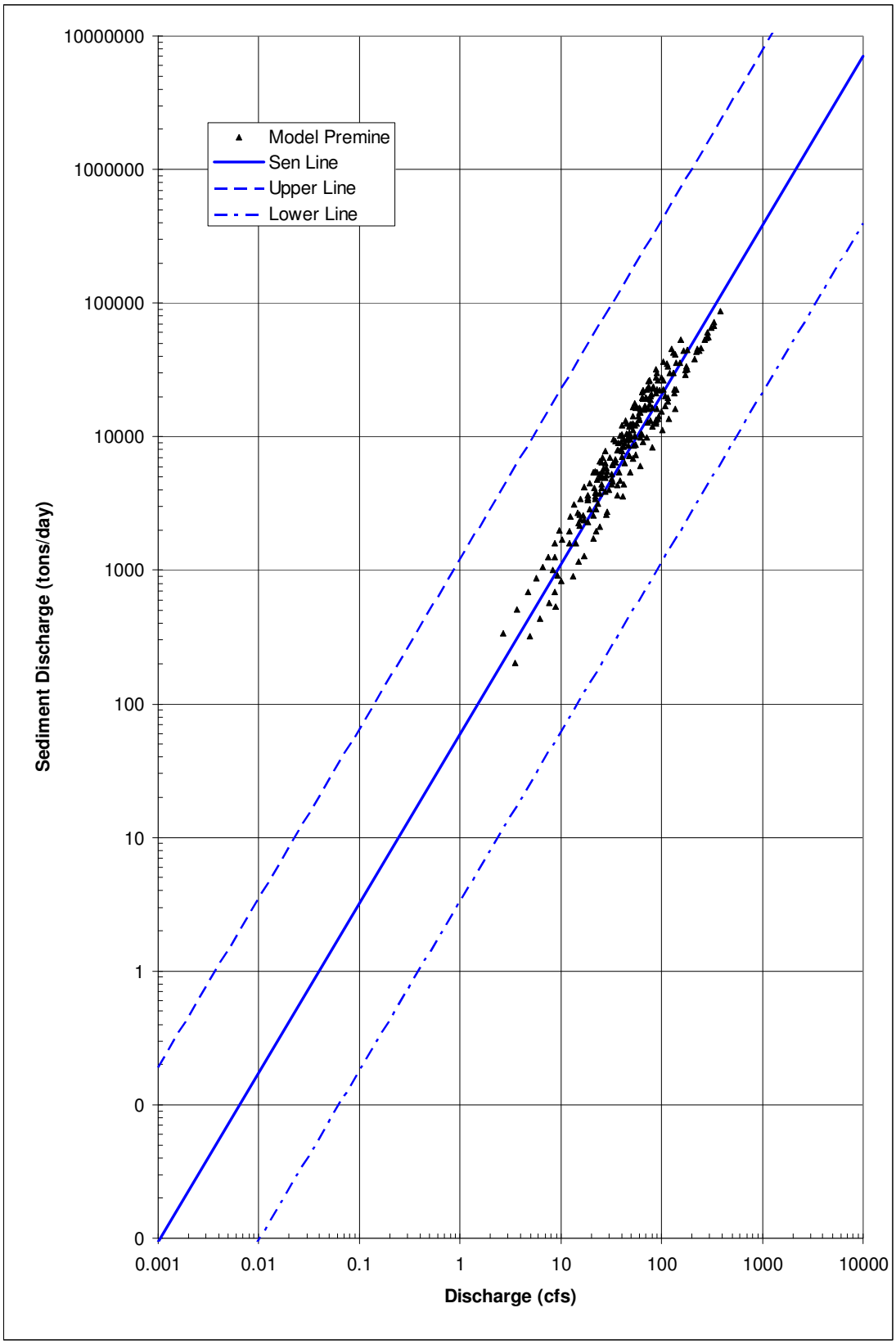


Figure 2.5. Modeled premine sediment and water discharge for the J7 WA with Sen lines.

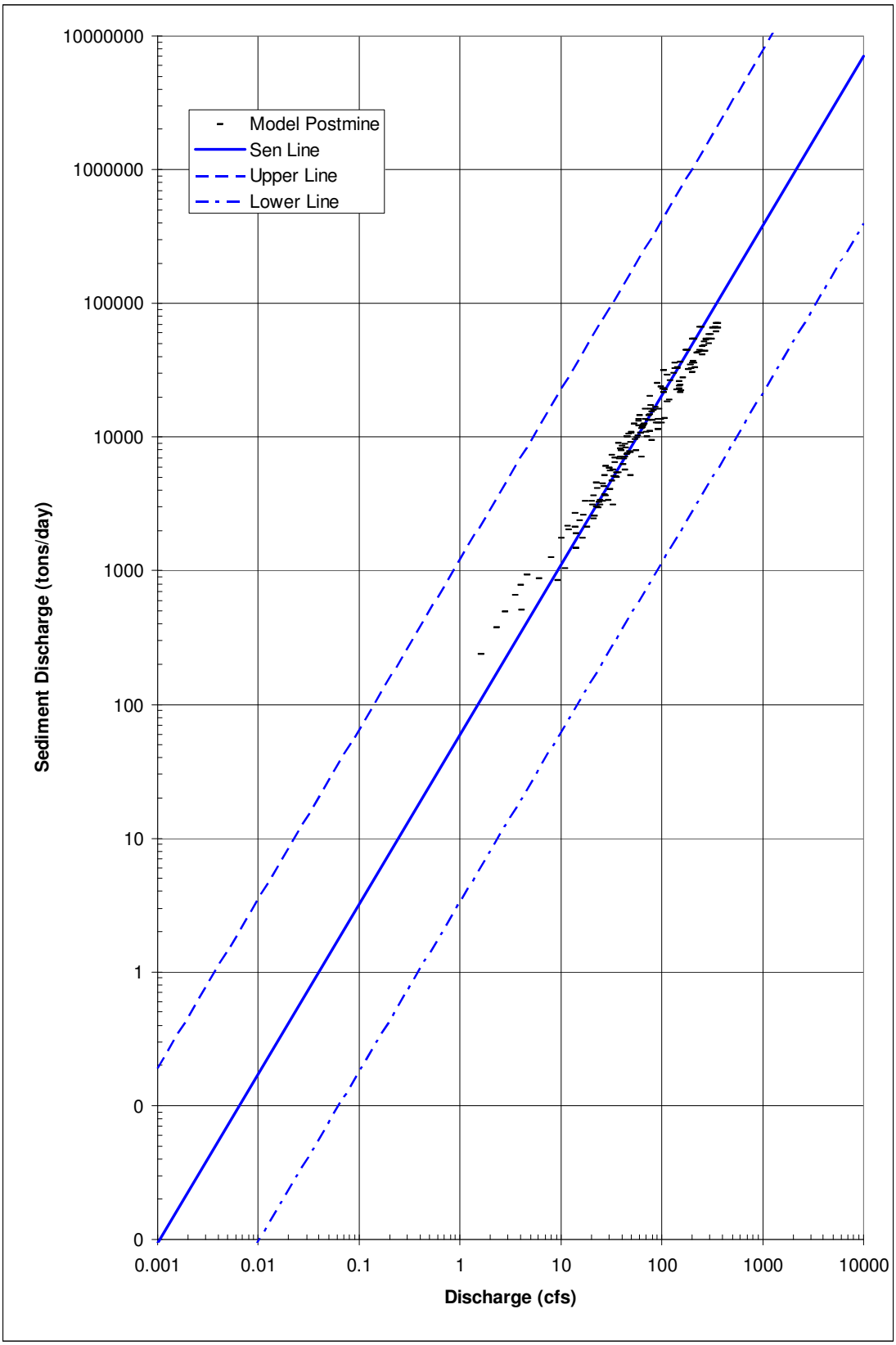


Figure 2.6. Modeled postmine sediment and water discharge for the J7 WA with Sen lines.

3. REFERENCES

Hjelmfelt, A.T., Kramer, L.A., and Spomer, R.G., 1986. Role of large events in average soil loss in Proceedings of the Fourth Federal Interagency Sedimentation Conference, March 24-27, 1986, Las Vegas, NV, p. 3-1 to 3-9.

Lagasse, P.F., Schall, J.D., and Peterson, M.R., 1985. Erosion Risk Analysis for a Southwestern Arroyo, Journal of Urban Planning and Management, American Society of Civil Engineers, v. III, no. I, November, 1985, Paper No. 20165.

Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973. "NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States," Volume VIII - Arizona, National Oceanic and Atmospheric Administration.

Renard, K.G. and Simaton, J.R., 1975. "Thunderstorm Precipitation Effects on the Rainfall-Erosion Index of the Universal Soil Loss Equation" in Volume 5 of Hydrology and Water Resources in Arizona and the Southwest, American Water Resources Assn., Arizona Section Arizona Academy of Science, Hydrology Section, Proceedings of April 11-12 meeting, Tempe AZ, v. 47-55.

Resource Consultants & Engineers, Inc. (RCE), 1993. "Surface Water Modeling of Reclaimed Parcels at the Black Mesa Complex," prepared for Peabody Western Coal Co.

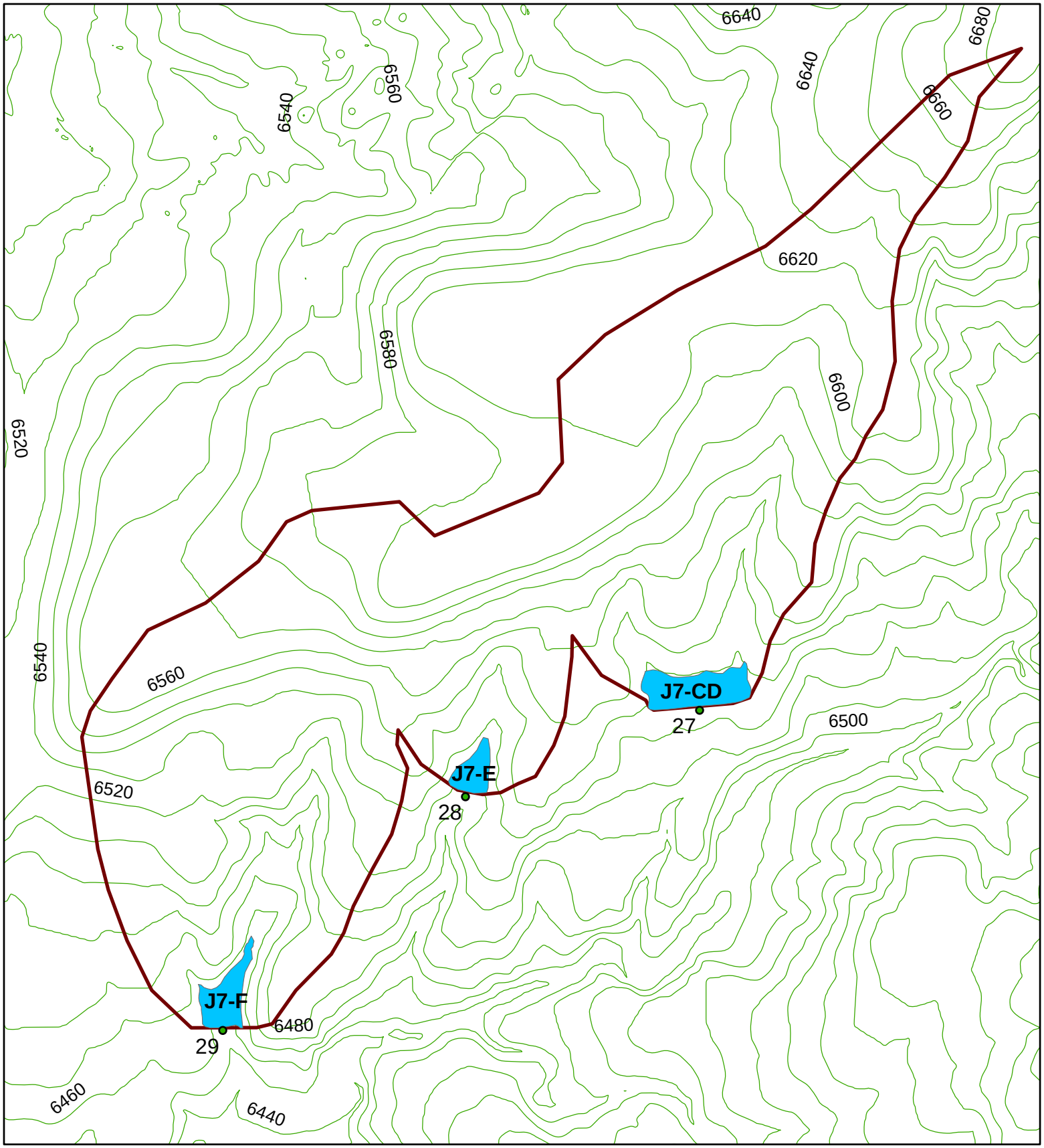
Sen, P.K., 1968. "Estimates of Regression Coefficient Based on Kendall's tau: Journal of American Statistical Association, v. 63, p. 1379-1389.

Smith, T. and Best, A., 2000. "Assessing Sedimentation and Protection of the Hydrologic Balance in Disturbed and Reclaimed Areas at the Black Mesa and Kayenta Mines, Arizona, Using Baseline Sediment Data Collected in Receiving Streams," presentation given at the Billings Mined Land Reclamation Symposium in 2001, Billings, MT.

Water Engineering & Technology, Inc. (WET), 1990. "Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control Technology at Surface Mines in the Semiarid West," prepared for Office of Surface Mining and the National Coal Association, Fort Collins, CO.

Zevenbergen, L.W., Peterson, M.R., and Watson, C.C., 1990. Computer simulation of watershed runoff and sedimentation processes, Proceedings of the Billings Symposium; Planning, Rehabilitation and Treatment of Disturbed Lands.

EXHIBIT 1
Postmine Topography



Legend

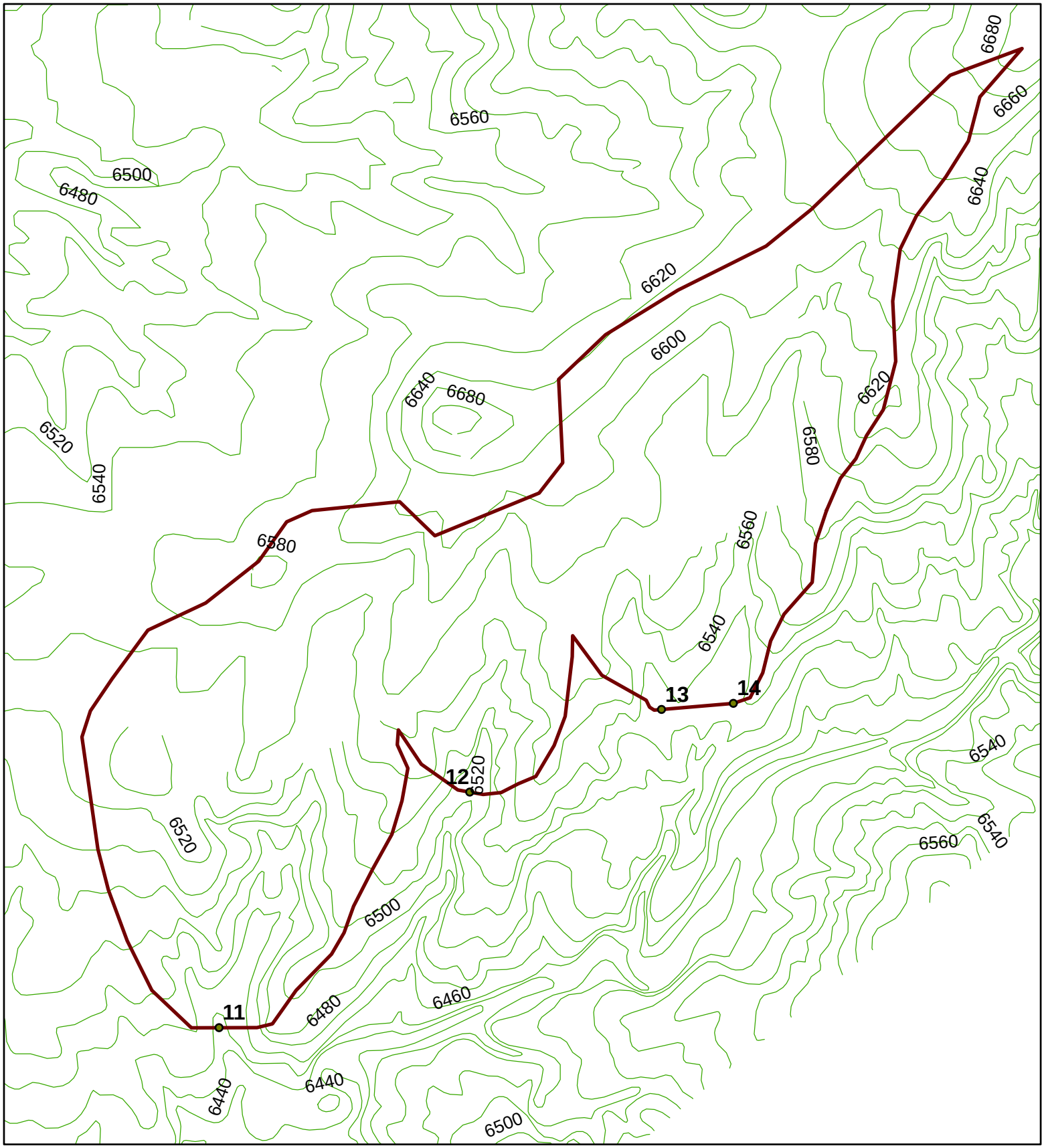
- End Points
- Ponds
- Modeling Area

N

0 250 500 1,000 1,500 Feet

Exhibit 1. Postmine Topography

EXHIBIT 2
Premine Topography



N

Legend

- End Points
- Modeling Area

0 250 500 1,000 1,500 Feet

Exhibit 2. Premine Topography

Appendix 2

Surface Water Modeling of the Reclaimed N6-C, N6-D, and N6-F Watershed Area at the Black Mesa Complex

SURFACE WATER MODELING OF THE RECLAIMED N6-C, N6-D, AND N6-F WATERSHED AREA AT BLACK MESA MINE

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES

SURFACE WATER MODELING OF THE RECLAIMED N6-C, N6-D, AND N6-F WATERSHED AREA AT BLACK MESA MINE

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES
P.O. Box 270460
Fort Collins, Colorado 80527
(970) 223-5556, FAX (970) 223-5578

Ayres Project No. 32-1304.00
PEAB-N6.DOC

August 2008

TABLE OF CONTENTS

1. Reclaimed Parcel Modeling 1.1

1.1 Introduction 1.1
1.2 Background 1.1
1.3 Data 1.2

1.3.1 Soils 1.2
1.3.2 Vegetation 1.2
1.3.3 Topography 1.3

1.4 Methodology 1.3

1.4.1 Synthetic Rainfall 1.8
1.4.2 Computation of Average Runoff and Sediment Yield 1.8

1.5 Results 1.8
1.6 Discussion 1.9

2. Comparisons With Measured Sediment Transport 2.1

3. References 3.1

Exhibit 1 – Postmine Topography ..... --
Exhibit 2 – Premine Topography ..... --

LIST OF FIGURES

Figure 1.1. Reclaimed area soils trilinear graph. 1.2

Figure 1.2. Spatial distribution of vegetative cover types for WA N6 premine condition..... 1.4

Figure 1.3. N6-C, N6-D, and N6-F postmine basins. 1.6

Figure 1.4. N6-C, N6-D, and N6-F premine basins..... 1.7

Figure 2.1. Observed and modeled sediment and water discharge. 2.2

Figure 2.2. Observed versus modeled sediment concentration and discharge. 2.3

Figure 2.3. Background measured sediment and water discharge with Sen lines..... 2.5

Figure 2.4. Reclaimed measured sediment and water discharge with Sen lines..... 2.6

Figure 2.5. Modeled premine sediment and water discharge for the N6 WA with Sen lines. ... 2.7

Figure 2.6. Modeled postmine sediment and water discharge for the N6 WA with Sen lines. . 2.8

LIST OF TABLES

Table 1.1. Soils Data. 1.3

Table 1.2. Cover Sampling Data. 1.5

Table 1.3. Cover Data for N6-C, N6-D, and N6-F Watersheds. 1.5

Table 1.4. Average Runoff and Sediment Yield Results. 1.8

Table 1.5. Average Physical Properties of the N6 WA. 1.9

1. RECLAIMED PARCEL MODELING

1.1 Introduction

The objective defined by PWCC for this project is to use a previously calibrated and validated runoff and erosion model (EASI, Zevenbergen et al. 1990; WET 1990) for the Black Mesa and Kayenta Mines to predict mean annual runoff and sediment yields from the reclaimed N6-C, N6-D, and N6-F watersheds. This objective included computation of runoff and sediment yields under premine conditions for the same area. All soils and rainfall input to the model are to be taken from models calibrated in the previous study (RCE 1993). The input variables that were calibrated to the mine areas and used in this study include soil infiltration parameters, erodibility parameters, and the grain size distribution. Parameters that are specific to this study are vegetative canopy and ground cover percentages from data collected on site.

The model calibration was conducted in a previous study (RCE 1993) using data obtained from instrumented watersheds and small hillslope plots collected under natural rainfall conditions. For a detailed discussion of data collection and model calibration, please refer to the previous study (RCE 1993).

1.2 Background

The N6-C, N6-D, and N6-F Watershed Area (WA) that is the focus of this project was reclaimed between 1982 and 1988. The fundamental purpose of this study was to quantify the expected behavior and hydrologic response of the reclaimed areas above each pond relative to the conditions that existed prior to the occurrence of mining activities.

Runoff and sediment yield response from the reclaimed lands should be managed by implementing Best Management Practices (BMP's) in conjunction with an OSM approved sediment control plan in order to not adversely impact the prevailing hydrologic balance and to limit additional contributions of suspended sediment to streamflow or runoff outside the mine permit areas. BMP's include regrading, replacing salvaged topsoil, revegetation, and other controls such as riprapped channel bottoms, check dams, and where practicable, contour terraces. The natural watersheds on the mesa contribute significant quantities of sediment to the channel system. It is expected that the postmine condition will also produce comparable amounts of sediment without adverse impact on the hydrologic balance.

This section describes the data and procedures used to evaluate the N6 WA. This area was modeled to determine the average annual hydrologic response following the completion of reclamation activities taking into account BMP's implemented as part of the reclamation process. Infiltration, runoff, and erosion processes from both hillslopes and channels within the N6 WA were modeled using EASI. Results were determined for concentration points at the outlets of the reclaimed watersheds, which correspond to the embankments associated with Ponds N6-C, N6-D, and N6-F. The locations of these points are shown in **Exhibit 1**. Modeling was also conducted to determine hydrologic response under premine conditions based on the topography, soils, cover, and other conditions that typified the undisturbed watersheds draining to each concentration point. **Exhibit 2** shows the modeling endpoints for the premine N6 WA.

1.3 Data

1.3.1 Soils

Soils data used for the current study (N6 WA) were based on data developed from the calibration of models used in the previous study for Coal Resource Areas (CRAs) N1/N2 and J27 (RCE 1993). The composition of postmine soil in the current study is depicted along with the composition of postmine soils from the previous study in **Figure 1.1**. This figure shows that the soil composition of WA N6 is very similar to soils evaluated during model calibration. Therefore, the soil properties developed in the previous study are valid for this modeling project. These properties include calibrated parameters, such as infiltration and erodibility coefficients, and measured soil size distributions. **Table 1.1** lists the premine and postmine soils data used during EASI modeling of WA N6.

1.3.2 Vegetation

Vegetative cover data representative of both pre- and postmine conditions in WA N6 were supplied by PWCC. For the premine condition, land was characterized as being covered by sagebrush or pinon juniper. The spatial distribution of vegetative cover for the N6 WA premine condition appears in **Figure 1.2**. Average cover properties for CRAs N1/N2 and J27 of the previous study and WA N6 of the current study appear in **Table 1.2**. For the postmine condition, the reclaimed area was assigned the postmine cover type and the unmined area was assigned the same cover type as the premine condition. **Table 1.3** lists the pre- and postmine vegetative cover data used in the EASI model runs generated for the N6 WA. Note that if a unit contained significant portions of both sagebrush and pinon juniper cover types, it was classified as half pinon juniper and half sagebrush.

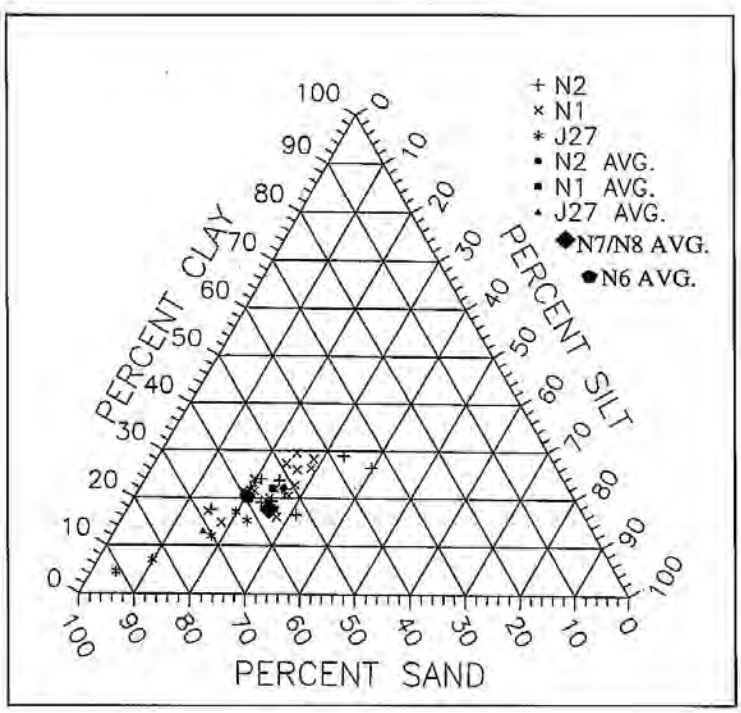


Figure 1.1. Reclaimed area soils trilinear graph.

Table 1.1. Soils Data.			
Condition	Premine	Postmine	Rock Chutes
Rainfall detachment	0.005	0.005	0
Overland flow detachment	0.44	0.44	0
Channel flow detachment	0.5	0.5	0
Initial soil moisture, %	70	70	70
Final soil moisture, %	90	90	90
Soil porosity, %	45	45	46
Temperature, *F	70	70	70
Hydraulic conductivity, in/hr	0.23	0.29	0.3
Capillary suction, in	3.7	2.6	2.6
	Particle Size Distribution (all conditions)		
	Size, mm	% Finer	
	0.001	0	
	0.004	18.0	
	0.016	27.4	
	0.062	36.6	
	0.125	56.2	
	0.250	64.3	
	0.500	72.4	
	1.000	80.5	
	2.000	88.6	
	4.000	92.4	
	16.000	100	

1.3.3 Topography

Pre- and postmine topography was supplied by PWCC in the form of ArcGIS geodatabase. Basin delineations, hillslope delineations, subwatershed delineations, as well as areas, slopes, and lengths of all units of the study area were defined and calculated using ArcGIS software. **Figures 1.3 and 1.4** show the watershed delineation and numbers assigned to the basins used in the EASI model for the post- and premine conditions, respectively. Channel dimensions input to EASI were based on the topography supplied and limited field observations.

1.4 Methodology

Runoff and sediment yield in the semiarid western United States is largely governed by the occurrence of high-intensity, short-duration rainstorms of limited areal extent (Renard and Simaton 1975). Research has indicated that relatively few events may produce the greatest erosion (e.g., Hjelmfelt et al. 1986 reported that only 3 to 4% of rainfall events accounted for 50% of long-term sediment yields). Although there is perhaps a relatively limited physical basis for definition of an "average annual" runoff or sediment yield in a semiarid environment due to the extreme variability in response and importance of single infrequent events, such a term does provide a useful basis for long-term comparison between reclaimed and undisturbed conditions.

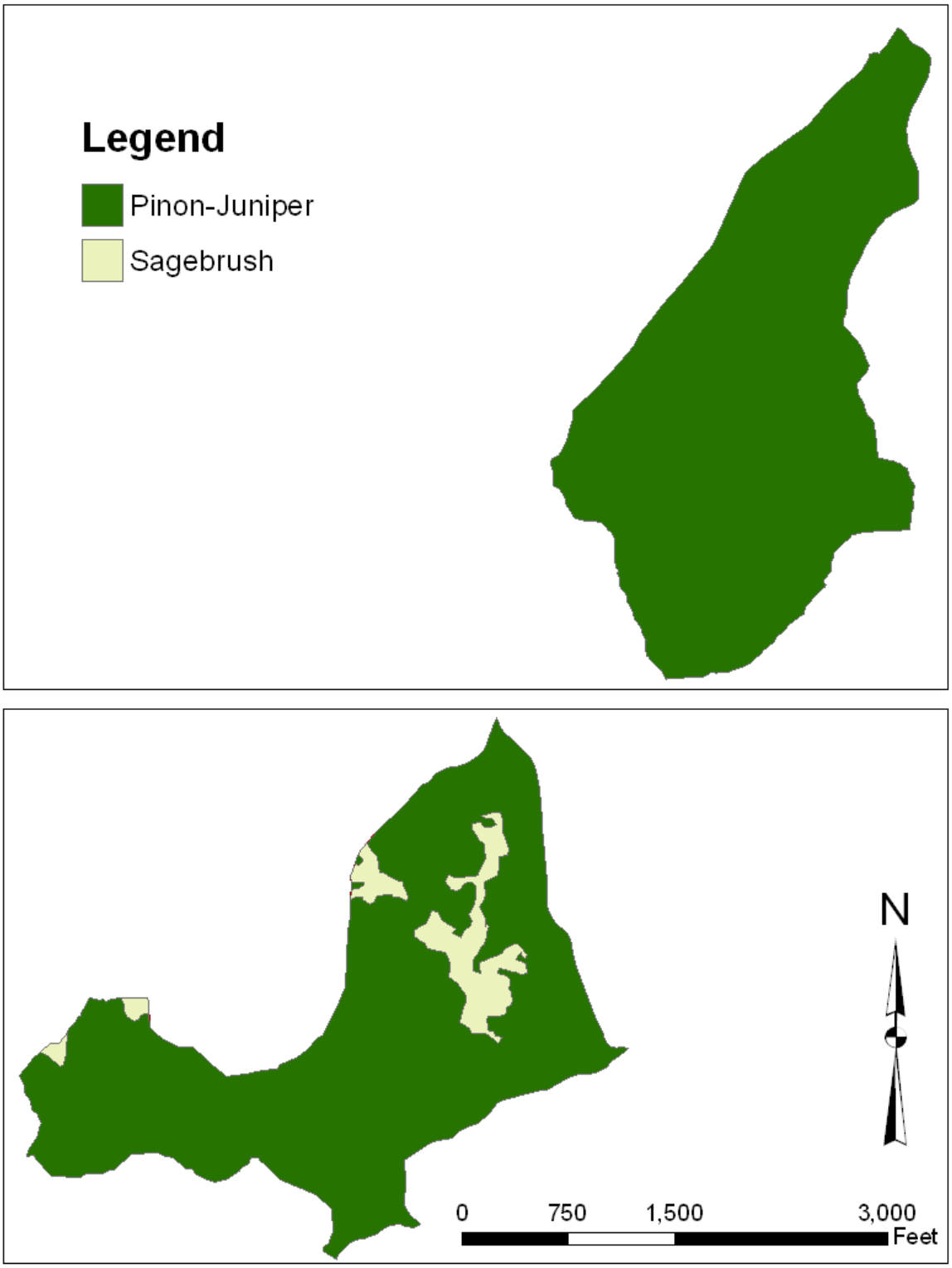


Figure 1.2. Spatial distribution of vegetative cover types for WA N6 premine condition.

Table 1.2. Cover Sampling Data.								
Area	Condition	Cover Type	Nonstratified Vegetation Cover (%)	Vegetation Canopy Cover (%)	Vegetation Ground Cover (%)	Litter* (%)	Rock (%)	Total Ground Cover (%)
N1/N2	Postmine	Postmine	25.6	1.4	24.2	13.6	4.2	41.9
N6 WA	Postmine	Postmine		0.9	20.5	15.5	2.7	38.2
N1/N2/J27	Premine	Pinon Juniper	32.7	31.1	3.0	44.0	19.7	66.7
N6 WA	Premine	Pinon Juniper		14.6	2.7	18.8	17.3	38.8
N1/N2	Premine	Sagebrush	25.1	16.0	10.3	25.3	18.1	53.7
J27	Premine	Sagebrush	30.6	9.7	22.0	24.0	1.6	47.6
N6 WA	Premine	Sagebrush		1.3	11.2	24.7	2.5	38.3
*Including standing dead litter								

Table 1.3. Cover Data for N6-C, N6-D, and N6-F Watersheds.				
Condition	Pinon Juniper	Sagebrush	Half Pinon Juniper-Half Sagebrush	Postmine
Canopy cover, %	14.6	1.3	8.0	0.9
Ground cover, %	38.8	38.3	38.5	38.2
Canopy storage, in	0.05	0.05	0.05	0.05
Ground storage, in	0.05	0.05	0.05	0.05
Depression storage, in	0.03	0.03	0.03	0.03
Impervious area, %	0	0	0	0
Manning n	0.07	0.07	0.07	0.05

To make comparisons between reclaimed lands and associated undisturbed lands at the Black Mesa Mining Complex on the basis of average annual sediment yield, a procedure was used that considers the importance of infrequent storm events in defining sediment yield in the semiarid west. First, however, the site-specific rainfall data available for the Black Mesa Mining Complex were used to evaluate the frequency and magnitude of the measured events relative to existing predictions for rainfall depth-duration (Miller et al. 1973). The analysis of the rainfall data was performed as part of a previous study of the N1/N2 and J27 CRAs (Resource Consultants and Engineers 1993).

Comparisons between runoff and sediment yield from undisturbed and reclaimed areas in WA N6 were developed for specific modeling endpoints shown in Exhibits 1 and 2. Mining and reclamation activities did not exactly replicate the topography, drainage network, or drainage areas that existed prior to mining. Consequently, direct comparisons of total runoff and sediment yield cannot be made between undisturbed and reclaimed response at a given point in a watershed. Comparisons were made on the basis of unit rates of runoff (inches) and sediment yield (tons/acre) at the various modeling computation endpoints. Although the same disturbance boundary was used to model extents for both pre- and postmine conditions, the topographic differences that resulted after mining and reclamation occurred in the N6 WA dictated that some small areas would be included or excluded from the modeling. The total area modeled (combined area for N6-C, N6-D, and N6-F watersheds) for premine conditions is 284.0 acres and for postmine conditions is 280.9 acres. The difference in area results from the sediment ponds in postmine conditions. The area bounded by the modeling boundary identified by PWCC as shown in Exhibits 1 and 2 is 284.0 acres.

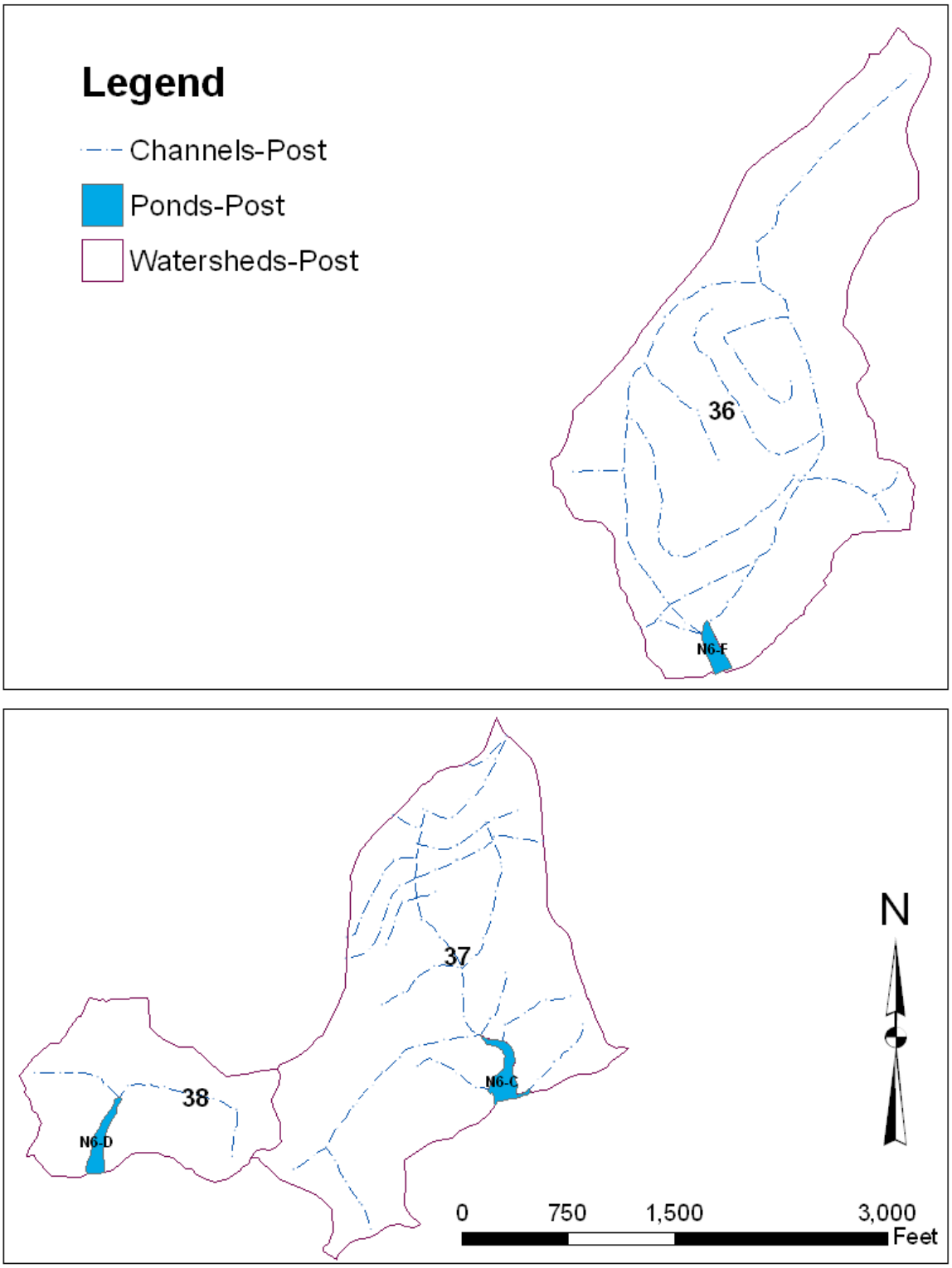


Figure 1.3. N6-C, N6-D, and N6-F postmine basins.

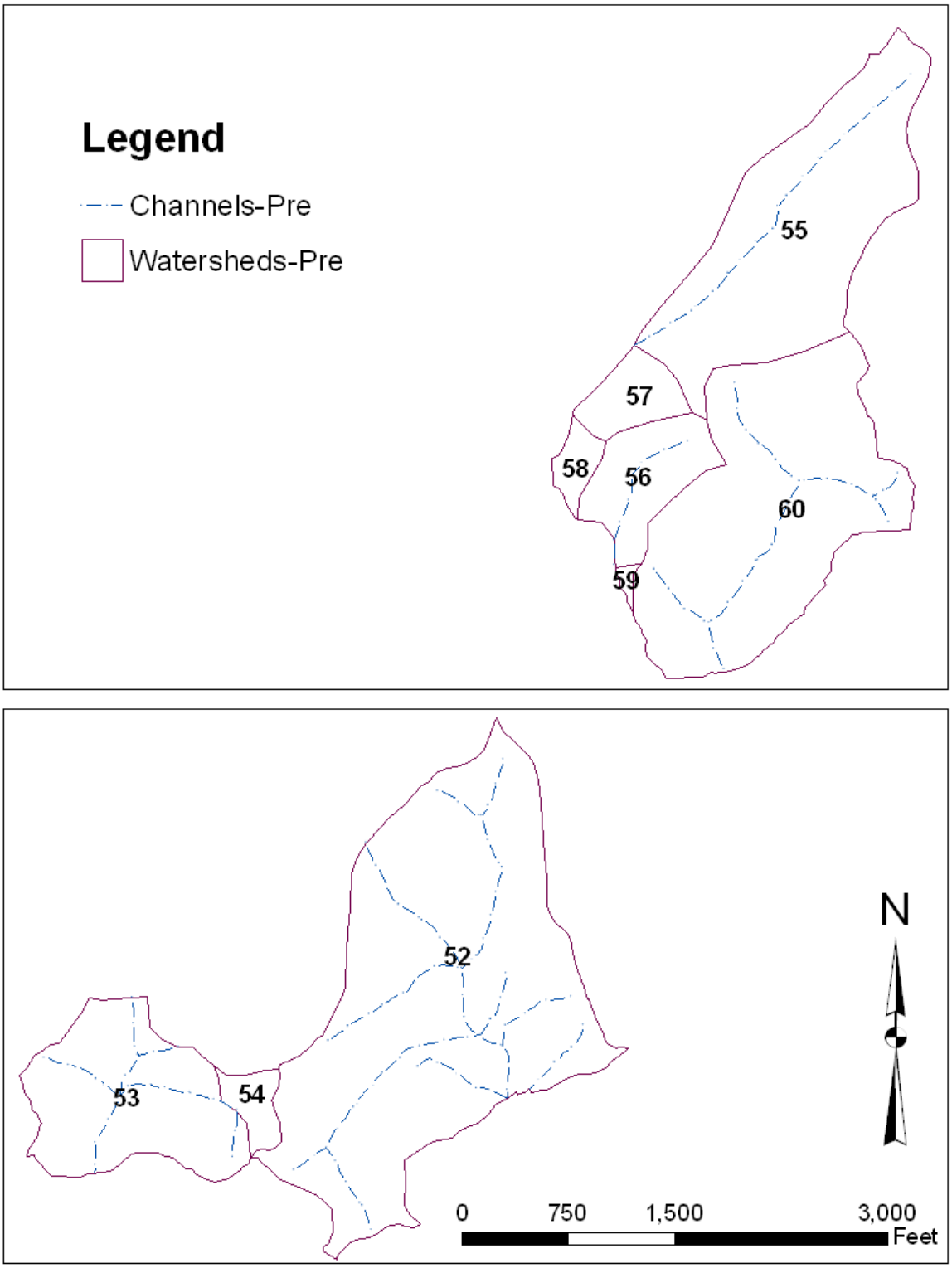


Figure 1.4. N6-C, N6-D, and N6-F premine basins.

1.4.1 Synthetic Rainfall

Synthetic storms of 2-, 5-, 10-, 25-, 50-, and 100-year return periods were used as input to the EASI model. Actual hyetographs were taken from the previous study (RCE 1993) and are based on both local data collection and the NOAA Atlas (Miller et al. 1973).

1.4.2 Computation of Average Runoff and Sediment Yield

The EASI model was used to evaluate runoff and sediment yield from a series of storm events having recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100 years. To define average annual conditions, the average annual runoff and sediment yield generated from storm events were computed using the commonly used equation of Lagasse et al. (1985).

1.5 Results

Figures 1.3 and 1.4 show the post- and premine basin delineations. Since the individual subareas differ in number, acreage and outlet locations, a direct comparison is not possible on a subarea basis. Therefore, the best way to compare the results is on an average basis for the WA. **Table 1.4** shows pre- and postmine drainage area, runoff, and sediment yield for the N6 WA. To consider the situation of pond removal for the postmine condition, the EASI model replaces a sediment pond with a channel, which lies near the location of the pond and discharges to the basin outlet. The channel is assumed to have a length equal to the pond's length and a slope similar to the outlet's natural slope. Runoff is defined as the total volume of water leaving the WA on an average annual basis and, therefore, does not include water stored in depression areas and ponds. For the premine condition, this is equal to the amount of water that drains off the hillslopes and subwatersheds because there are no ponds or significant depressions. For the postmine condition, this is equal to the amount of hillslope runoff less the amount stored in ponds. No ponds or significant depressions exist within the reclaimed N6 WA that was modeled. Similarly, the sediment yield is the amount of eroded material that leaves the WA on an average annual basis computed using the equation of Lagasse et al. (1985). The sediment yield is the production from the hillslope areas and erosion from the channels. The amount of erosion is the sediment yield from the hillslopes and subwatersheds only and does not include channel erosion, channel deposition or sediment trapped in ponds. Sediment yield can be greater or less than erosion, depending on the amount of channel erosion and the capacity of the channel network to convey sediment off the leasehold.

Table 1.4. Average Runoff and Sediment Yield Results.

Area	Condition	Drainage Area (ac)	Runoff (in)	Sediment Yield (t/ac/yr)
N6 WA	Premine	284.0	0.42	3.12
N6 WA	Postmine	280.9	0.42	2.51
N6-C	Premine	105.6	0.42	3.65
N6-C	Postmine	104.4	0.42	3.33
N6-D	Premine	36.1	0.42	1.76
N6-D	Postmine	35.1	0.42	1.07
N6-F	Premine	142.4	0.42	3.07
N6-F	Postmine	141.5	0.42	2.25

For the postmine condition, the overall sediment yield is less than those in the premine condition. Sediment yield is approximately 80% of the premine amount, and runoff is the same as the premine amount. The reduction of sediment yield is primarily due to the channel erosion control measures (BMP's) for the postmine condition.

Table 1.4 also shows pre- and postmine drainage area, runoff, and sediment yield for three individual watersheds (N6-C, N6-D, and N6-F) within the N6 WA. Modeling results of individual watersheds are similar to the overall N6 WA.

1.6 Discussion

Table 1.5 gives an overview of the geometric properties of the pre- and postmine disturbed areas. Premine hillslopes are generally longer than postmine hillslopes, postmine channels are not as steep as premine channels, and the drainage density of the postmine condition is greater than that of the premine condition. These properties agree with the postmine versus premine topography: the greater drainage density and shorter hillslopes of the postmine condition are due to the terracing of the land to allow less sediment erosion and transport. Generally, in a natural setting, a greater drainage density would be equated with higher sediment yields. However, the terraces are not "natural" channels as they are designed to segment long hillslopes into shorter lengths and the terrace channels are designed with low gradients to reduce erosion and sediment transport. A high drainage density in a natural setting would result in a short time of concentration and higher peak flows but a high drainage density due to terracing would increase time of concentration and decrease peak flows. Such differences in pre- and postmine topography make it difficult to generalize about sediment yield from pre- and postmine areas. This shows the value of modeling. One generalization that can be made, however, is that the significantly shorter hillslope lengths are the cause of lower erosion rates.

Table 1.5. Average Physical Properties of the N6 WA.

	Premine	Postmine
Total Area (ac)	284.0	280.9
Total Channel Length (ft)	21583	32108
Mean Channel Slope	0.0619	0.0529
Drainage Density (mi/mi^2)	9.2	13.9
Mean Hillslope Length (ft)	234	212
Mean Hillslope Gradient	0.1192	0.1150

2. COMPARISONS WITH MEASURED SEDIMENT TRANSPORT

As discussed in Section 1, PWCC has monitored flow and sediment on the main channels, principal tributaries and small watersheds within the leasehold. These data, along with the runoff plots, were used to calibrate the EASI model soil erodibility and infiltration input variables. **Figures 2.1** and **2.2** show sediment transport and sediment concentration versus discharge for measured unmined (background), measured reclaimed, WA N6's modeled unmined (premine) and modeled reclaimed (postmine) data. Although there is significant scatter shown in the data (as is expected with any sediment transport conditions), there are several conclusions that can be drawn from this data.

The open symbols in both figures depict measured data and whether the data were collected from reclaimed areas (the small watershed study) or from unmined or background surface water monitoring stations. The range of flows is generally greater for the background data but there is significant overlap between the two data sets between 0.1 and 100 cfs. This is because the reclaimed data are from small watersheds and the unmined data are from channels draining larger basins. These data show the same trend for sediment transport and sediment concentration over the entire range of flows and very close agreement in the area of discharge overlap. This, in itself, is strong evidence that (1) the sediment yields are channel transport capacity limited, (2) overlap of model predictions for both pre- and postmine conditions with measured data strongly indicate that EASI model predictions are representative and reasonable, and (3) sediment yields from reclaimed areas will not be additive to yields on the receiving streams.

The closed symbols depict data from WA N6's pre- and postmine EASI model runs. They represent data generated by EASI for both subwatersheds and channels for peak discharges resulting from 2-, 5-, 10-, 25-, 50-, and 100-year storms. Using the peak flows from extreme events results in discharges that generally exceed 10 cfs. The trend of the model-derived data is similar and the ranges of concentration and sediment transport are similar to the measured data and between pre- and postmine conditions.

The sediment discharge plot (Figure 2.1) shows a stronger trend because it is plotting discharge (sediment) against discharge (flow). This is expected because the sediment discharge does depend on flow discharge. The concentration plot (Figure 2.2) shows the two separate variables and, therefore, a less significant trend. PWCC believes that data measurement may have some influence on the scatter (outliers were removed), but the process variability is probably the major influence. The majority of the data, however, fall in a group centered on 100 cfs and 100,000 mg/l, both in the observed data and in the model results. These plots support the use of the EASI model, the results of the modeling, the conclusion that sediment yields from reclaimed areas are not additive to receiving stream sediment loads, and that sediment impacts to the prevailing hydrologic balance have been minimized.

From Figures 2.1 and 2.2 it is apparent that sediment loads and concentrations are dependent on the channel sediment transport capacity for both pre- and postmine conditions. Channel sources of sediment in this arid environment are virtually unlimited. Therefore, channel transport capacity and channel derived sediment limits and governs sediment yields from the small tributaries, large channels and the WA as a whole. The similarity of sediment discharge (or concentration) between pre- and postmine conditions appears to be inconsistent with the lower rates of sediment yield shown in Table 1.4.

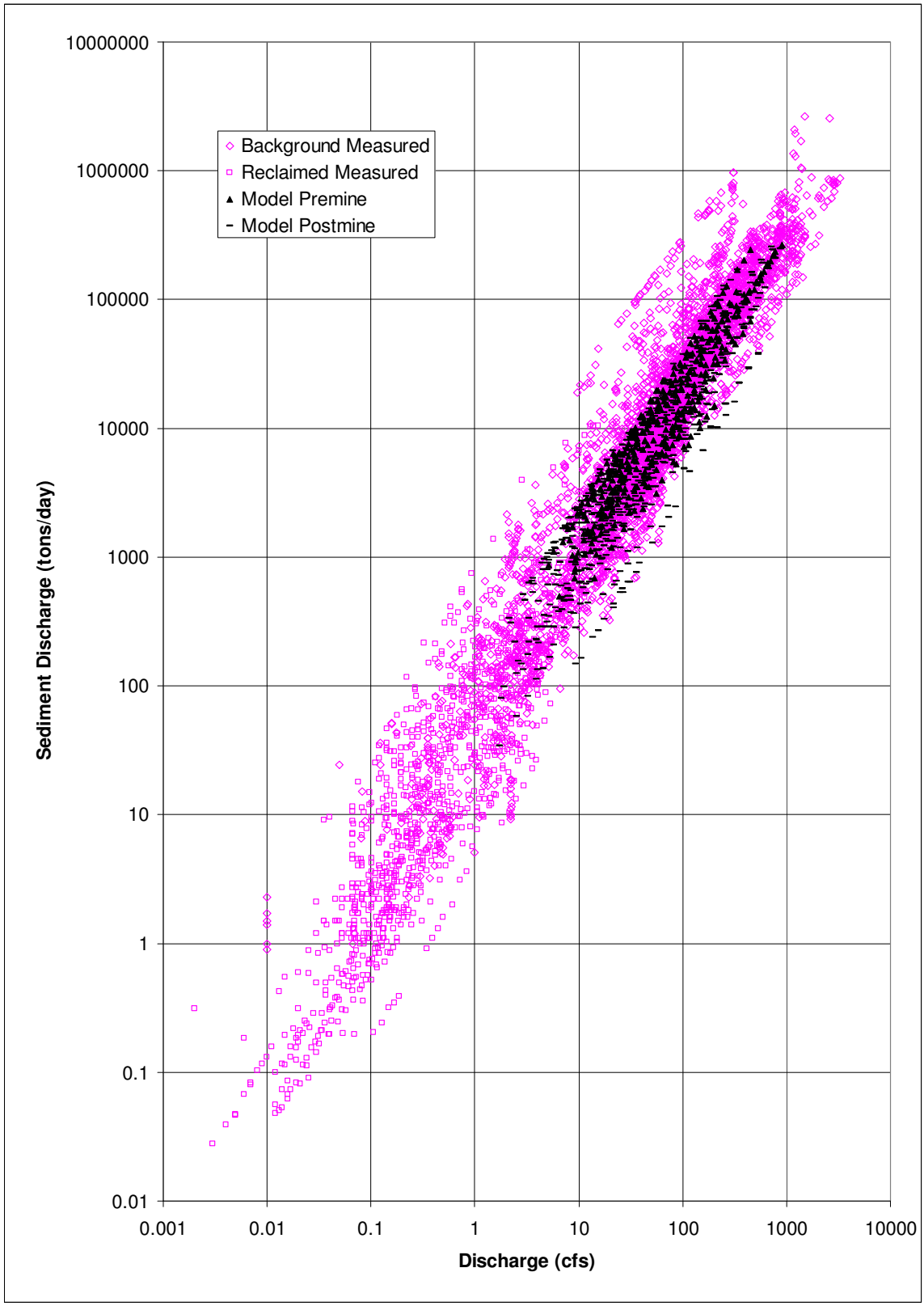


Figure 2.1. Observed and modeled sediment and water discharge.

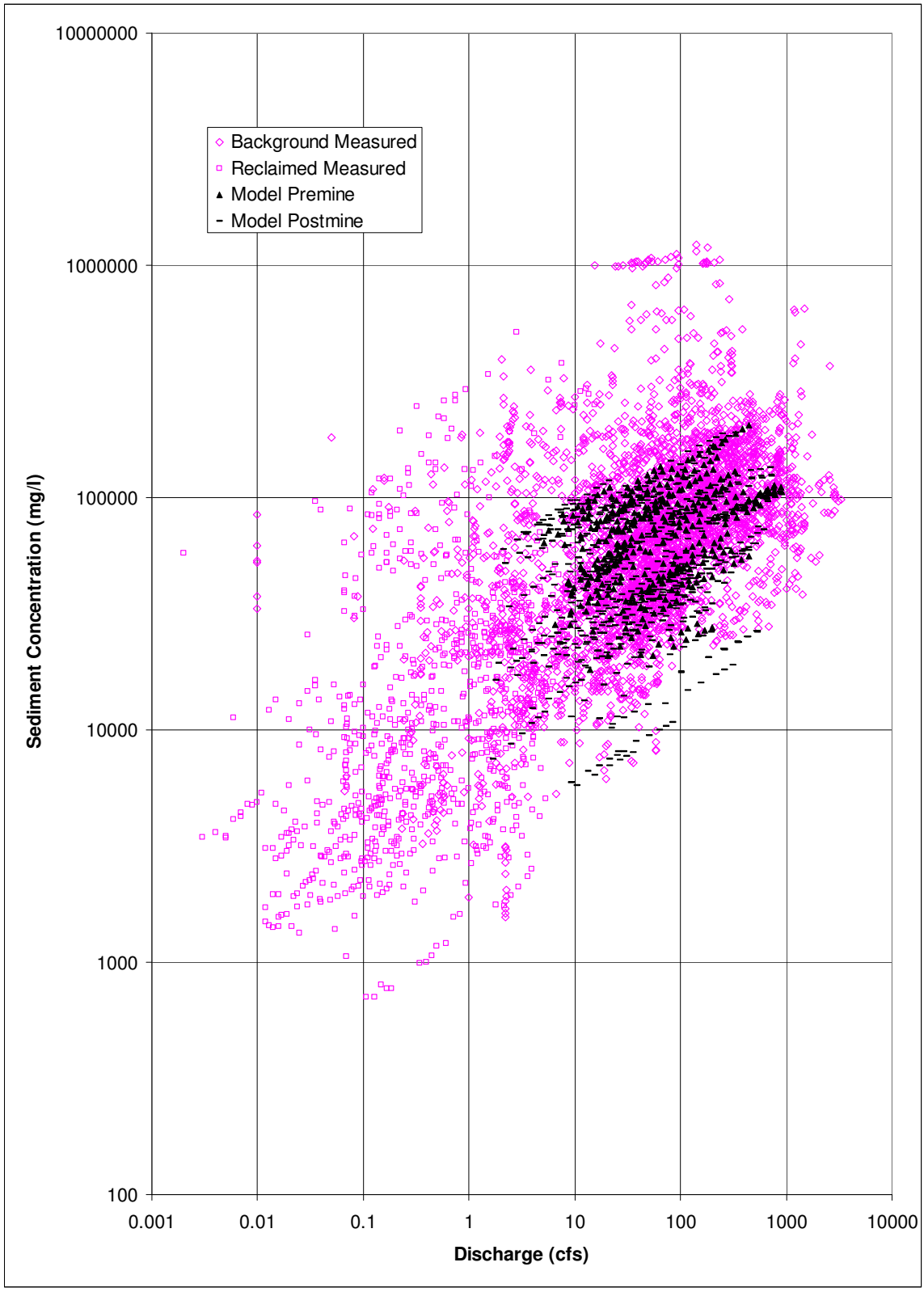


Figure 2.2. Observed versus modeled sediment concentration and discharge.

However, the sediment yield shown in Table 1.4 is the average annual amount of sediment leaving the N6 WA whereas the sediment discharge shown in Figure 2.1 is the peak rate of sediment in transport occurring in any channel represented by the data, whether the channel is located upstream or downstream of a pond. Therefore, it should be concluded that with or without a pond left in the postmine landscape that traps sediment or stores water, the mine reclamation is not contributing additional sediment to the receiving streams and sediment impacts to the prevailing hydrologic balance have been minimized.

Smith and Best (2000) analyzed the measured data (background and reclaimed) shown in Figure 2.1 to develop an approach that can be used to determine if channels in reclaimed areas have similar sediment transport characteristics as background channels. The method that they used was to develop Sen lines (Sen 1968) and confidence intervals around the data. The slope of the Sen line is a non-parametric statistic computed as the median slope of all possible slopes determined from pairing all the data points. The Sen line is drawn through the median coordinate of the data. Smith and Best first showed that the large channel flume data (background) and the small watershed background data could be combined. They concluded that since the data from one data set fall within the Sen line bounds of the other data set then the two data sets are merely extensions of each other and could be combined. Also, because the main channel and background small watershed site data could be combined, it indicated there is an unlimited supply of sediment and the channels are conveying sediment at (or near) capacity. The Sen line and bounds are shown with the background measured data in **Figure 2.3**.

They then plotted the reclaimed measured data (**Figure 2.4**) with the Sen line and bounds from the background data to show that the reclaimed data have the same characteristics even though the flow range of the measurements is lower. The data indicate that channel flows in this environment achieve the sediment transport capacity of the channel, whether in reclaimed or background conditions.

Using the same approach with the modeled data generated for the N6 WA, **Figures 2.5 and 2.6** show the pre- and postmine computed sediment transport rates with the Sen lines and bounds. One difference between the plots is that the measured data occur throughout the flow hydrograph whereas the modeled data are tabulated at the peak of the simulation flow hydrograph. The premine data plot (Figure 2.5) shows the data grouped around the Sen line and well within the bounds. Similarly, the postmine data (Figure 2.6) plot around the Sen line.

Several conclusions can be drawn from these data plots: (1) EASI model well replicates erosion and sediment transport processes at the mine site for background and reclaimed conditions, (2) all data show similar trends and are within the same bounds, (3) data trends indicate that channels are transporting sediment at or near capacity, and (4) amounts of sediment leaving the WA for postmine conditions are similar to premine conditions and within the range expected for the background conditions. Therefore, the overall conclusion is that the postmine reclaimed condition in N6 WA is not contributing additional suspended solids to receiving streams, and related impacts to the hydrologic balance have been minimized.

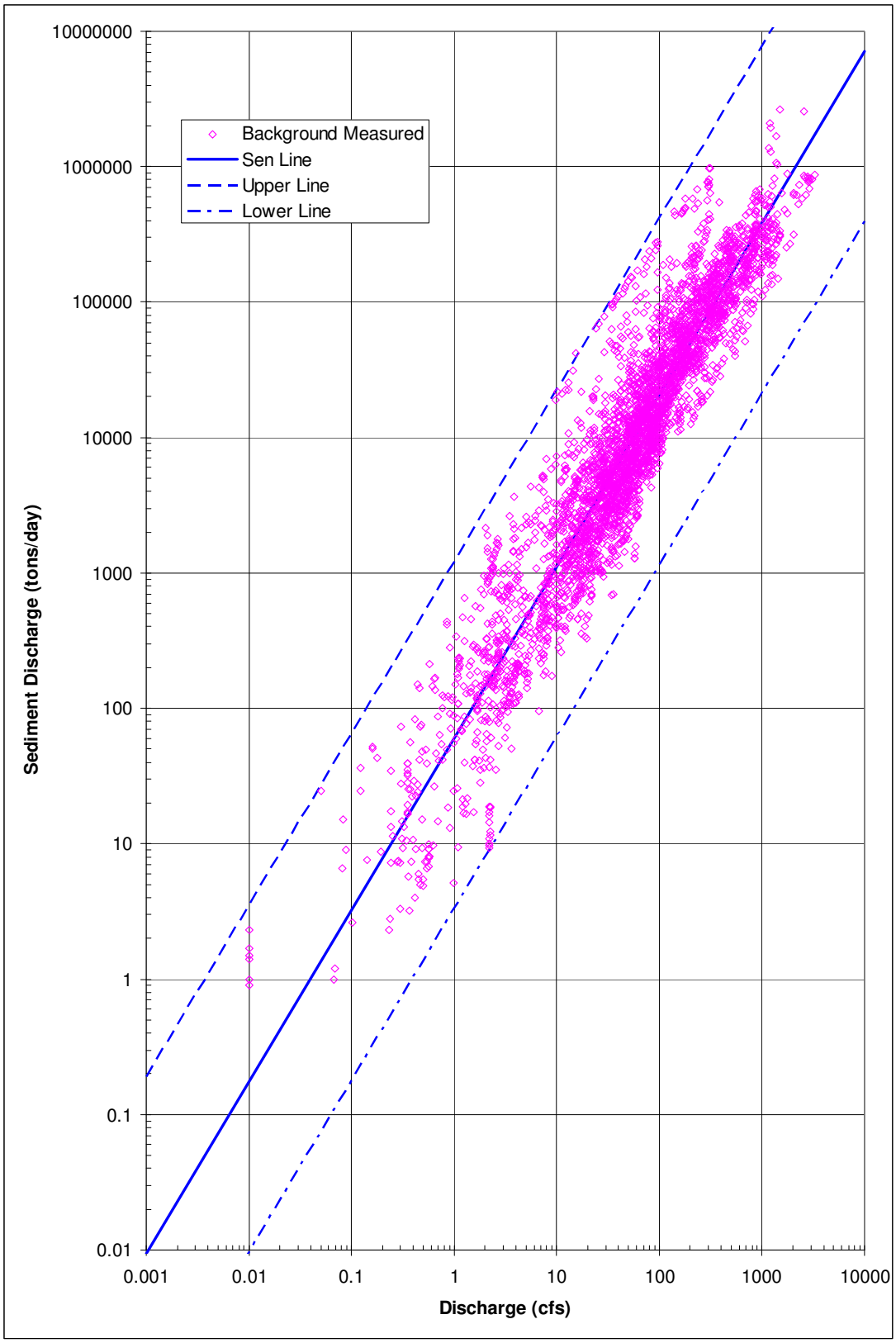


Figure 2.3. Background measured sediment and water discharge with Sen lines.

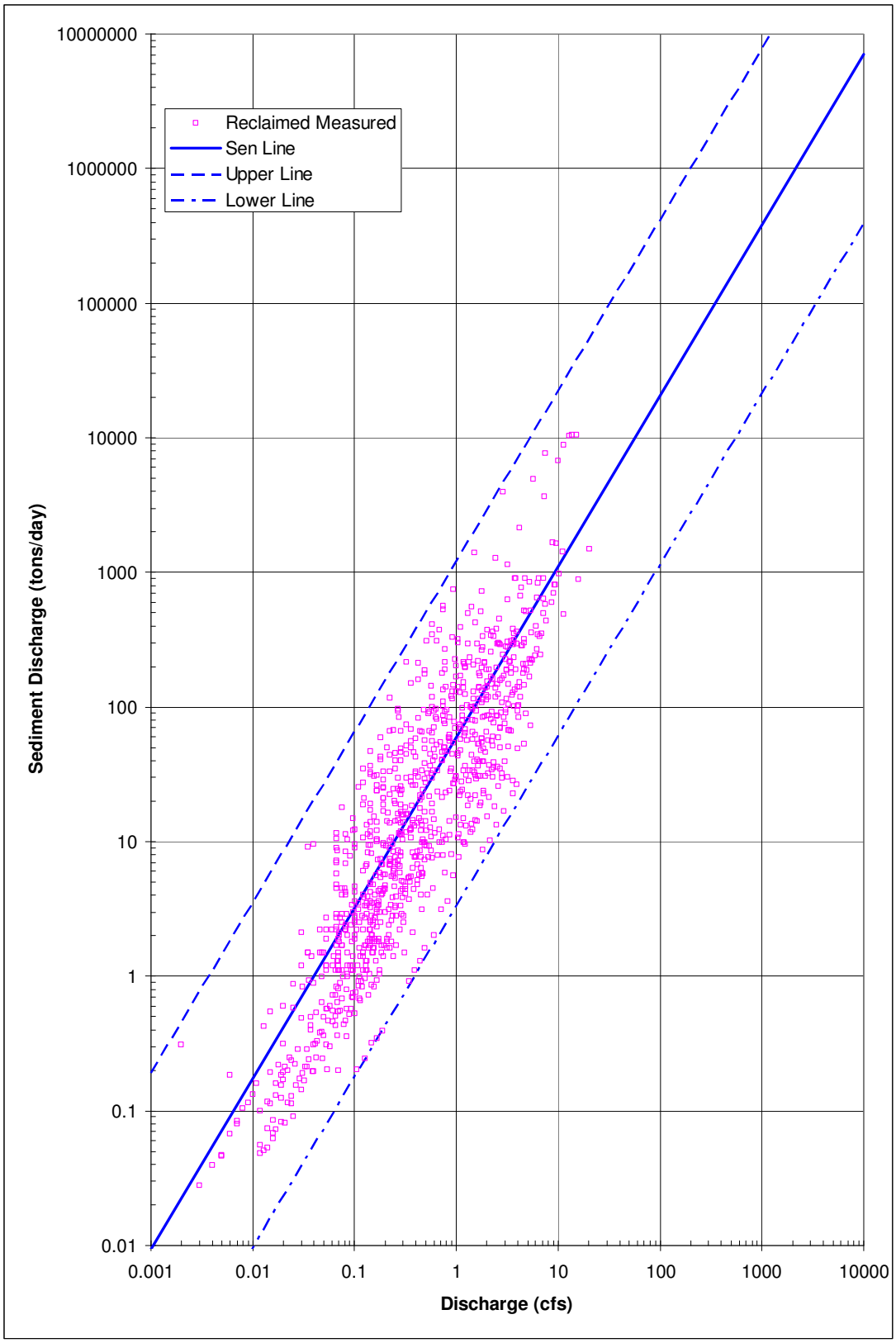


Figure 2.4. Reclaimed measured sediment and water discharge with Sen lines.

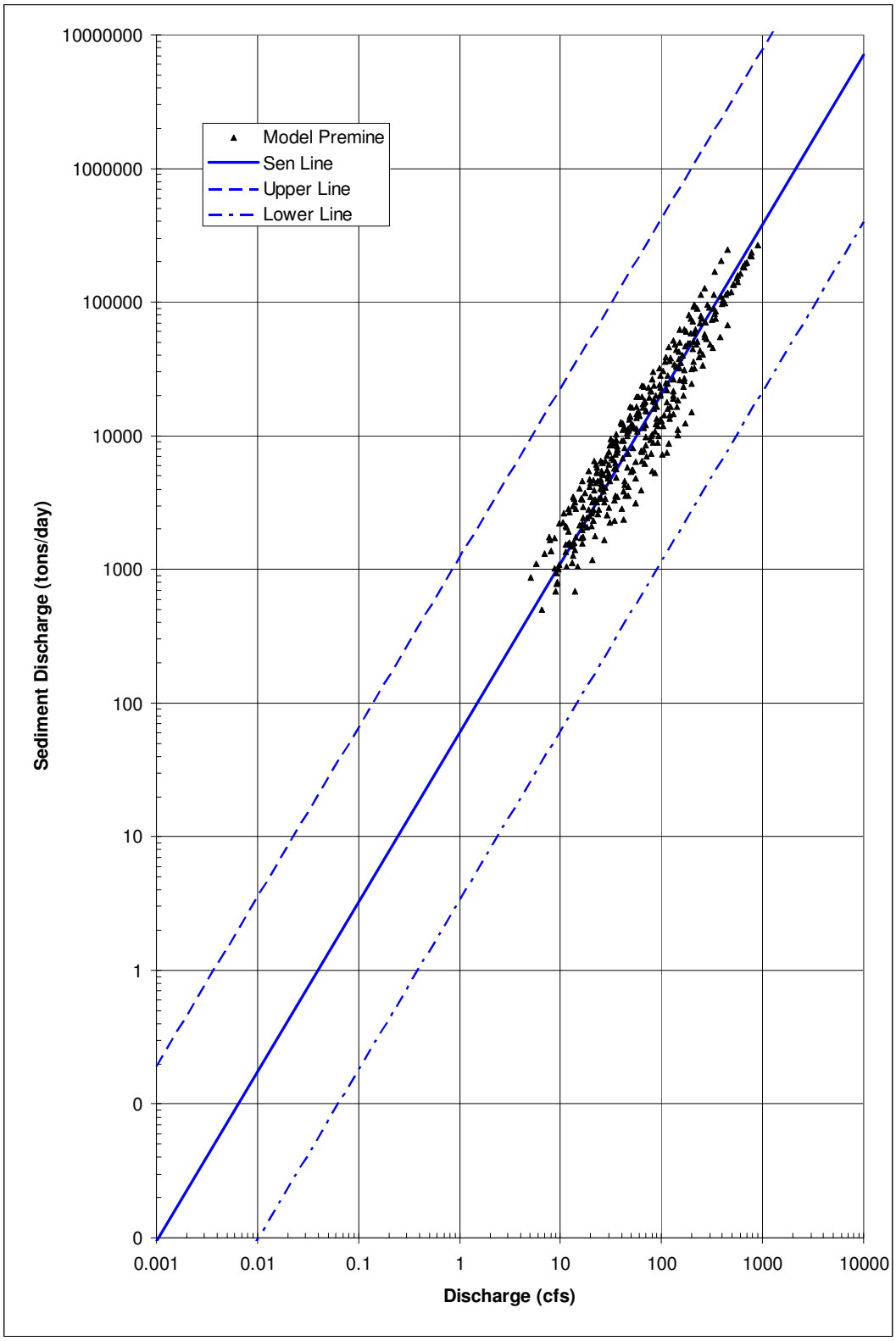


Figure 2.5. Modeled premine sediment and water discharge for the N6 WA with Sen lines.

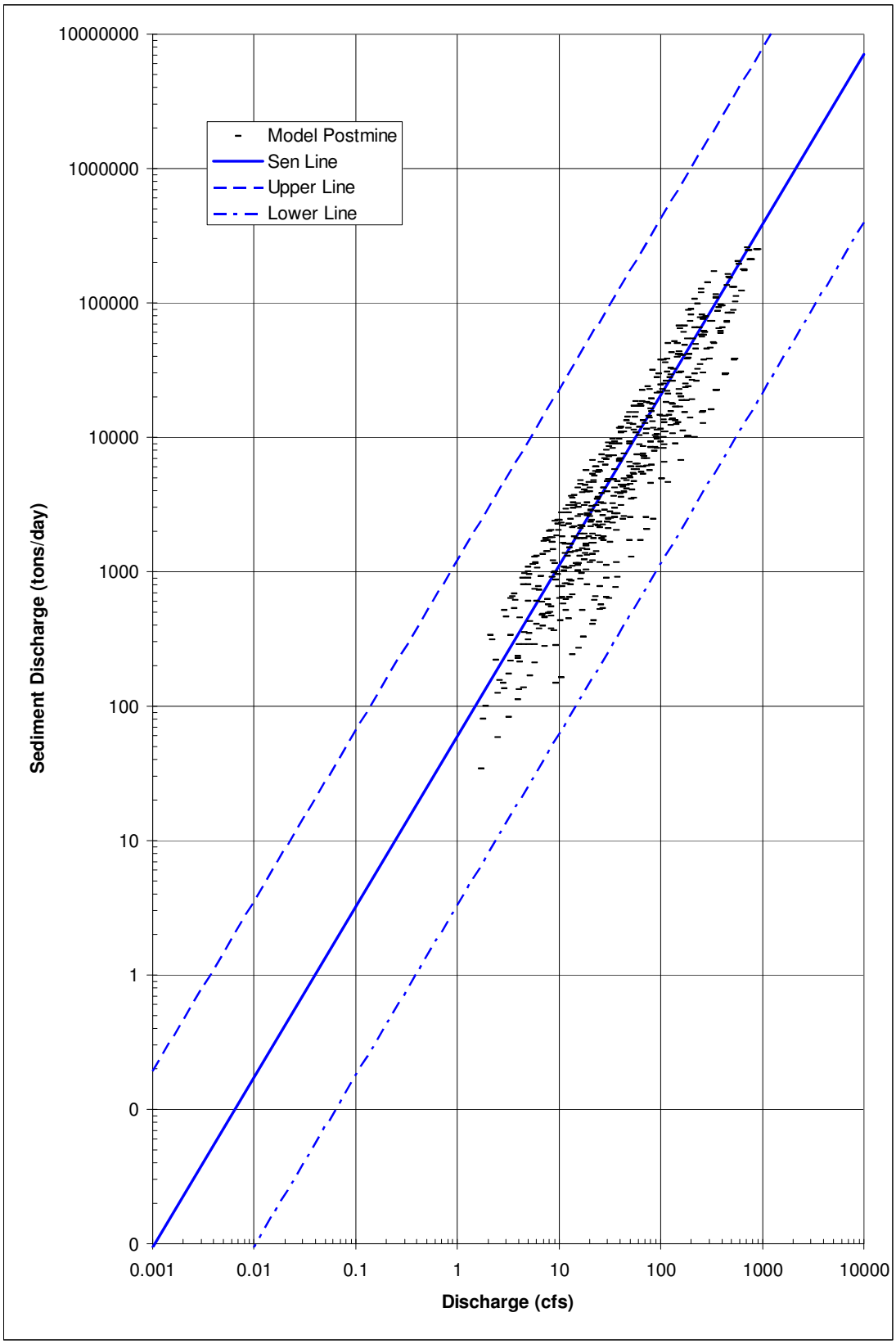


Figure 2.6. Modeled postmine sediment and water discharge for the N6 WA with Sen lines.

3. REFERENCES

Hjelmfelt, A.T., Kramer, L.A., and Spomer, R.G., 1986. Role of large events in average soil loss in Proceedings of the Fourth Federal Interagency Sedimentation Conference, March 24-27, 1986, Las Vegas, NV, p. 3-1 to 3-9.

Lagasse, P.F., Schall, J.D., and Peterson, M.R., 1985. Erosion Risk Analysis for a Southwestern Arroyo, Journal of Urban Planning and Management, American Society of Civil Engineers, v. III, no. I, November, 1985, Paper No. 20165.

Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973. "NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States," Volume VIII - Arizona, National Oceanic and Atmospheric Administration.

Renard, K.G. and Simaton, J.R., 1975. "Thunderstorm Precipitation Effects on the Rainfall-Erosion Index of the Universal Soil Loss Equation" in Volume 5 of Hydrology and Water Resources in Arizona and the Southwest, American Water Resources Assn., Arizona Section Arizona Academy of Science, Hydrology Section, Proceedings of April 11-12 meeting, Tempe AZ, v. 47-55.

Resource Consultants & Engineers, Inc. (RCE), 1993. "Surface Water Modeling of Reclaimed Parcels at the Black Mesa Complex," prepared for Peabody Western Coal Co.

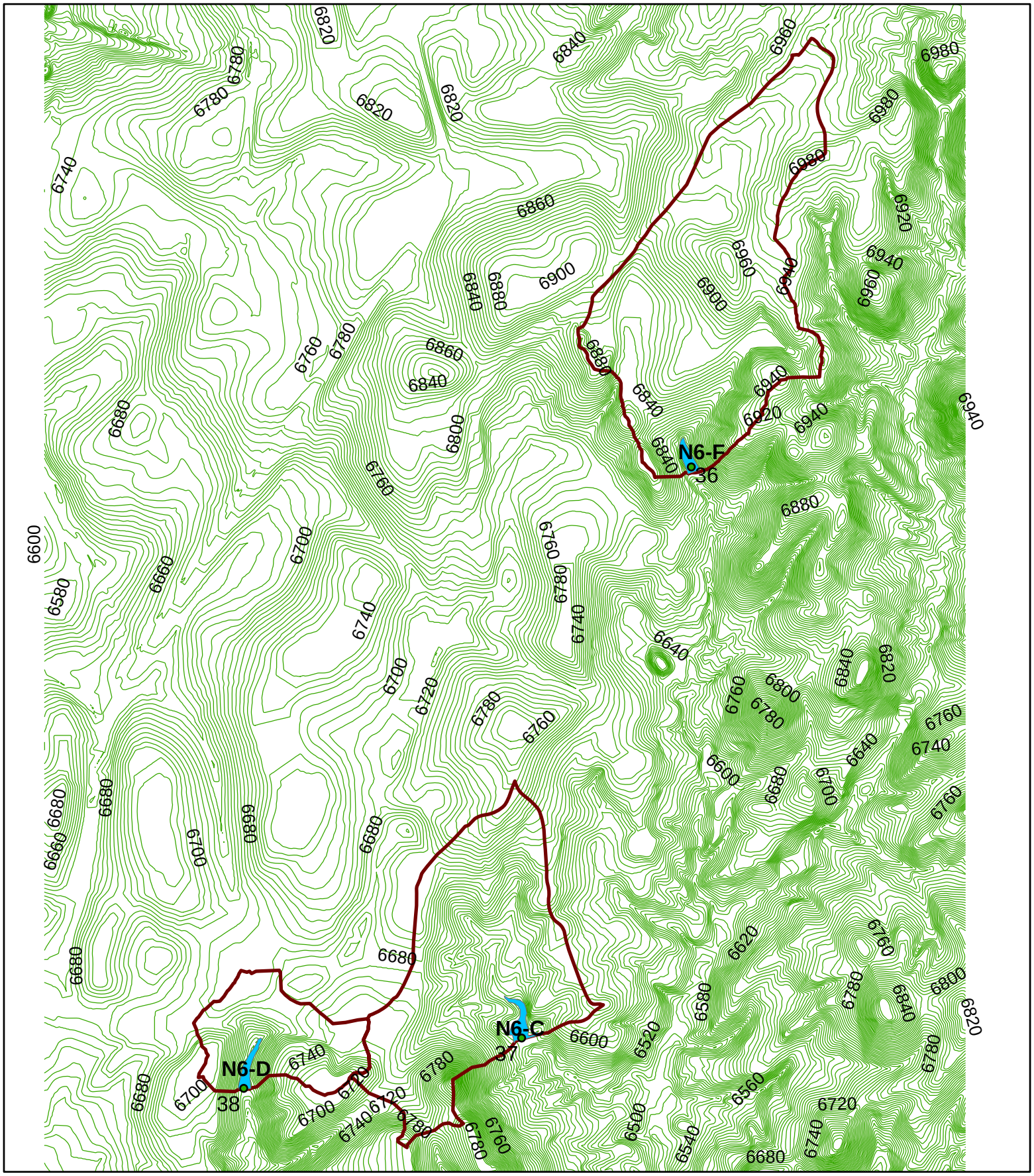
Sen, P.K., 1968. "Estimates of Regression Coefficient Based on Kendall's tau: Journal of American Statistical Association, v. 63, p. 1379-1389.

Smith, T. and Best, A., 2000. "Assessing Sedimentation and Protection of the Hydrologic Balance in Disturbed and Reclaimed Areas at the Black Mesa and Kayenta Mines, Arizona, Using Baseline Sediment Data Collected in Receiving Streams," presentation given at the Billings Mined Land Reclamation Symposium in 2001, Billings, MT.

Water Engineering & Technology, Inc. (WET), 1990. "Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control Technology at Surface Mines in the Semiarid West," prepared for Office of Surface Mining and the National Coal Association, Fort Collins, CO.

Zevenbergen, L.W., Peterson, M.R., and Watson, C.C., 1990. Computer simulation of watershed runoff and sedimentation processes, Proceedings of the Billings Symposium; Planning, Rehabilitation and Treatment of Disturbed Lands.

EXHIBIT 1
Postmine Topography



Legend

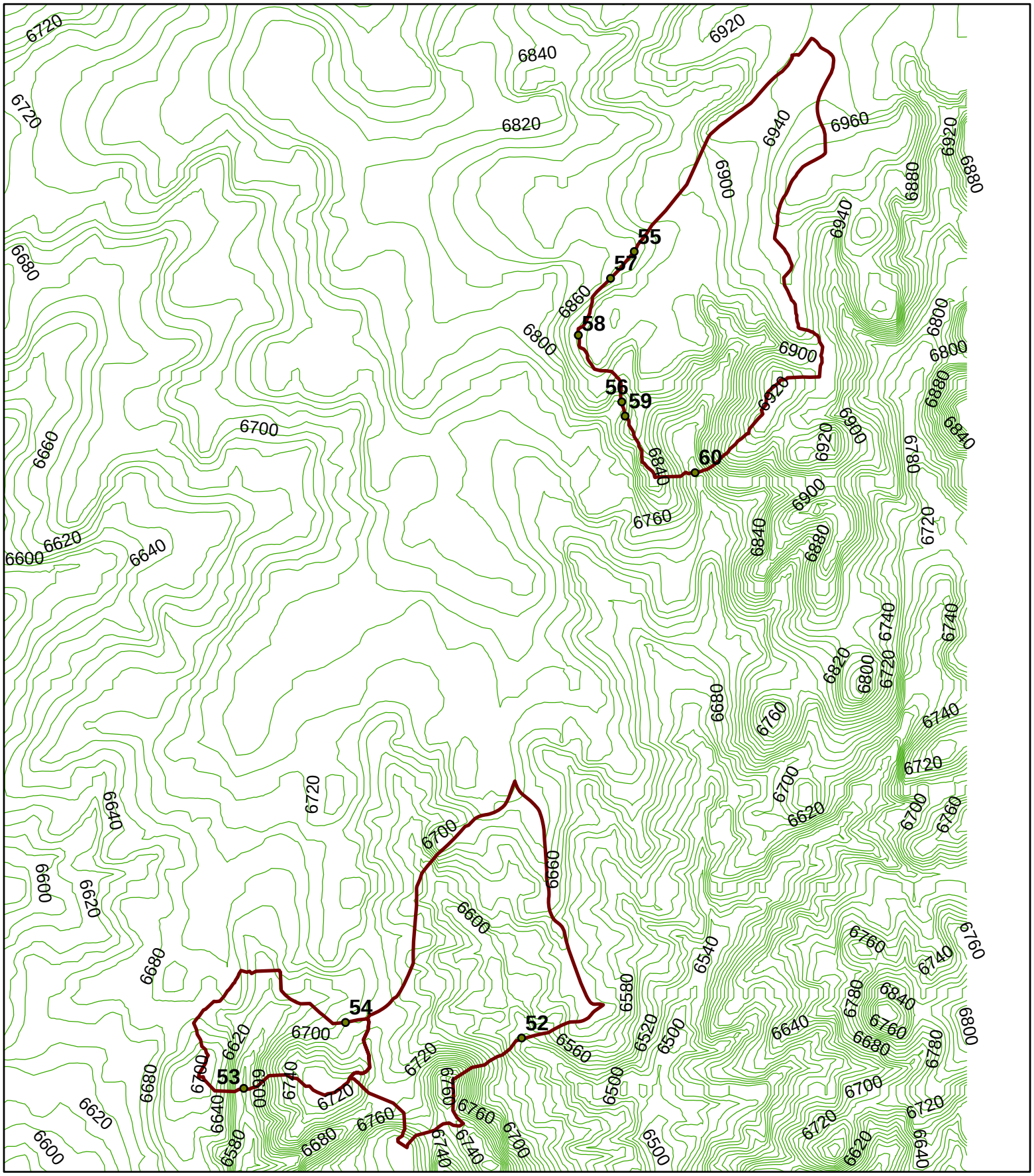
- End Points
- Ponds
- Modeling Area

N

0 750 1,500 3,000 4,500 Feet

Exhibit 1. Postmine Topography

EXHIBIT 2
Premine Topography



N

Legend

- End Points
- Modeling Area

0 750 1,500 3,000 4,500 Feet

Exhibit 2. Premine Topography

Appendix 3

Surface Water Modeling of the Reclaimed J21-D and J21-E Watershed Area at the Black Mesa Complex

SURFACE WATER MODELING OF THE RECLAIMED J21-D AND J21-E WATERSHED AREA AT KAYENTA MINE

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES

SURFACE WATER MODELING OF THE RECLAIMED J21-D AND J21-E WATERSHED AREA AT KAYENTA MINE

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES
P.O. Box 270460
Fort Collins, Colorado 80527
(970) 223-5556, FAX (970) 223-5578

Ayres Project No. 32-1304.00
PEAB-J21.DOC

August 2008

TABLE OF CONTENTS

1. Reclaimed Parcel Modeling 1.1

1.1 Introduction 1.1
1.2 Background 1.1
1.3 Data 1.2

1.3.1 Soils 1.2
1.3.2 Vegetation 1.2
1.3.3 Topography 1.3

1.4 Methodology 1.3

1.4.1 Synthetic Rainfall 1.8
1.4.2 Computation of Average Runoff and Sediment Yield 1.8

1.5 Results 1.8
1.6 Discussion 1.9

2. Comparisons with Measured Sediment Transport 2.1

3. References 3.1

Exhibit 1 – Postmine Topography ..... --
Exhibit 2 – Premine Topography ..... --

LIST OF FIGURES

Figure 1.1. Reclaimed area soils trilinear graph. 1.2

Figure 1.2. Spatial distribution of vegetative cover types for WA J21 premine condition 1.4

Figure 1.3. J21-D and J21-E postmine basins. 1.6

Figure 1.4. J21-D and J21-E premine basins..... 1.7

Figure 2.1. Observed and modeled sediment and water discharge. 2.2

Figure 2.2. Observed versus modeled sediment concentration and discharge. 2.3

Figure 2.3. Background measured sediment and water discharge with Sen lines..... 2.5

Figure 2.4. Reclaimed measured sediment and water discharge with Sen lines. 2.6

Figure 2.5. Modeled premine sediment and water discharge for the J21 WA with Sen lines... 2.7

Figure 2.6. Modeled postmine sediment and water discharge for the J21 WA with Sen lines. 2.8

LIST OF TABLES

Table 1.1. Soils Data. 1.3

Table 1.2. Cover Sampling Data. 1.5

Table 1.3. Cover Data for J21-D and J21-E Watersheds. 1.5

Table 1.4. Average Runoff and Sediment Yield Results. 1.8

Table 1.5. Average Physical Properties of the J21 WA. 1.9

1. RECLAIMED PARCEL MODELING

1.1 Introduction

The objective defined by PWCC for this project is to use a previously calibrated and validated runoff and erosion model (EASI, Zevenbergen et al. 1990; WET 1990) for the Black Mesa and Kayenta Mines to predict mean annual runoff and sediment yields from the reclaimed J21-D and J21-E watersheds. This objective included computation of runoff and sediment yields under premine conditions for the same area. All soils and rainfall input to the model are to be taken from models calibrated in the previous study (RCE 1993). The input variables that were calibrated to the mine areas and used in this study include soil infiltration parameters, erodibility parameters, and the grain size distribution. Parameters that are specific to this study are vegetative canopy and ground cover percentages from data collected on site.

The model calibration was conducted in a previous study (RCE 1993) using data obtained from instrumented watersheds and small hillslope plots collected under natural rainfall conditions. For a detailed discussion of data collection and model calibration, please refer to the previous study (RCE 1993).

1.2 Background

The J21-D and J21-E Watershed Area (WA) that is the focus of this project was reclaimed in 2002. The fundamental purpose of this study was to quantify the expected behavior and hydrologic response of the reclaimed areas above each pond relative to the conditions that existed prior to the occurrence of mining activities.

Runoff and sediment yield response from the reclaimed lands should be managed by implementing Best Management Practices (BMP's) in conjunction with an OSM approved sediment control plan in order to not adversely impact the prevailing hydrologic balance and to limit additional contributions of suspended sediment to streamflow or runoff outside the mine permit areas. BMP's include regrading, replacing salvaged topsoil, revegetation, and other controls such as riprapped channel bottoms, check dams, and where practicable, contour terraces. The natural watersheds on the mesa contribute significant quantities of sediment to the channel system. It is expected that the postmine condition will also produce comparable amounts of sediment without adverse impact on the hydrologic balance.

This section describes the data and procedures used to evaluate the J21 WA. This area was modeled to determine the average annual hydrologic response following the completion of reclamation activities taking into account BMP's implemented as part of the reclamation process. Infiltration, runoff, and erosion processes from both hillslopes and channels within the J21 WA were modeled using EASI. Results were determined for concentration points at the outlets of the reclaimed watersheds, which correspond to the embankments associated with Ponds J21-D and J21-E. The locations of these points are shown in **Exhibit 1**. Modeling was also conducted to determine hydrologic response under premine conditions based on the topography, soils, cover, and other conditions that typified the undisturbed watersheds draining to each concentration point. **Exhibit 2** shows the modeling endpoints for the premine J21 WA.

1.3 Data

1.3.1 Soils

Soils data used for the current study (J21 WA) were based on data developed from the calibration of models used in the previous study for Coal Resource Areas (CRAs) N1/N2 and J27 (RCE 1993). The composition of postmine soil in the current study is depicted along with the composition of postmine soils from the previous study in **Figure 1.1**. This figure shows that the soil composition of WA J21 is very similar to soils evaluated during model calibration. Therefore, the soil properties developed in the previous study are valid for this modeling project. These properties include calibrated parameters, such as infiltration and erodibility coefficients, and measured soil size distributions. **Table 1.1** lists the premine and postmine soils data used during EASI modeling of WA J21.

1.3.2 Vegetation

Vegetative cover data representative of both pre- and postmine conditions in WA J21 were supplied by PWCC. For the premine condition, land was characterized as being covered by sagebrush or pinon juniper. The spatial distribution of vegetative cover for the J21 WA premine condition appears in **Figure 1.2**. Average cover properties for CRAs N1/N2 and J27 of the previous study and WA J21 of the current study appear in **Table 1.2**. For the postmine condition, the reclaimed area was assigned the postmine cover type and the unmined area was assigned the same cover type as the premine condition. **Table 1.3** lists the pre- and postmine vegetative cover data used in the EASI model runs generated for the J21 WA. Note that if a unit contained significant portions of both sagebrush and pinon juniper cover types, it was classified as half pinon juniper and half sagebrush.

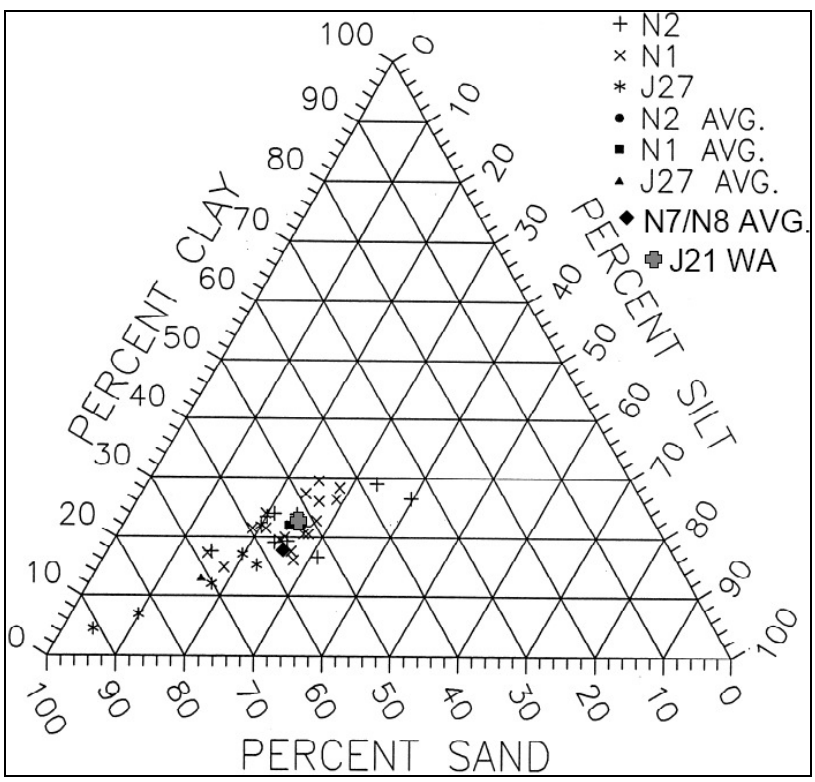


Figure 1.1. Reclaimed area soils trilinear graph.

Table 1.1. Soils Data.			
Condition	Premine	Postmine	Rock Chutes
Rainfall detachment	0.005	0.005	0
Overland flow detachment	0.44	0.44	0
Channel flow detachment	0.5	0.5	0
Initial soil moisture, %	70	70	70
Final soil moisture, %	90	90	90
Soil porosity, %	45	45	46
Temperature, *F	70	70	70
Hydraulic conductivity, in/hr	0.23	0.29	0.3
Capillary suction, in	3.7	2.6	2.6
	Particle Size Distribution (all conditions)		
	Size, mm	% Finer	
	0.001	0	
	0.004	18.0	
	0.016	27.4	
	0.062	36.6	
	0.125	56.2	
	0.250	64.3	
	0.500	72.4	
	1.000	80.5	
	2.000	88.6	
	4.000	92.4	
	16.000	100	

1.3.3 Topography

Pre- and postmine topography was supplied by PWCC in the form of ArcGIS geodatabase. Basin delineations, hillslope delineations, subwatershed delineations, as well as areas, slopes, and lengths of all units of the study area were defined and calculated using ArcGIS software. **Figures 1.3 and 1.4** show the watershed delineation and numbers assigned to the basins used in the EASI model for the post- and premine conditions, respectively. Channel dimensions input to EASI were based on the topography supplied and limited field observations.

1.4 Methodology

Runoff and sediment yield in the semiarid western United States is largely governed by the occurrence of high-intensity, short-duration rainstorms of limited areal extent (Renard and Simaton 1975). Research has indicated that relatively few events may produce the greatest erosion (e.g., Hjelmfelt et al. 1986 reported that only 3 to 4% of rainfall events accounted for 50% of long-term sediment yields). Although there is perhaps a relatively limited physical basis for definition of an "average annual" runoff or sediment yield in a semiarid environment due to the extreme variability in response and importance of single infrequent events, such a term does provide a useful basis for long-term comparison between reclaimed and undisturbed conditions.

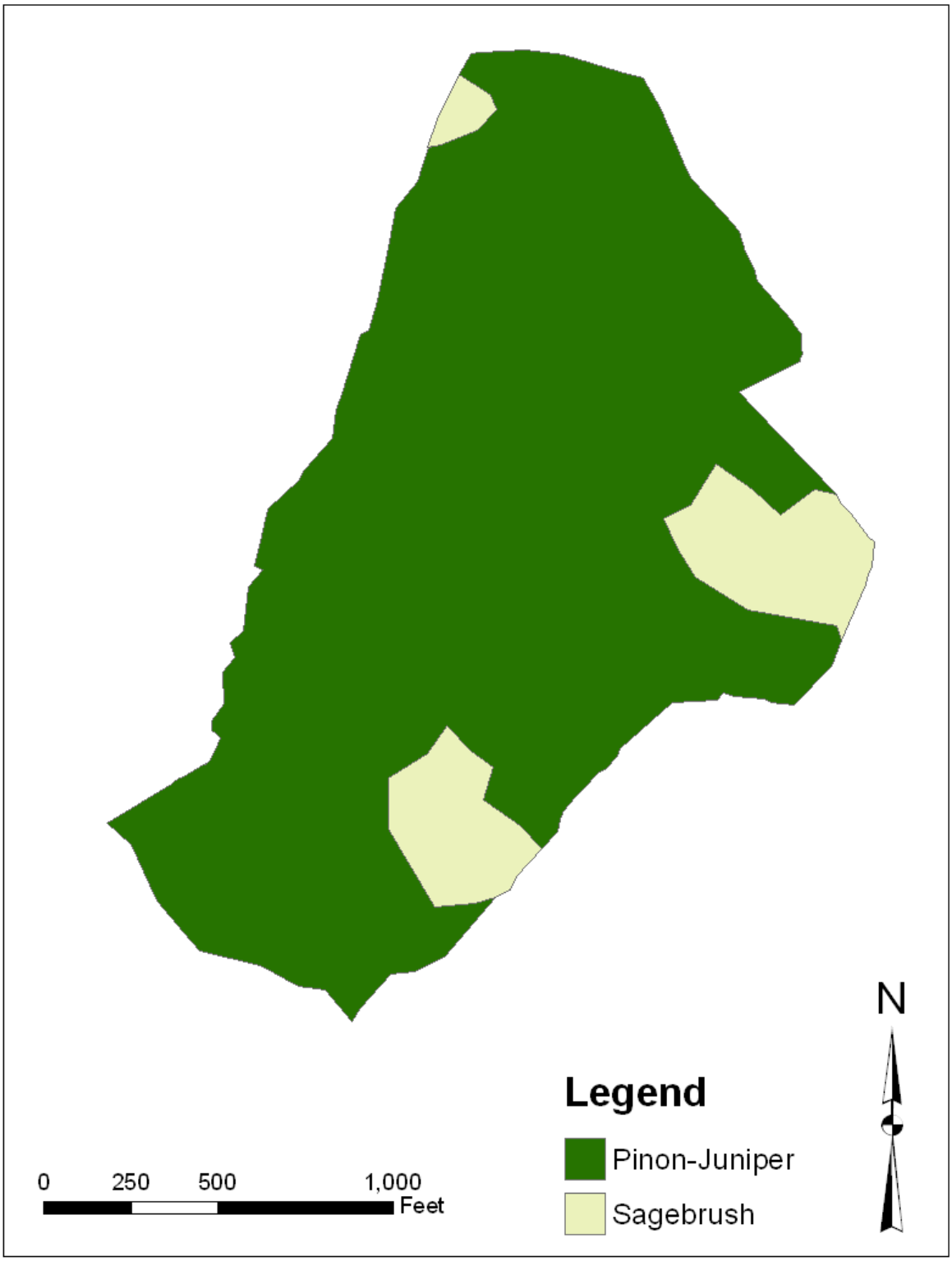


Figure 1.2. Spatial distribution of vegetative cover types for WA J21 premine condition.

Table 1.2. Cover Sampling Data.								
Area	Condition	Cover Type	Nonstratified Vegetation Cover (%)	Vegetation Canopy Cover (%)	Vegetation Ground Cover (%)	Litter* (%)	Rock (%)	Total Ground Cover (%)
N1/N2	Postmine	Postmine	25.6	1.4	24.2	13.6	4.2	41.9
J21 WA	Postmine	Postmine		0.3	33.2	19.1	13.4	65.6
N1/N2/J27	Premine	Pinon Juniper	32.7	31.1	3.0	44.0	19.7	66.7
J21 WA	Premine	Pinon Juniper		16.8	3.9	28.8	16.7	49.3
N1/N2	Premine	Sagebrush	25.1	16.0	10.3	25.3	18.1	53.7
J27	Premine	Sagebrush	30.6	9.7	22.0	24.0	1.6	47.6
J21 WA	Premine	Sagebrush		1.7	15.5	30.6	1.7	47.8
*Including standing dead litter								

Table 1.3. Cover Data for J21-D and J21-E Watersheds.				
Condition	Pinon Juniper	Sagebrush	Half Pinon Juniper-Half Sagebrush	Postmine
Canopy cover, %	16.8	1.7	9.3	0.3
Ground cover, %	49.3	47.8	48.5	65.6
Canopy storage, in	0.05	0.05	0.05	0.05
Ground storage, in	0.05	0.05	0.05	0.05
Depression storage, in	0.03	0.03	0.03	0.03
Impervious area, %	0	0	0	0
Manning n	0.07	0.07	0.07	0.05

To make comparisons between reclaimed lands and associated undisturbed lands at the Black Mesa Mining Complex on the basis of average annual sediment yield, a procedure was used that considers the importance of infrequent storm events in defining sediment yield in the semiarid west. First, however, the site-specific rainfall data available for the Black Mesa Mining Complex were used to evaluate the frequency and magnitude of the measured events relative to existing predictions for rainfall depth-duration (Miller et al. 1973). The analysis of the rainfall data was performed as part of a previous study of the N1/N2 and J27 CRAs (Resource Consultants and Engineers 1993).

Comparisons between runoff and sediment yield from undisturbed and reclaimed areas in WA J21 were developed for specific modeling endpoints shown in Exhibits 1 and 2. Mining and reclamation activities did not exactly replicate the topography, drainage network, or drainage areas that existed prior to mining. Consequently, direct comparisons of total runoff and sediment yield cannot be made between undisturbed and reclaimed response at a given point in a watershed. Comparisons were made on the basis of unit rates of runoff (inches) and sediment yield (tons/acre) at the various modeling computation endpoints. Although the same disturbance boundary was used to model extents for both pre- and postmine conditions, the topographic differences that resulted after mining and reclamation occurred in the J21 WA dictated that some small areas would be included or excluded from the modeling. The total area modeled (combined area for both J21-D and J21-E watersheds) for premine conditions is 71.6 acres and for postmine conditions is 68.9 acres. The difference in area results from the sediment ponds in postmine conditions. The area bounded by the modeling boundary identified by PWCC as shown in Exhibits 1 and 2 is 71.6 acres.

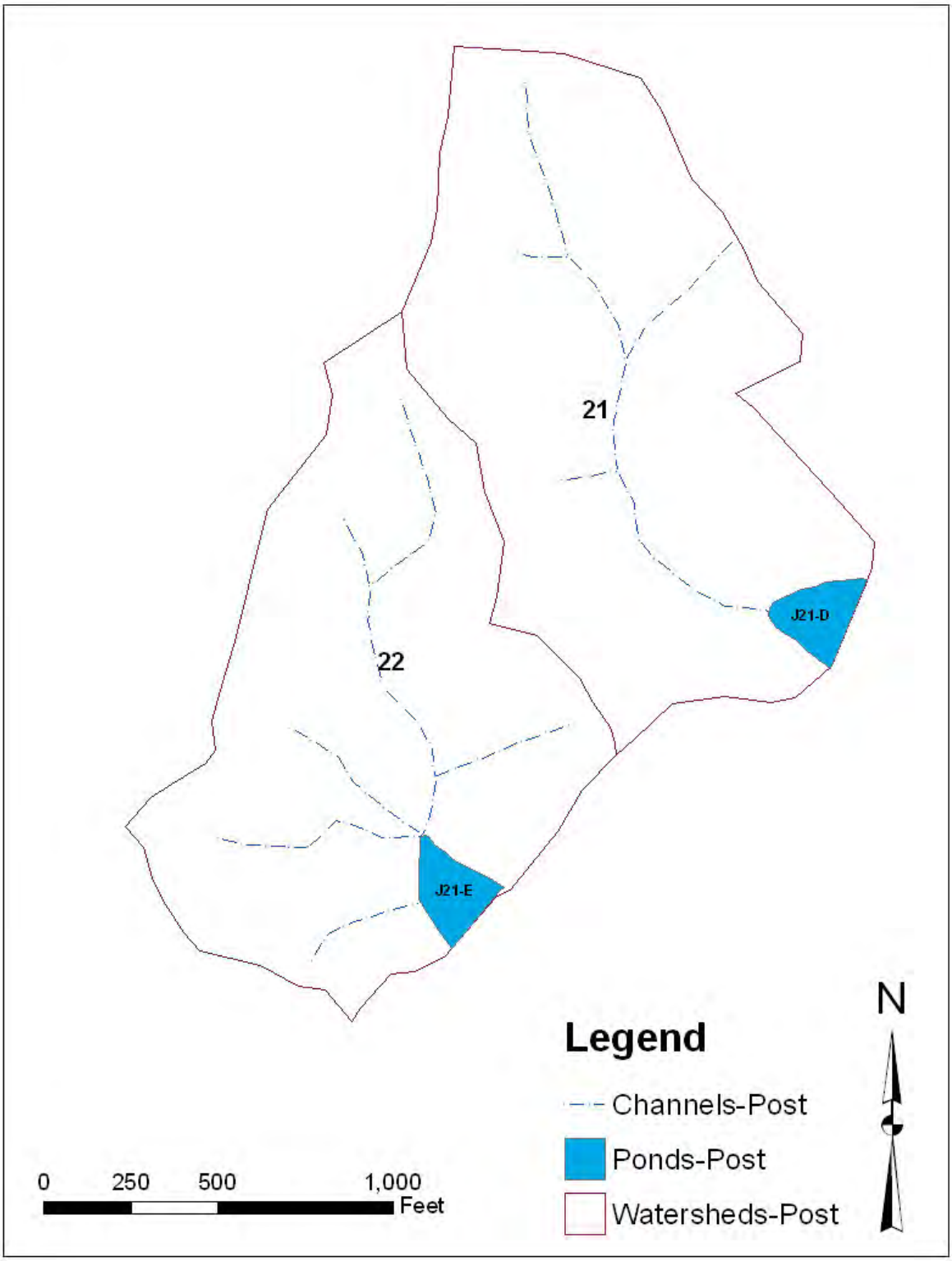


Figure 1.3. J21-D and J21-E postmine basins.

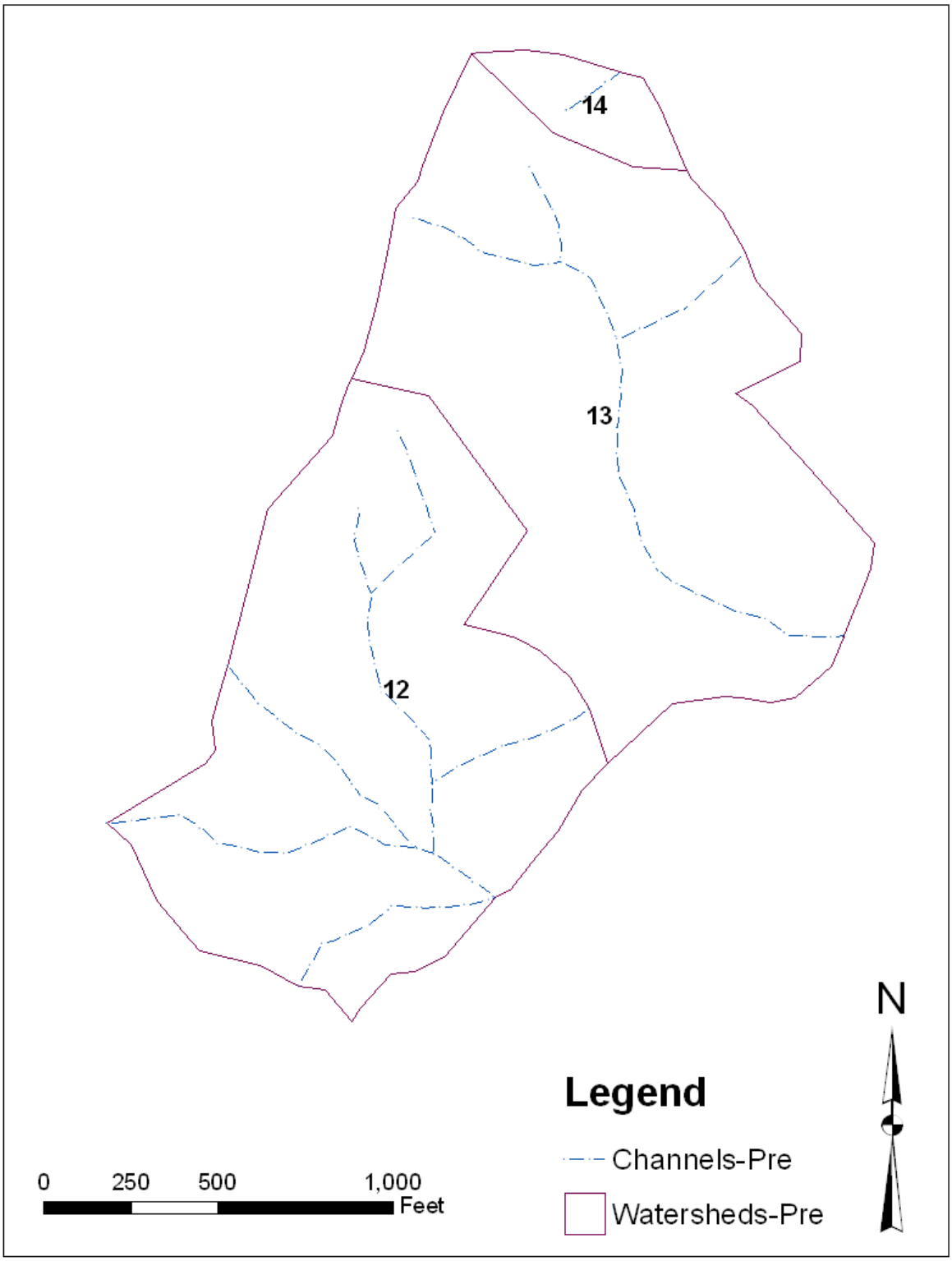


Figure 1.4. J21-D and J21-E premine basins.

1.4.1 Synthetic Rainfall

Synthetic storms of 2-, 5-, 10-, 25-, 50-, and 100-year return periods were used as input to the EASI model. Actual hyetographs were taken from the previous study (RCE 1993) and are based on both local data collection and the NOAA Atlas (Miller et al. 1973).

1.4.2 Computation of Average Runoff and Sediment Yield

The EASI model was used to evaluate runoff and sediment yield from a series of storm events having recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100 years. To define average annual conditions, the average annual runoff and sediment yield generated from storm events were computed using the commonly used equation of Lagasse et al. (1985).

1.5 Results

Figures 1.3 and 1.4 show the post- and premine basin delineations. Since the individual subareas differ in number, acreage and outlet locations, a direct comparison is not possible on a subarea basis. Therefore, the best way to compare the results is on an average basis for the WA. **Table 1.4** shows pre- and postmine drainage area, runoff, and sediment yield for the J21 WA. To consider the situation of pond removal for the postmine condition, the EASI model replaces a sediment pond with a channel, which lies near the location of the pond and discharges to the basin outlet. The channel is assumed to have a length equal to the pond's length and a slope similar to the outlet's natural slope. Runoff is defined as the total volume of water leaving the WA on an average annual basis and, therefore, does not include water stored in depression areas and ponds. For the premine condition, this is equal to the amount of water that drains off the hillslopes and subwatersheds because there are no ponds or significant depressions. For the postmine condition, this is equal to the amount of hillslope runoff less the amount stored in ponds. No ponds or significant depressions exist within the reclaimed J21 WA that was modeled. Similarly, the sediment yield is the amount of eroded material that leaves the WA on an average annual basis computed using the equation of Lagasse et al. (1985). The sediment yield is the production from the hillslope areas and erosion from the channels. The amount of erosion is the sediment yield from the hillslopes and subwatersheds only and does not include channel erosion, channel deposition or sediment trapped in ponds. Sediment yield can be greater or less than erosion, depending on the amount of channel erosion and the capacity of the channel network to convey sediment off the leasehold.

Table 1.4. Average Runoff and Sediment Yield Results.

Area	Condition	Drainage Area (ac)	Runoff (in)	Sediment Yield (t/ac/yr)
J21 WA	Premine	71.6	0.42	4.50
J21 WA	Postmine	68.9	0.42	4.12
J21-D	Premine	39.4	0.42	4.28
J21-D	Postmine	36.7	0.42	4.14
J21-E	Premine	32.2	0.42	4.77
J21-E	Postmine	32.2	0.42	4.10

For the postmine condition, the overall sediment yield is less than those in the premine condition. Sediment yield is slightly different from the premine amount, and runoff is the same as the premine amount. Only a small portion of J21 WA was disturbed, thus sediment yields for pre- and postmine conditions are close.

Table 1.4 also shows pre- and postmine drainage area, runoff, and sediment yield for two individual watersheds (J21-D and J21-E) within the J21 WA. Modeling results of individual watersheds are similar to the overall J21 WA.

1.6 Discussion

Table 1.5 gives an overview of the geometric properties of the pre- and postmine disturbed areas. Average properties for hillslopes and channels are similar because only a small portion of J21 WA was disturbed.

Table 1.5. Average Physical Properties of the J21 WA.

	Premine	Postmine
Total Area (ac)	71.6	68.9
Total Channel Length (ft)	7153	7066
Mean Channel Slope	0.1085	0.1200
Drainage Density (mi/mi^2)	12.1	12.4
Mean Hillslope Length (ft)	171	186
Mean Hillslope Gradient	0.1662	0.1703

2. COMPARISONS WITH MEASURED SEDIMENT TRANSPORT

As discussed in Section 1, PWCC has monitored flow and sediment on the main channels, principal tributaries and small watersheds within the leasehold. These data, along with the runoff plots, were used to calibrate the EASI model soil erodibility and infiltration input variables. **Figures 2.1** and **2.2** show sediment transport and sediment concentration versus discharge for measured unmined (background), measured reclaimed, WA J21's modeled unmined (premine) and modeled reclaimed (postmine) data. Although there is significant scatter shown in the data (as is expected with any sediment transport conditions), there are several conclusions that can be drawn from this data.

The open symbols in both figures depict measured data and whether the data were collected from reclaimed areas (the small watershed study) or from unmined or background surface water monitoring stations. The range of flows is generally greater for the background data but there is significant overlap between the two data sets between 0.1 and 100 cfs. This is because the reclaimed data are from small watersheds and the unmined data are from channels draining larger basins. These data show the same trend for sediment transport and sediment concentration over the entire range of flows and very close agreement in the area of discharge overlap. This, in itself, is strong evidence that (1) the sediment yields are channel transport capacity limited, (2) overlap of model predictions for both pre- and postmine conditions with measured data strongly indicate that EASI model predictions are representative and reasonable, and (3) sediment yields from reclaimed areas will not be additive to yields on the receiving streams.

The closed symbols depict data from WA J21's pre- and postmine EASI model runs. They represent data generated by EASI for both subwatersheds and channels for peak discharges resulting from 2-, 5-, 10-, 25-, 50-, and 100-year storms. Using the peak flows from extreme events results in discharges that generally exceed 10 cfs. The trend of the model-derived data is similar and the ranges of concentration and sediment transport are similar to the measured data and between pre- and postmine conditions.

The sediment discharge plot (Figure 2.1) shows a stronger trend because it is plotting discharge (sediment) against discharge (flow). This is expected because the sediment discharge does depend on flow discharge. The concentration plot (Figure 2.2) shows the two separate variables and, therefore, a less significant trend. PWCC believes that data measurement may have some influence on the scatter (outliers were removed), but the process variability is probably the major influence. The majority of the data, however, fall in a group centered on 100 cfs and 100,000 mg/l, both in the observed data and in the model results. These plots support the use of the EASI model, the results of the modeling, the conclusion that sediment yields from reclaimed areas are not additive to receiving stream sediment loads, and that sediment impacts to the prevailing hydrologic balance have been minimized.

From Figures 2.1 and 2.2 it is apparent that sediment loads and concentrations are dependent on the channel sediment transport capacity for both pre- and postmine conditions. Channel sources of sediment in this arid environment are virtually unlimited. Therefore, channel transport capacity and channel derived sediment limits and governs sediment yields from the small tributaries, large channels and the WA as a whole. The similarity of sediment discharge (or concentration) between pre- and postmine conditions appears to be inconsistent with the lower rates of sediment yield shown in Table 1.4.

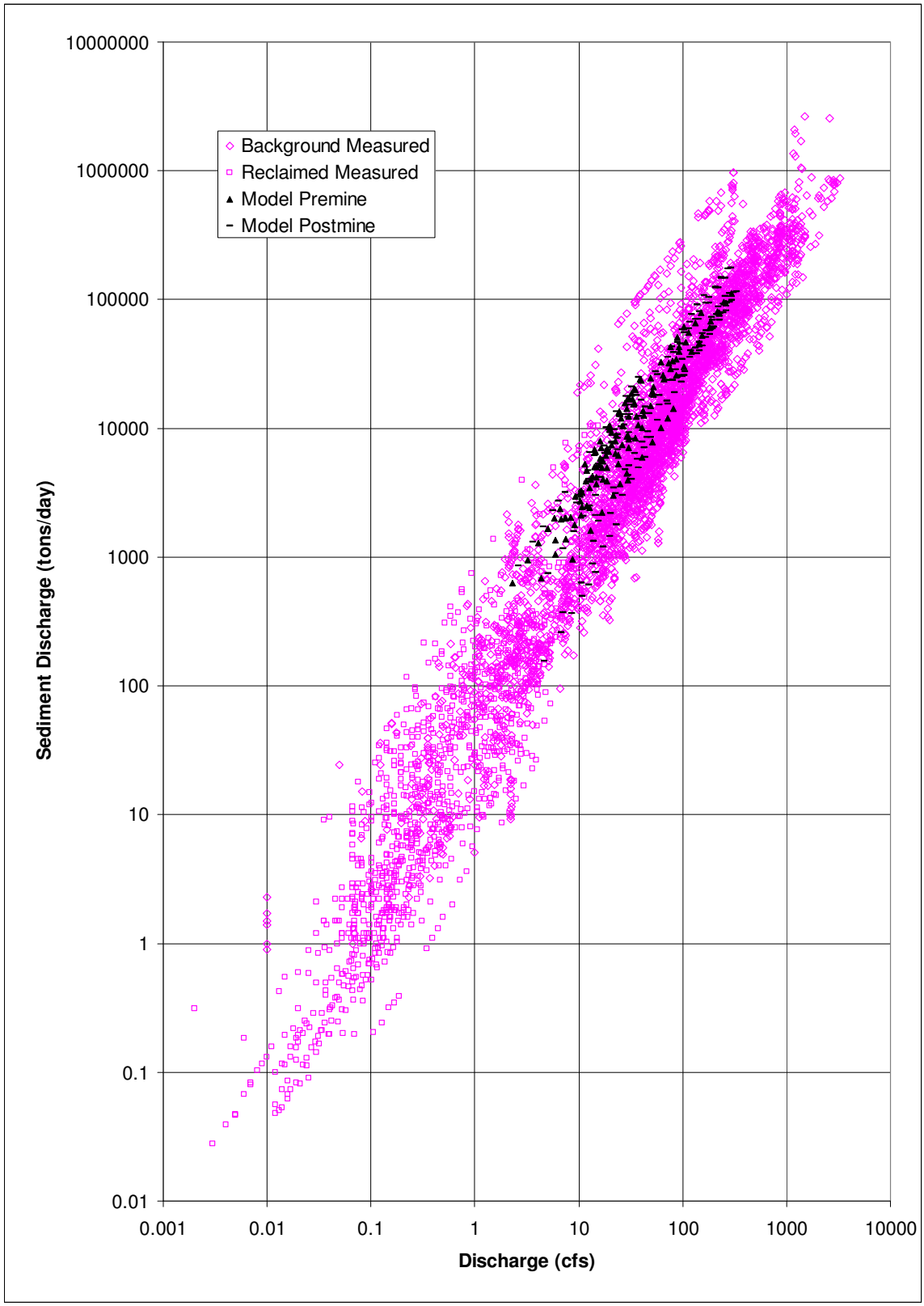


Figure 2.1. Observed and modeled sediment and water discharge.

Figure 2.2. Observed versus modeled sediment concentration and discharge.

However, the sediment yield shown in Table 1.4 is the average annual amount of sediment leaving the J21 WA whereas the sediment discharge shown in Figure 2.1 is the peak rate of sediment in transport occurring in any channel represented by the data, whether the channel is located upstream or downstream of a pond. Therefore, it should be concluded that with or without a pond left in the postmine landscape that traps sediment or stores water, the mine reclamation is not contributing additional sediment to the receiving streams and sediment impacts to the prevailing hydrologic balance have been minimized.

Smith and Best (2000) analyzed the measured data (background and reclaimed) shown in Figure 2.1 to develop an approach that can be used to determine if channels in reclaimed areas have similar sediment transport characteristics as background channels. The method that they used was to develop Sen lines (Sen 1968) and confidence intervals around the data. The slope of the Sen line is a non-parametric statistic computed as the median slope of all possible slopes determined from pairing all the data points. The Sen line is drawn through the median coordinate of the data. Smith and Best first showed that the large channel flume data (background) and the small watershed background data could be combined. They concluded that since the data from one data set fall within the Sen line bounds of the other data set then the two data sets are merely extensions of each other and could be combined. Also, because the main channel and background small watershed site data could be combined, it indicated there is an unlimited supply of sediment and the channels are conveying sediment at (or near) capacity. The Sen line and bounds are shown with the background measured data in **Figure 2.3**.

They then plotted the reclaimed measured data (**Figure 2.4**) with the Sen line and bounds from the background data to show that the reclaimed data have the same characteristics even though the flow range of the measurements is lower. The data indicate that channel flows in this environment achieve the sediment transport capacity of the channel, whether in reclaimed or background conditions.

Using the same approach with the modeled data generated for the J21 WA, **Figures 2.5 and 2.6** show the pre- and postmine computed sediment transport rates with the Sen lines and bounds. One difference between the plots is that the measured data occur throughout the flow hydrograph whereas the modeled data are tabulated at the peak of the simulation flow hydrograph. The premine data plot (Figure 2.5) shows the data grouped above the Sen line and well within the bounds. The postmine data (Figure 2.6) plot most densely above the Sen line and are more scattered. On these graphs data plotting above the Sen line indicate that there is more sediment in transport for a given discharge.

Several conclusions can be drawn from these data plots: (1) EASI model well replicates erosion and sediment transport processes at the mine site for background and reclaimed conditions, (2) all data show similar trends and are within the same bounds, (3) data trends indicate that channels are transporting sediment at or near capacity, and (4) amounts of sediment leaving the WA for postmine conditions are similar to premine conditions and within the range expected for the background conditions. Therefore, the overall conclusion is that the postmine reclaimed condition in J21 WA is not contributing additional suspended solids to receiving streams, and related impacts to the hydrologic balance have been minimized.

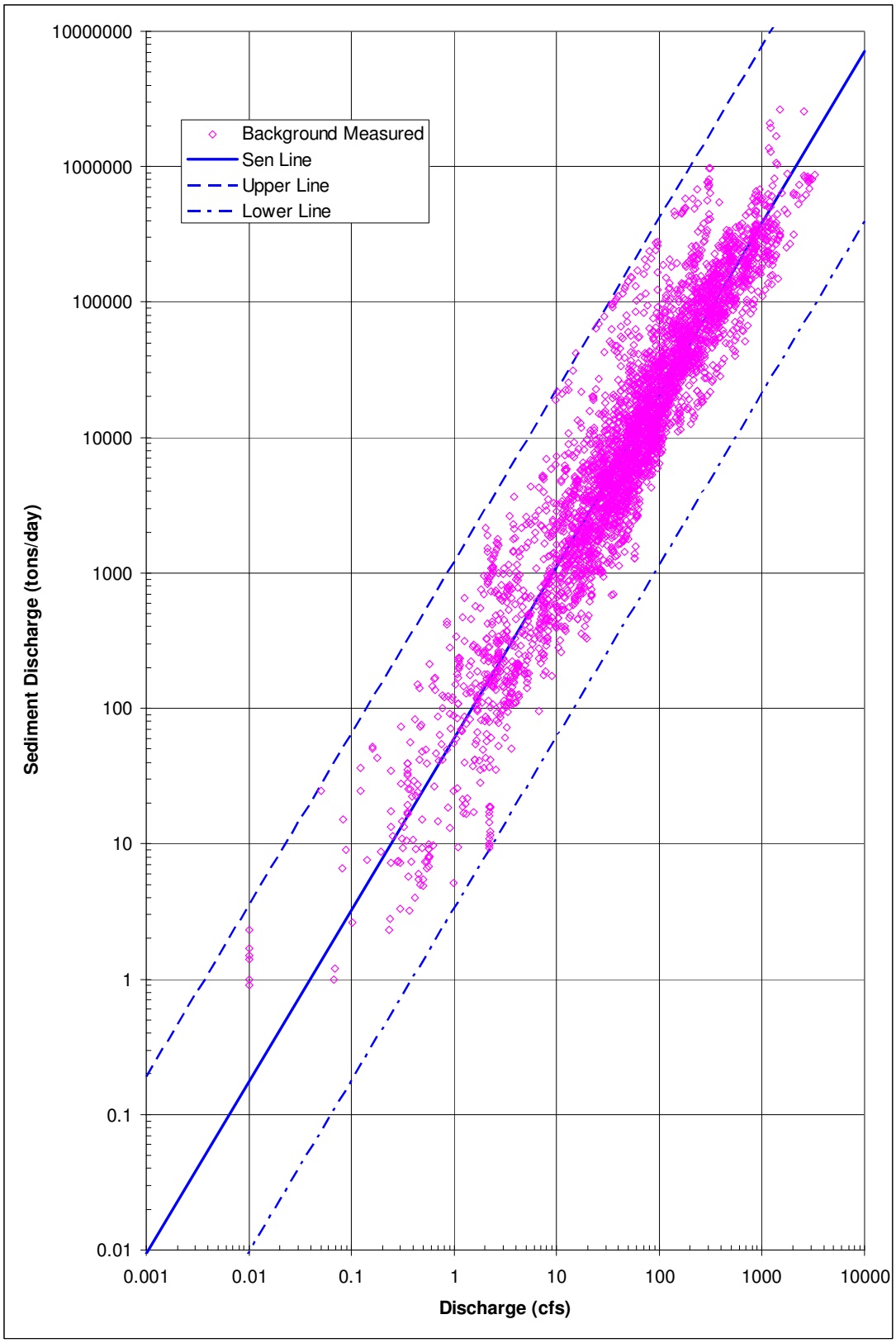


Figure 2.3. Background measured sediment and water discharge with Sen lines.

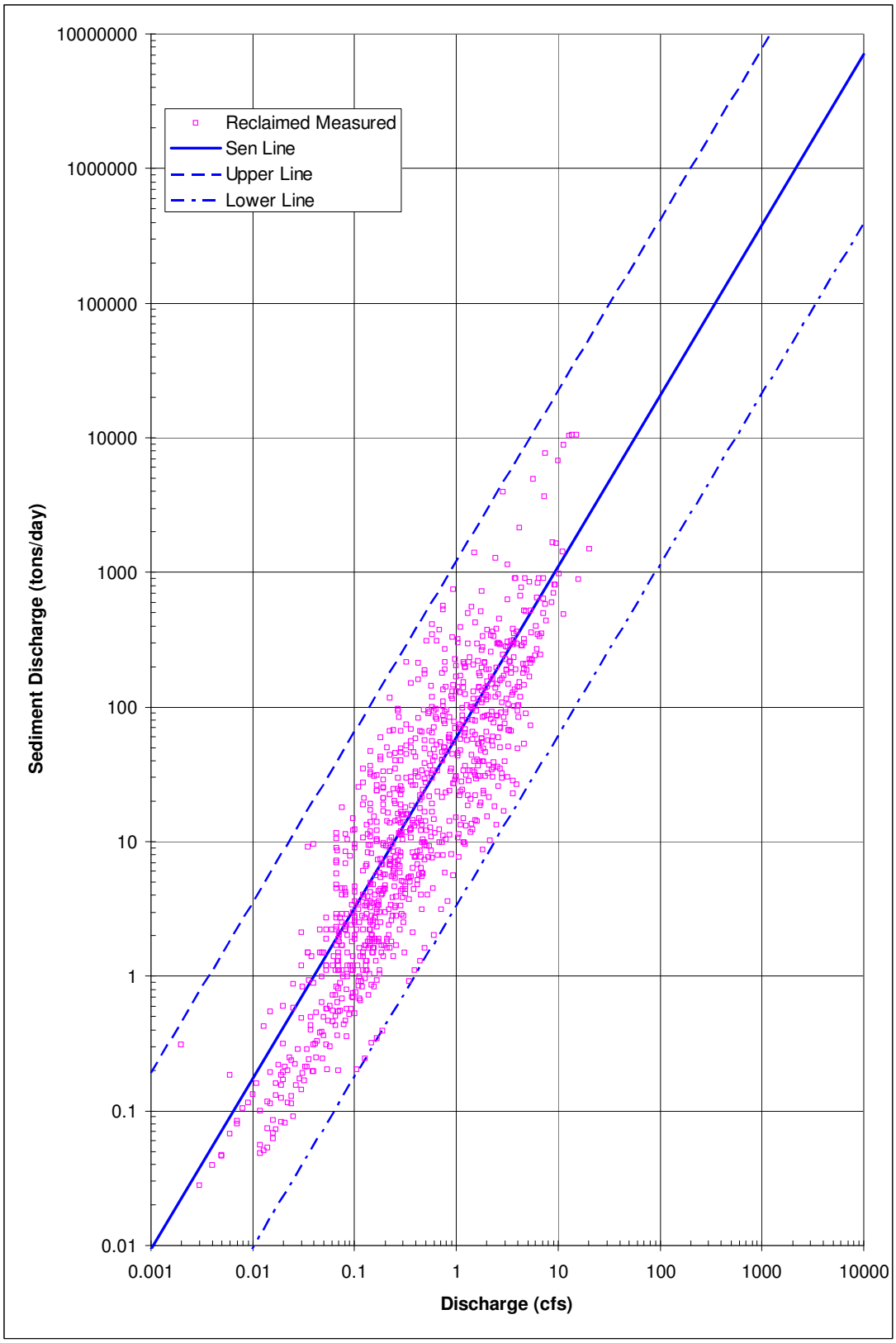


Figure 2.4. Reclaimed measured sediment and water discharge with Sen lines.

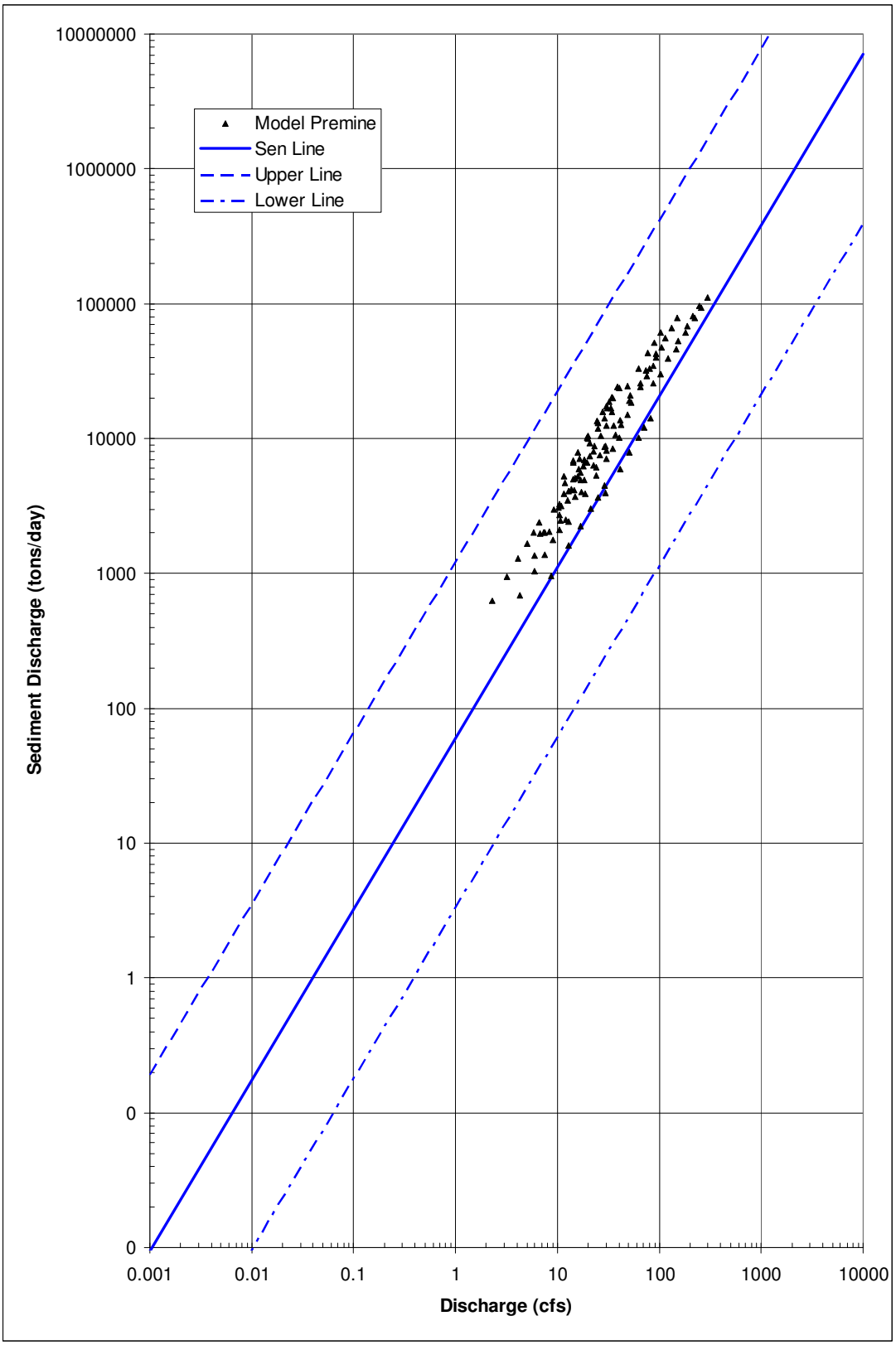


Figure 2.5. Modeled premine sediment and water discharge for the J21 WA with Sen lines.

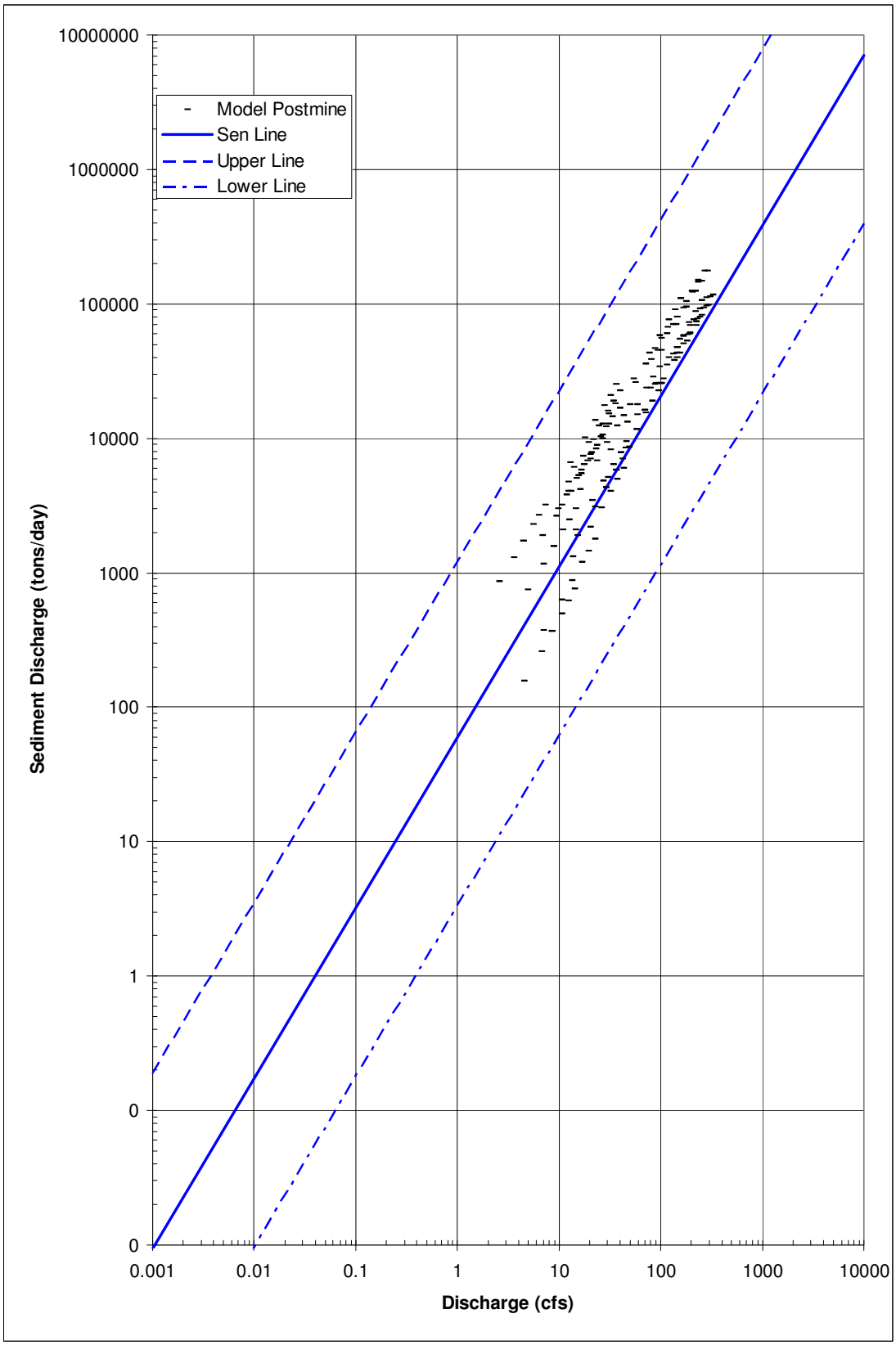


Figure 2.6. Modeled postmine sediment and water discharge for the J21 WA with Sen lines.

3. REFERENCES

Hjelmfelt, A.T., Kramer, L.A., and Spomer, R.G., 1986. Role of large events in average soil loss in Proceedings of the Fourth Federal Interagency Sedimentation Conference, March 24-27, 1986, Las Vegas, NV, p. 3-1 to 3-9.

Lagasse, P.F., Schall, J.D., and Peterson, M.R., 1985. Erosion Risk Analysis for a Southwestern Arroyo, Journal of Urban Planning and Management, American Society of Civil Engineers, v. III, no. I, November, 1985, Paper No. 20165.

Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973. "NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States," Volume VIII - Arizona, National Oceanic and Atmospheric Administration.

Renard, K.G. and Simaton, J.R., 1975. "Thunderstorm Precipitation Effects on the Rainfall-Erosion Index of the Universal Soil Loss Equation" in Volume 5 of Hydrology and Water Resources in Arizona and the Southwest, American Water Resources Assn., Arizona Section Arizona Academy of Science, Hydrology Section, Proceedings of April 11-12 meeting, Tempe AZ, v. 47-55.

Resource Consultants & Engineers, Inc. (RCE), 1993. "Surface Water Modeling of Reclaimed Parcels at the Black Mesa Complex," prepared for Peabody Western Coal Co.

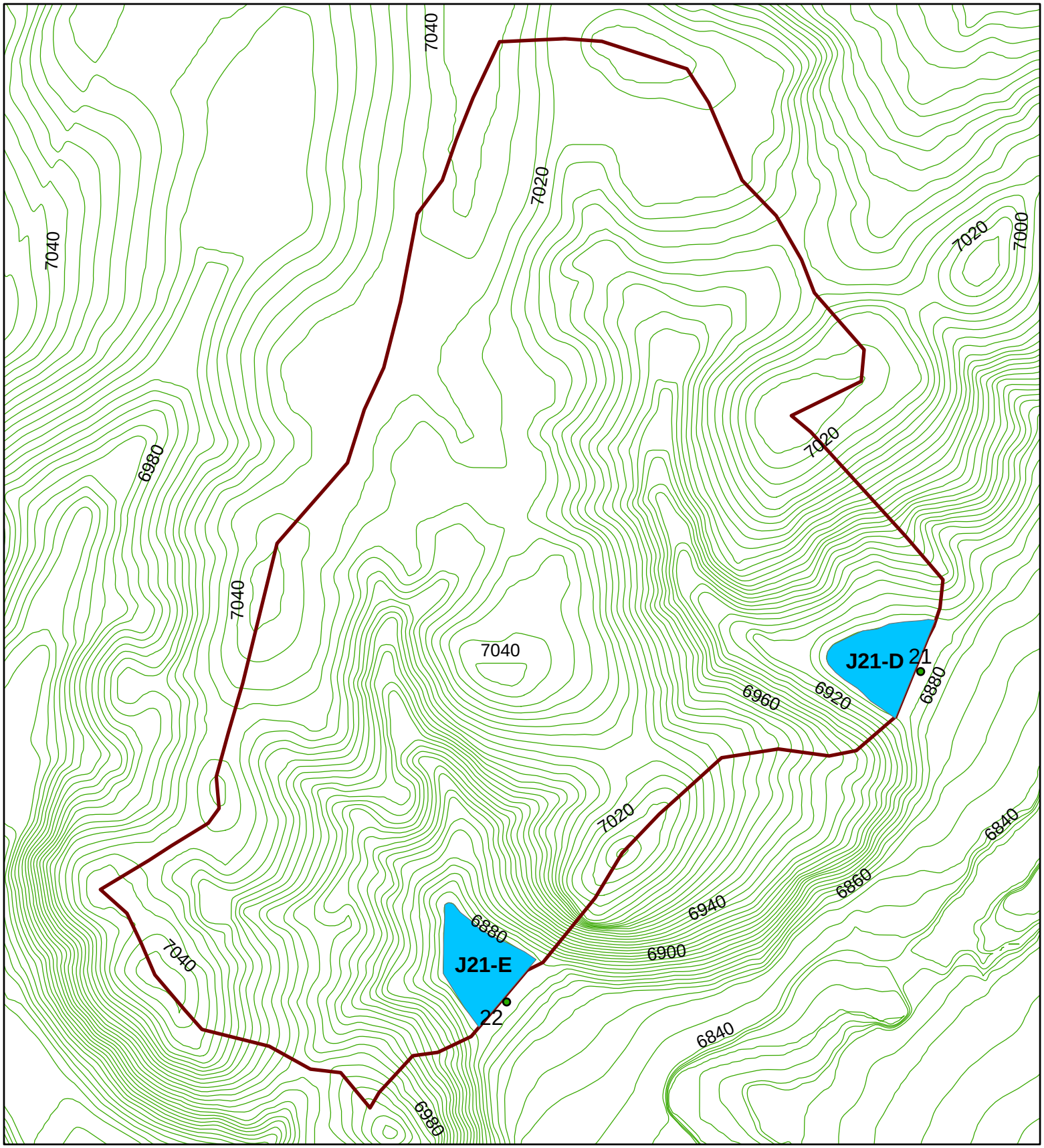
Sen, P.K., 1968. "Estimates of Regression Coefficient Based on Kendall's tau: Journal of American Statistical Association, v. 63, p. 1379-1389.

Smith, T. and Best, A., 2000. "Assessing Sedimentation and Protection of the Hydrologic Balance in Disturbed and Reclaimed Areas at the Black Mesa and Kayenta Mines, Arizona, Using Baseline Sediment Data Collected in Receiving Streams," presentation given at the Billings Mined Land Reclamation Symposium in 2001, Billings, MT.

Water Engineering & Technology, Inc. (WET), 1990. "Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control Technology at Surface Mines in the Semiarid West," prepared for Office of Surface Mining and the National Coal Association, Fort Collins, CO.

Zevenbergen, L.W., Peterson, M.R., and Watson, C.C., 1990. Computer simulation of watershed runoff and sedimentation processes, Proceedings of the Billings Symposium; Planning, Rehabilitation and Treatment of Disturbed Lands.

EXHIBIT 1
Postmine Topography



N

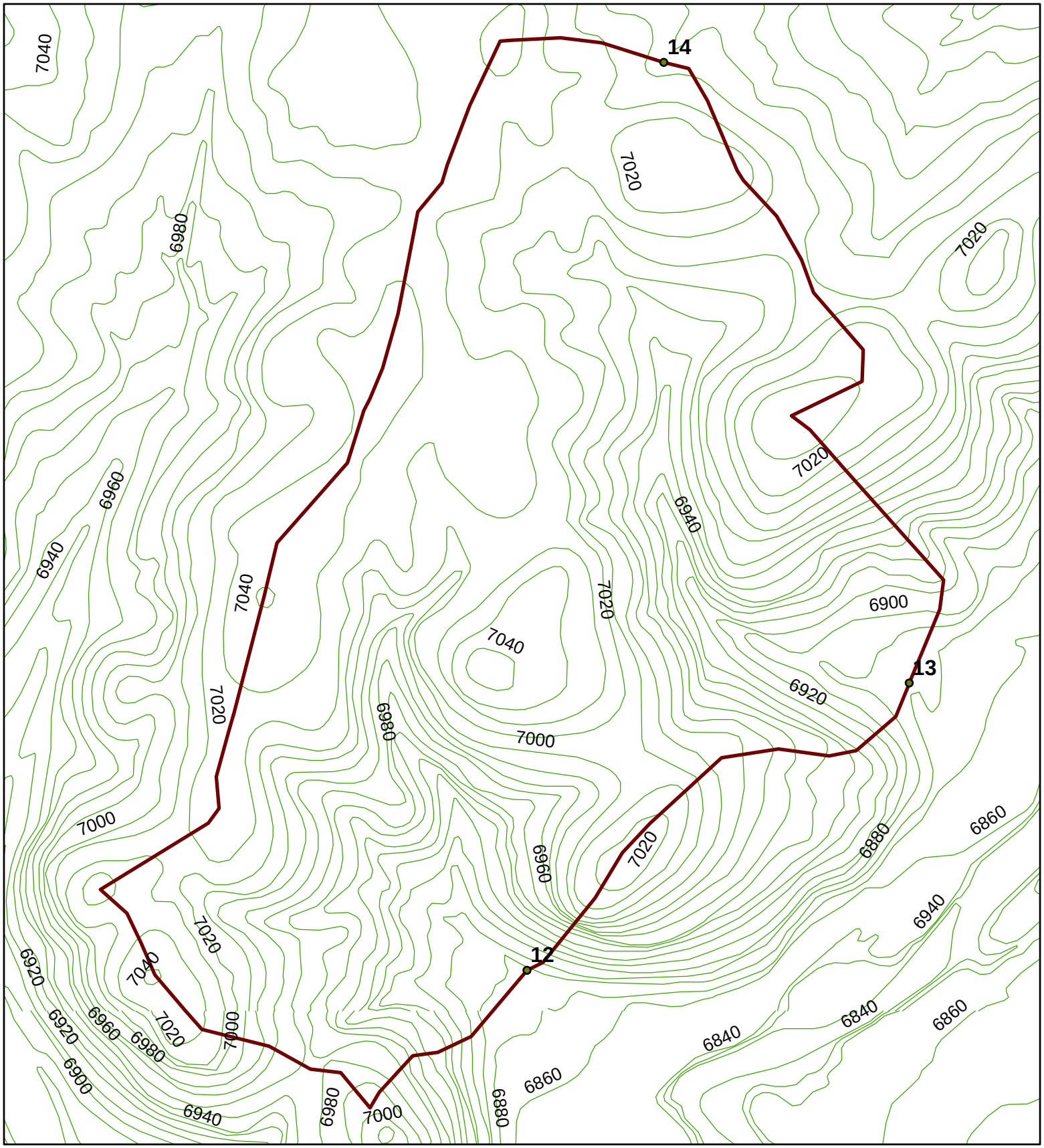
Legend

- End Points
- Ponds
- Modeling Area

0 150 300 600 900 Feet

Exhibit 1. Postmine Topography

EXHIBIT 2
Premine Topography



N

Legend

- End Points
- Modeling Area

0 150 300 600 900 Feet

Exhibit 2. Premine Topography

Appendix 4

Surface Water Modeling of the Reclaimed J16-E and J16-F Watershed Area at Kayenta Mine

SURFACE WATER MODELING OF THE RECLAIMED J16-E AND J16-F WATERSHED AREA AT KAYENTA MINE

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES

SURFACE WATER MODELING OF THE RECLAIMED J16-E AND J16-F WATERSHED AREA AT KAYENTA MINE

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES
P.O. Box 270460
Fort Collins, Colorado 80527
(970) 223-5556, FAX (970) 223-5578

Ayres Project No. 32-1304.00
PEAB8-TX.DOC

August 2008

TABLE OF CONTENTS

1. Reclaimed Parcel Modeling 1.1

1.1 Introduction 1.1
1.2 Background 1.1
1.3 Data 1.2

1.3.1 Soils 1.2
1.3.2 Vegetation 1.2
1.3.3 Topography 1.3

1.4 Methodology 1.3

1.4.1 Synthetic Rainfall 1.8
1.4.2 Computation of Average Runoff and Sediment Yield 1.8

1.5 Results 1.8
1.6 Discussion 1.9

2. Comparisons with Measured Sediment Transport 2.1

3. References 3.1

Exhibit 1 – Postmine Topography ..... --
Exhibit 2 – Premine Topography ..... --

LIST OF FIGURES

Figure 1.1. Reclaimed area soils trilinear graph. 1.2

Figure 1.2. Spatial distribution of vegetative cover types for WA J16 premine condition 1.4

Figure 1.3. J16-E and J16-F postmine basins. 1.6

Figure 1.4. J16-E and J16-F premine basins. 1.7

Figure 2.1. Observed and modeled sediment and water discharge. 2.2

Figure 2.2. Observed versus modeled sediment concentration and discharge. 2.3

Figure 2.3. Background measured sediment and water discharge with Sen lines..... 2.5

Figure 2.4. Reclaimed measured sediment and water discharge with Sen lines. 2.6

Figure 2.5. Modeled premine sediment and water discharge for the J16 WA with Sen lines... 2.7

Figure 2.6. Modeled postmine sediment and water discharge for the J16 WA with Sen lines. 2.8

LIST OF TABLES

Table 1.1. Soils Data. 1.3

Table 1.2. Cover Sampling Data. 1.5

Table 1.3. Cover Data for J16-E and J16-F Watersheds. 1.5

Table 1.4. Average Runoff and Sediment Yield Results. 1.8

Table 1.5. Average Physical Properties of the J16 WA. 1.9

1. RECLAIMED PARCEL MODELING

1.1 Introduction

The objective defined by PWCC for this project is to use a previously calibrated and validated runoff and erosion model (EASI, Zevenbergen et al. 1990; WET 1990) for the Black Mesa and Kayenta Mines to predict mean annual runoff and sediment yields from the reclaimed J16-E and J16-F watersheds. This objective included computation of runoff and sediment yields under premine conditions for the same area. All soils and rainfall input to the model are to be taken from models calibrated in the previous study (RCE 1993). The input variables that were calibrated to the mine areas and used in this study include soil infiltration parameters, erodibility parameters, and the grain size distribution. Parameters that are specific to this study are vegetative canopy and ground cover percentages from data collected on site.

The model calibration was conducted in a previous study (RCE 1993) using data obtained from instrumented watersheds and small hillslope plots collected under natural rainfall conditions. For a detailed discussion of data collection and model calibration, please refer to the previous study (RCE 1993).

1.2 Background

The J16-E and J16-F Watershed Area (WA) that is the focus of this project was reclaimed between 1984 and 2002. The fundamental purpose of this study was to quantify the expected behavior and hydrologic response of the reclaimed areas above each pond relative to the conditions that existed prior to the occurrence of mining activities.

Runoff and sediment yield response from the reclaimed lands should be managed by implementing Best Management Practices (BMP's) in conjunction with an OSM approved sediment control plan in order to not adversely impact the prevailing hydrologic balance and to limit additional contributions of suspended sediment to streamflow or runoff outside the mine permit areas. BMP's include regrading, replacing salvaged topsoil, revegetation, and other controls such as riprapped channel bottoms, check dams, and where practicable, contour terraces. The natural watersheds on the mesa contribute significant quantities of sediment to the channel system. It is expected that the postmine condition will also produce comparable amounts of sediment without adverse impact on the hydrologic balance.

This section describes the data and procedures used to evaluate the J16 WA. This area was modeled to determine the average annual hydrologic response following the completion of reclamation activities taking into account BMP's implemented as part of the reclamation process. Infiltration, runoff, and erosion processes from both hillslopes and channels within the J16 WA were modeled using EASI. Results were determined for concentration points at the outlets of the reclaimed watersheds, which correspond to the embankments associated with Ponds J16-E and J16-F. The locations of these points are shown in **Exhibit 1**. Modeling was also conducted to determine hydrologic response under premine conditions based on the topography, soils, cover, and other conditions that typified the undisturbed watersheds draining to each concentration point. **Exhibit 2** shows the modeling endpoints for the premine J16 WA.

1.3 Data

1.3.1 Soils

Soils data used for the current study (J16 WA) were based on data developed from the calibration of models used in the previous study for Coal Resource Areas (CRAs) N1/N2 and J27 (RCE 1993). The composition of postmine soil in the current study is depicted along with the composition of postmine soils from the previous study in **Figure 1.1**. This figure shows that the soil composition of WA J16 is very similar to soils evaluated during model calibration. Therefore, the soil properties developed in the previous study are valid for this modeling project. These properties include calibrated parameters, such as infiltration and erodibility coefficients, and measured soil size distributions. **Table 1.1** lists the premine and postmine soils data used during EASI modeling of WA J16.

1.3.2 Vegetation

Vegetative cover data representative of both pre- and postmine conditions in WA J16 were supplied by PWCC. For the premine condition, land was characterized as being covered by sagebrush or pinon juniper. The spatial distribution of vegetative cover for the J16 WA premine condition appears in **Figure 1.2**. Average cover properties for CRAs N1/N2 and J27 of the previous study and WA J16 of the current study appear in **Table 1.2**. For the postmine condition, the reclaimed area was assigned the postmine cover type and the unmined area was assigned the same cover type as the premine condition. **Table 1.3** lists the pre- and postmine vegetative cover data used in the EASI model runs generated for the J16 WA. Note that if a unit contained significant portions of both sagebrush and pinon juniper cover types, it was classified as half pinon juniper and half sagebrush.

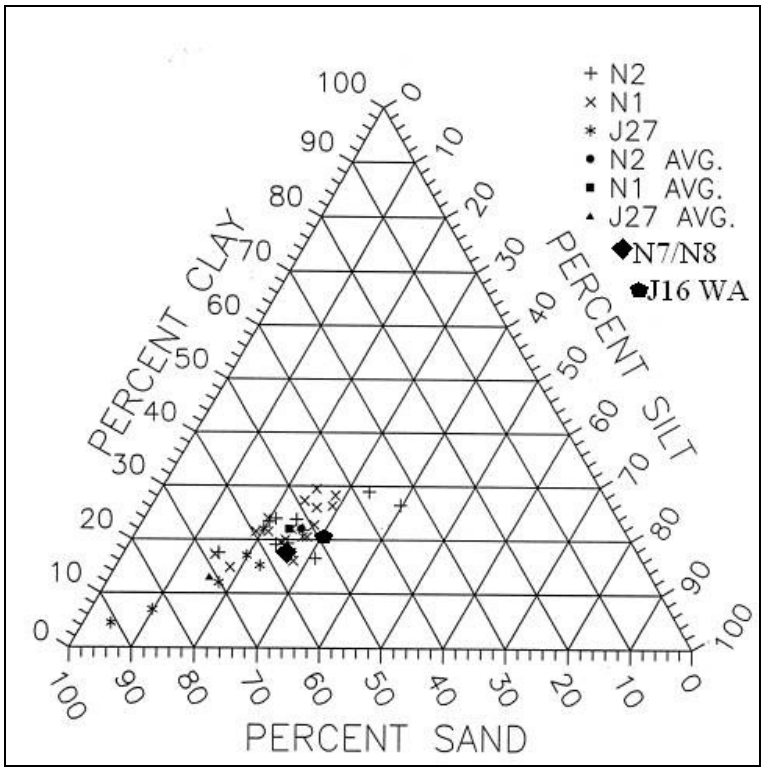


Figure 1.1. Reclaimed area soils trilinear graph.

Table 1.1. Soils Data.			
Condition	Premine	Postmine	Rock Chutes
Rainfall detachment	0.005	0.005	0
Overland flow detachment	0.44	0.44	0
Channel flow detachment	0.5	0.5	0
Initial soil moisture, %	70	70	70
Final soil moisture, %	90	90	90
Soil porosity, %	45	45	46
Temperature, *F	70	70	70
Hydraulic conductivity, in/hr	0.23	0.29	0.3
Capillary suction, in	3.7	2.6	2.6
	Particle Size Distribution (all conditions)		
	Size, mm	% Finer	
	0.001	0	
	0.004	18.0	
	0.016	27.4	
	0.062	36.6	
	0.125	56.2	
	0.250	64.3	
	0.500	72.4	
	1.000	80.5	
	2.000	88.6	
	4.000	92.4	
	16.000	100	

1.3.3 Topography

Pre- and postmine topography was supplied by PWCC in the form of ArcGIS geodatabase. Basin delineations, hillslope delineations, subwatershed delineations, as well as areas, slopes, and lengths of all units of the study area were defined and calculated using ArcGIS software. **Figures 1.3 and 1.4** show the watershed delineation and numbers assigned to the basins used in the EASI model for the post- and premine conditions, respectively. Channel dimensions input to EASI were based on the topography supplied and limited field observations.

1.4 Methodology

Runoff and sediment yield in the semiarid western United States is largely governed by the occurrence of high-intensity, short-duration rainstorms of limited areal extent (Renard and Simaton 1975). Research has indicated that relatively few events may produce the greatest erosion (e.g., Hjelmfelt et al. 1986 reported that only 3 to 4% of rainfall events accounted for 50% of long-term sediment yields). Although there is perhaps a relatively limited physical basis for definition of an "average annual" runoff or sediment yield in a semiarid environment due to the extreme variability in response and importance of single infrequent events, such a term does provide a useful basis for long-term comparison between reclaimed and undisturbed conditions.

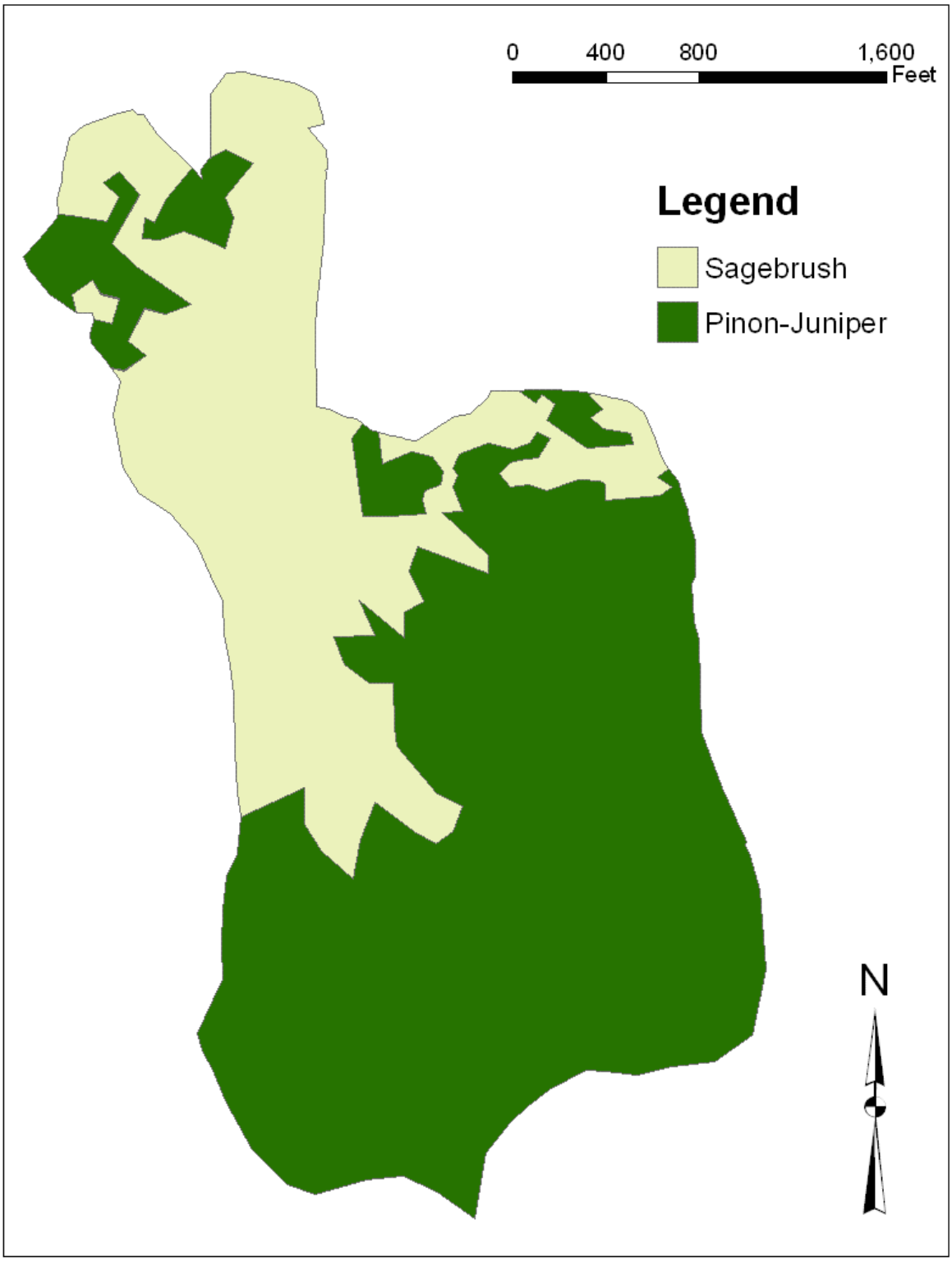


Figure 1.2. Spatial distribution of vegetative cover types for WA J16 premine condition.

Table 1.2. Cover Sampling Data.								
Area	Condition	Cover Type	Nonstratified Vegetation Cover (%)	Vegetation Canopy Cover (%)	Vegetation Ground Cover (%)	Litter* (%)	Rock (%)	Total Ground Cover (%)
N1/N2	Postmine	Postmine	25.6	1.4	24.2	13.6	4.2	41.9
J16 WA	Postmine	Postmine		0.3	34.7	20.2	6.1	61.0
N1/N2/J27	Premine	Pinon Juniper	32.7	31.1	3.0	44.0	19.7	66.7
J16 WA	Premine	Pinon Juniper		16.8	3.9	28.8	16.7	49.3
N1/N2	Premine	Sagebrush	25.1	16.0	10.3	25.3	18.1	53.7
J27	Premine	Sagebrush	30.6	9.7	22.0	24.0	1.6	47.6
J16 WA	Premine	Sagebrush		1.7	15.5	30.6	1.7	47.8
*Including standing dead litter								

Table 1.3. Cover Data for J16-E and J16-F Watersheds.				
Condition	Pinon Juniper	Sagebrush	Half Pinon Juniper-Half Sagebrush	Postmine
Canopy cover, %	16.8	1.7	9.3	0.3
Ground cover, %	49.3	47.8	48.5	61
Canopy storage, in	0.05	0.05	0.05	0.05
Ground storage, in	0.05	0.05	0.05	0.05
Depression storage, in	0.03	0.03	0.03	0.03
Impervious area, %	0	0	0	0
Manning n	0.07	0.07	0.07	0.05

To make comparisons between reclaimed lands and associated undisturbed lands at the Black Mesa Mining Complex on the basis of average annual sediment yield, a procedure was used that considers the importance of infrequent storm events in defining sediment yield in the semiarid west. First, however, the site-specific rainfall data available for the Black Mesa Mining Complex were used to evaluate the frequency and magnitude of the measured events relative to existing predictions for rainfall depth-duration (Miller et al. 1973). The analysis of the rainfall data was performed as part of a previous study of the N1/N2 and J27 CRAs (Resource Consultants and Engineers 1993).

Comparisons between runoff and sediment yield from undisturbed and reclaimed areas in WA J16 were developed for specific modeling endpoints shown in Exhibits 1 and 2. Mining and reclamation activities did not exactly replicate the topography, drainage network, or drainage areas that existed prior to mining. Consequently, direct comparisons of total runoff and sediment yield cannot be made between undisturbed and reclaimed response at a given point in a watershed. Comparisons were made on the basis of unit rates of runoff (inches) and sediment yield (tons/acre) at the various modeling computation endpoints. Although the same disturbance boundary was used to model extents for both pre- and postmine conditions, the topographic differences that resulted after mining and reclamation occurred in the J16 WA dictated that some small areas would be included or excluded from the modeling. The total area modeled (combined area for both J16-E and J16-F watersheds) for premine conditions is 179.2 acres and for postmine conditions is 148.5 acres. The difference in area results from the sediment ponds in postmine conditions and the extension of J16F's premine basin. The area bounded by the disturbance limits identified by PWCC as shown in Exhibit 1 is 150.2 acres.

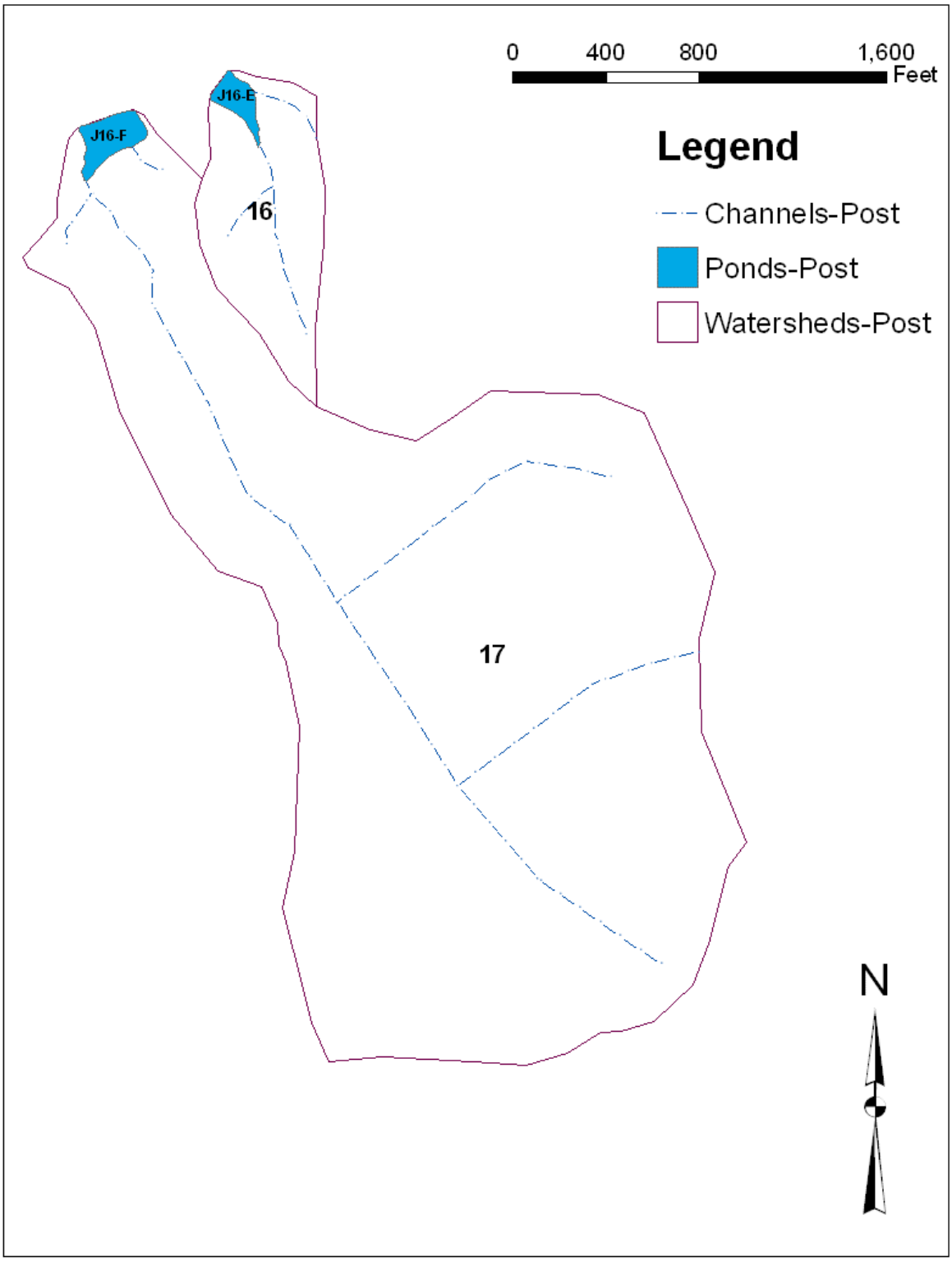


Figure 1.3. J16-E and J16-F postmine basins.

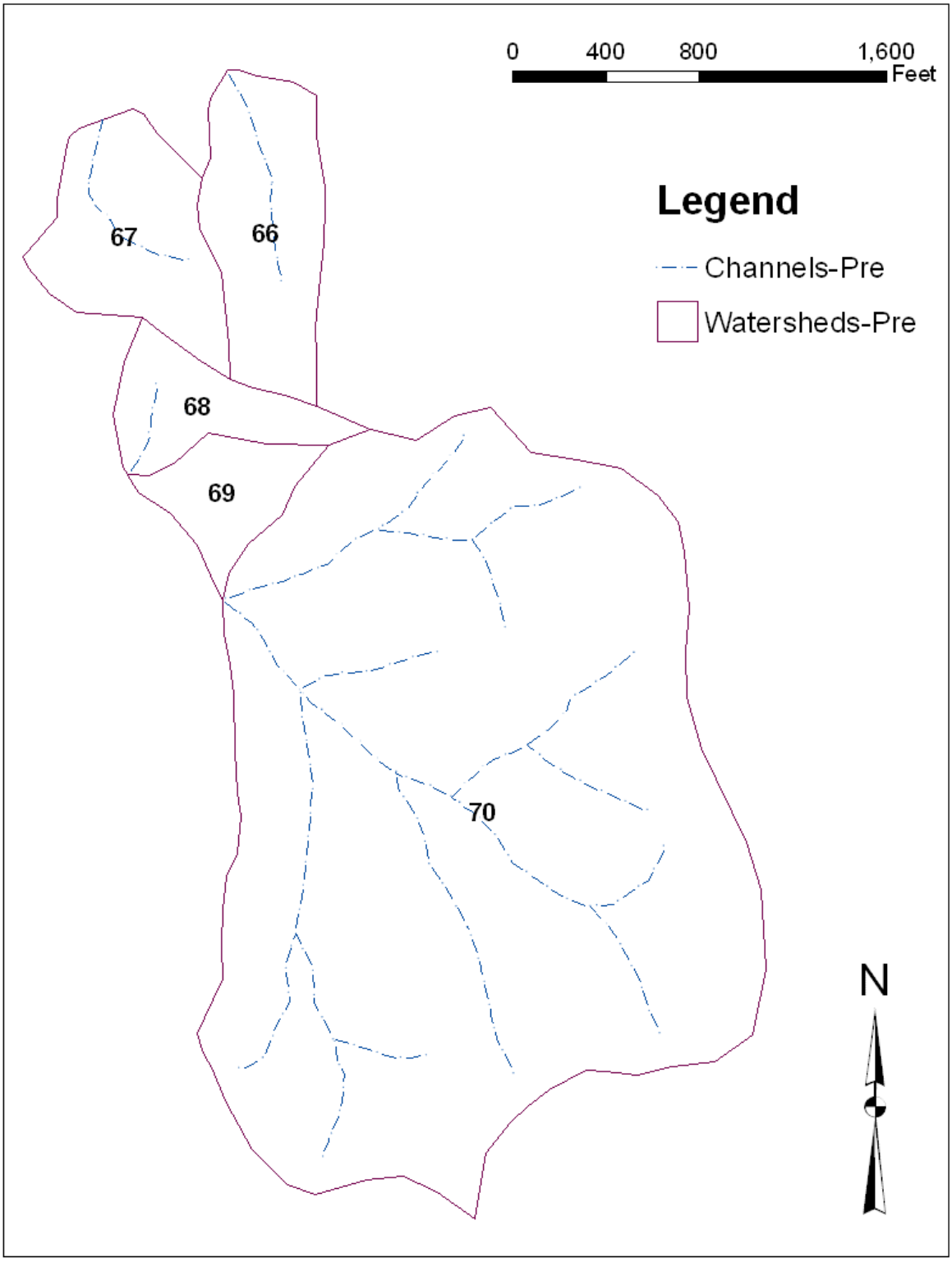


Figure 1.4. J16-E and J16-F premine basins.

1.4.1 Synthetic Rainfall

Synthetic storms of 2-, 5-, 10-, 25-, 50-, and 100-year return periods were used as input to the EASI model. Actual hyetographs were taken from the previous study (RCE 1993) and are based on both local data collection and the NOAA Atlas (Miller et al. 1973).

1.4.2 Computation of Average Runoff and Sediment Yield

The EASI model was used to evaluate runoff and sediment yield from a series of storm events having recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100 years. To define average annual conditions, the average annual runoff and sediment yield generated from storm events were computed using the commonly used equation of Lagasse et al. (1985).

1.5 Results

Figures 1.3 and 1.4 show the post- and premine basin delineations. Since the individual subareas differ in number, acreage and outlet locations, a direct comparison is not possible on a subarea basis. Therefore, the best way to compare the results is on an average basis for the WA. **Table 1.4** shows pre- and postmine drainage area, runoff, and sediment yield for the J16 WA. Runoff is defined as the total volume of water leaving the WA on an average annual basis and, therefore, does not include water stored in depression areas and ponds. For the premine condition, this is equal to the amount of water that drains off the hillslopes and subwatersheds because there are no ponds or significant depressions. For the postmine condition, this is equal to the amount of hillslope runoff less the amount stored in ponds. No ponds or significant depressions exist within the reclaimed J16 WA that was modeled. Similarly, the sediment yield is the amount of eroded material that leaves the WA on an average annual basis computed using the equation of Lagasse et al. (1985). The sediment yield is the production from the hillslope areas and erosion from the channels. The amount of erosion is the sediment yield from the hillslopes and subwatersheds only and does not include channel erosion, channel deposition or sediment trapped in ponds. Sediment yield can be greater or less than erosion, depending on the amount of channel erosion and the capacity of the channel network to convey sediment off the leasehold.

Table 1.4. Average Runoff and Sediment Yield Results.

Area	Condition	Drainage Area (ac)	Runoff (in)	Sediment Yield (t/ac/yr)
J16 WA	Premine	179.2	0.42	2.28
J16 WA	Postmine	148.5	0.42	1.14
J16-E	Premine	13.8	0.42	1.50
J16-E	Postmine	11.9	0.42	1.07
J16-F	Premine	165.4	0.42	2.34
J16-F	Postmine	136.6	0.42	1.15

For the postmine condition, the overall sediment yield is less than those in the premine condition. Sediment yield is approximately one-half of the premine amount, and runoff is the same as the premine amount. The reduction of sediment yield is primarily due to the channel erosion control measures (BMP's) for the postmine condition.

Table 1.4 also shows pre- and postmine drainage area, runoff, and sediment yield for two individual watersheds (J16-E and J16-F) within the J16 WA. Modeling results of individual watersheds are similar to the overall J16 WA.

1.6 Discussion

Table 1.5 gives an overview of the geometric properties of the pre- and postmine disturbed areas. Premine hillslopes are generally longer than postmine hillslopes, and postmine channels are not as steep as premine channels. The drainage density of the postmine condition is smaller than that of the premine condition, because the postmine topography has simple geometric characteristics and the premine topography is highly dissected.

Table 1.5. Average Physical Properties of the J16 WA.

	Premine	Postmine
Total Area (ac)	179.2	148.5
Total Channel Length (ft)	14773	8715
Mean Channel Slope	0.0733	0.0594
Drainage Density (mi/mi^2)	10.0	7.1
Mean Hillslope Length (ft)	257	248
Mean Hillslope Gradient	0.1354	0.0702

2. COMPARISONS WITH MEASURED SEDIMENT TRANSPORT

As discussed in Section 1, PWCC has monitored flow and sediment on the main channels, principal tributaries and small watersheds within the leasehold. These data, along with the runoff plots, were used to calibrate the EASI model soil erodibility and infiltration input variables. **Figures 2.1** and **2.2** show sediment transport and sediment concentration versus discharge for measured unmined (background), measured reclaimed, WA J16's modeled unmined (premine) and modeled reclaimed (postmine) data. Although there is significant scatter shown in the data (as is expected with any sediment transport conditions), there are several conclusions that can be drawn from this data.

The open symbols in both figures depict measured data and whether the data were collected from reclaimed areas (the small watershed study) or from unmined or background surface water monitoring stations. The range of flows is generally greater for the background data but there is significant overlap between the two data sets between 0.1 and 100 cfs. This is because the reclaimed data are from small watersheds and the unmined data are from channels draining larger basins. These data show the same trend for sediment transport and sediment concentration over the entire range of flows and very close agreement in the area of discharge overlap. This, in itself, is strong evidence that (1) the sediment yields are channel transport capacity limited, (2) overlap of model predictions for both pre- and postmine conditions with measured data strongly indicate that EASI model predictions are representative and reasonable, and (3) sediment yields from reclaimed areas will not be additive to yields on the receiving streams.

The closed symbols depict data from WA J16's pre- and postmine EASI model runs. They represent data generated by EASI for both subwatersheds and channels for peak discharges resulting from 2-, 5-, 10-, 25-, 50-, and 100-year storms. Using the peak flows from extreme events results in discharges that generally exceed 10 cfs. The trend of the model-derived data is similar and the ranges of concentration and sediment transport are similar to the measured data and between pre- and postmine conditions.

The sediment discharge plot (Figure 2.1) shows a stronger trend because it is plotting discharge (sediment) against discharge (flow). This is expected because the sediment discharge does depend on flow discharge. The concentration plot (Figure 2.2) shows the two separate variables and, therefore, a less significant trend. PWCC believes that data measurement may have some influence on the scatter (outliers were removed), but the process variability is probably the major influence. The majority of the data, however, fall in a group centered on 100 cfs and 100,000 mg/l, both in the observed data and in the model results. These plots support the use of the EASI model, the results of the modeling, the conclusion that sediment yields from reclaimed areas are not additive to receiving stream sediment loads, and that sediment impacts to the prevailing hydrologic balance have been minimized.

From Figures 2.1 and 2.2 it is apparent that sediment loads and concentrations are dependent on the channel sediment transport capacity for both pre- and postmine conditions. Channel sources of sediment in this arid environment are virtually unlimited. Therefore, channel transport capacity and channel derived sediment limits and governs sediment yields from the small tributaries, large channels and the WA as a whole. The similarity of sediment discharge (or concentration) between pre- and postmine conditions appears to be inconsistent with the lower rates of sediment yield shown in Table 1.4.

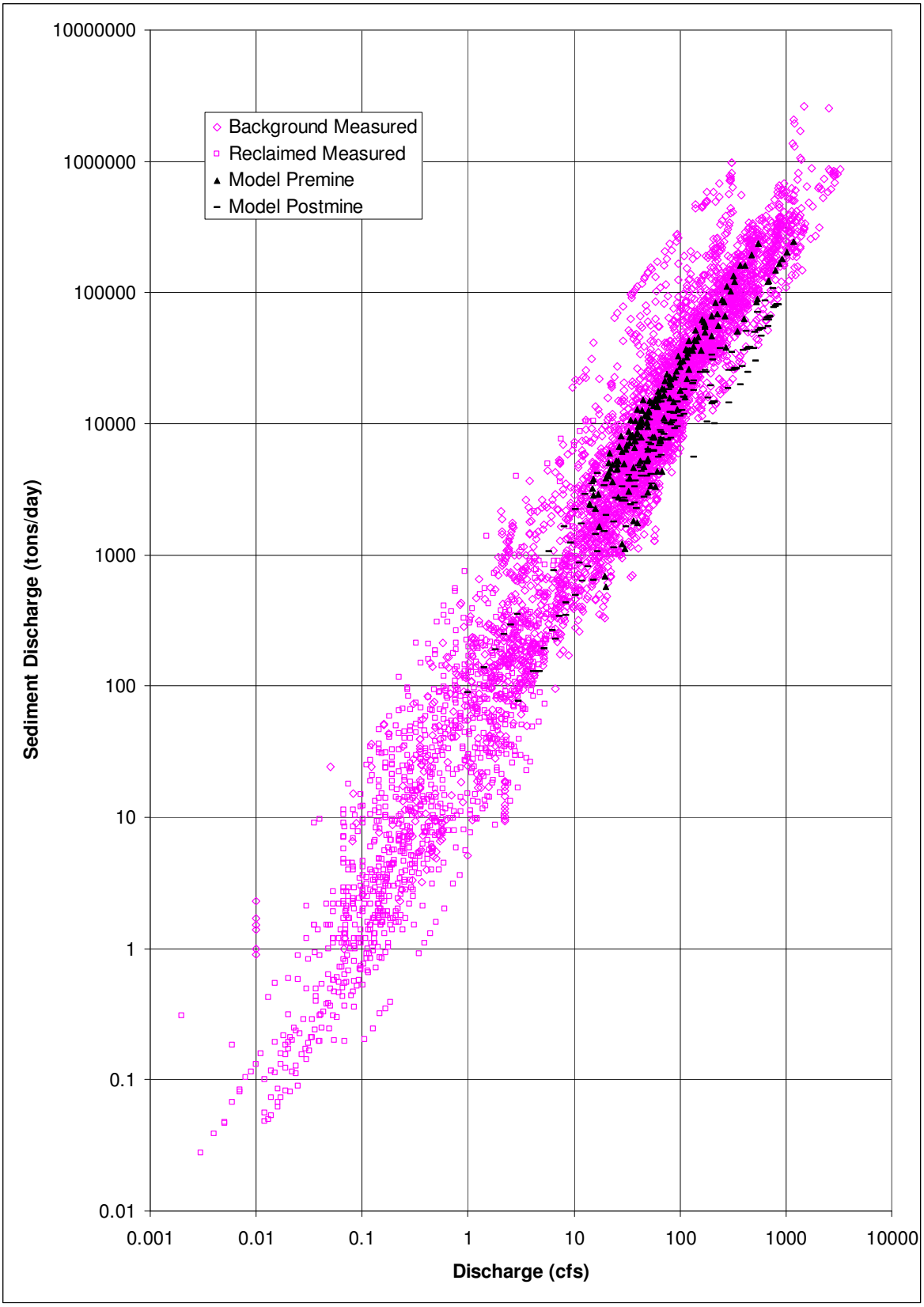


Figure 2.1. Observed and modeled sediment and water discharge.

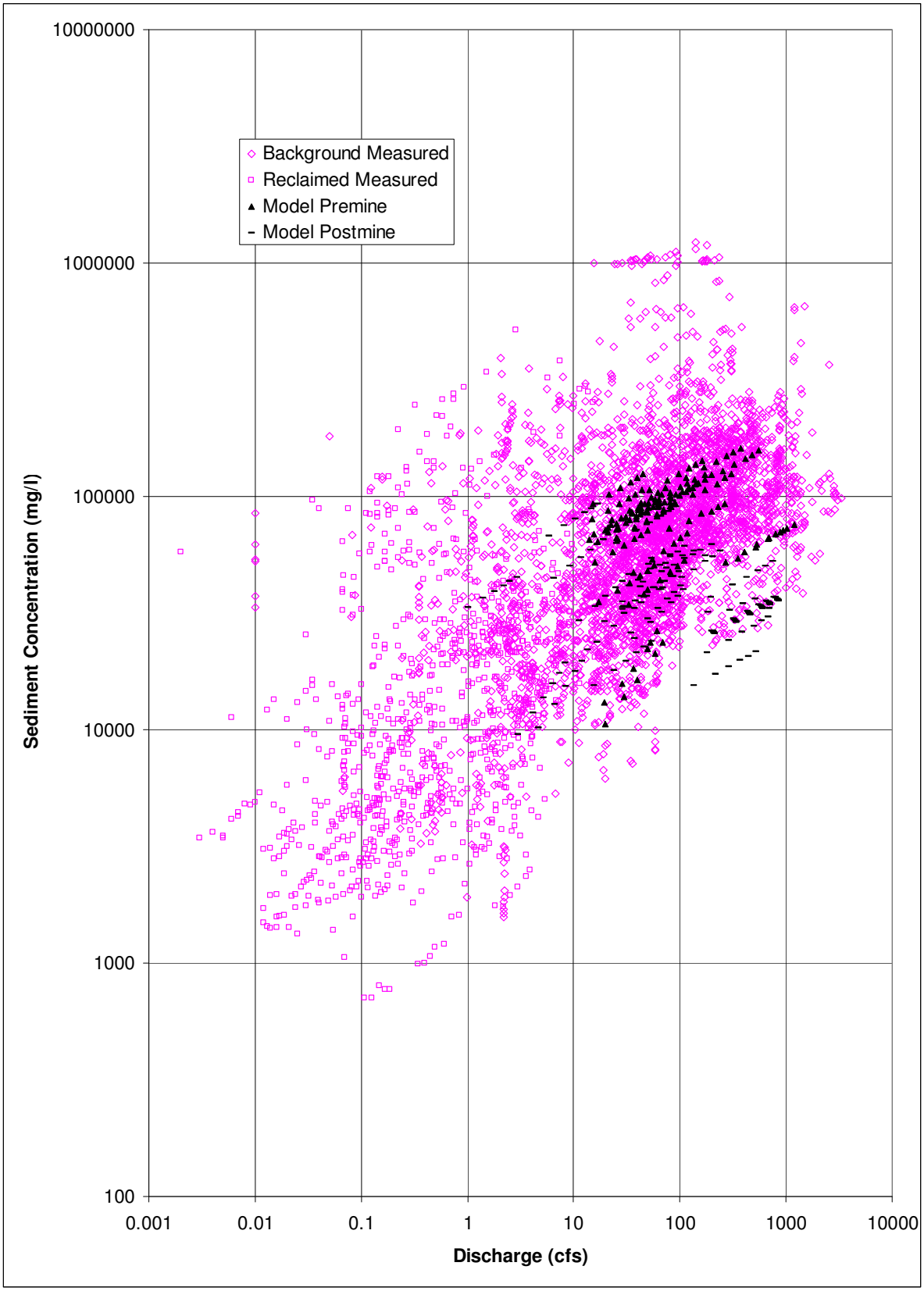


Figure 2.2. Observed versus modeled sediment concentration and discharge.

However, the sediment yield shown in Table 1.4 is the average annual amount of sediment leaving the J16 WA whereas the sediment discharge shown in Figure 2.1 is the peak rate of sediment in transport occurring in any channel represented by the data, whether the channel is located upstream or downstream of a pond. Therefore, it should be concluded that with or without a pond left in the postmine landscape that traps sediment or stores water, the mine reclamation is not contributing additional sediment to the receiving streams and sediment impacts to the prevailing hydrologic balance have been minimized.

Smith and Best (2000) analyzed the measured data (background and reclaimed) shown in Figure 2.1 to develop an approach that can be used to determine if channels in reclaimed areas have similar sediment transport characteristics as background channels. The method that they used was to develop Sen lines (Sen 1968) and confidence intervals around the data. The slope of the Sen line is a non-parametric statistic computed as the median slope of all possible slopes determined from pairing all the data points. The Sen line is drawn through the median coordinate of the data. Smith and Best first showed that the large channel flume data (background) and the small watershed background data could be combined. They concluded that since the data from one data set fall within the Sen line bounds of the other data set then the two data sets are merely extensions of each other and could be combined. Also, because the main channel and background small watershed site data could be combined, it indicated there is an unlimited supply of sediment and the channels are conveying sediment at (or near) capacity. The Sen line and bounds are shown with the background measured data in **Figure 2.3**.

They then plotted the reclaimed measured data (**Figure 2.4**) with the Sen line and bounds from the background data to show that the reclaimed data have the same characteristics even though the flow range of the measurements is lower. The data indicate that channel flows in this environment achieve the sediment transport capacity of the channel, whether in reclaimed or background conditions.

Using the same approach with the modeled data generated for the J16 WA, **Figures 2.5 and 2.6** show the pre- and postmine computed sediment transport rates with the Sen lines and bounds. One difference between the plots is that the measured data occur throughout the flow hydrograph whereas the modeled data are tabulated at the peak of the simulation flow hydrograph. The premine data plot (Figure 2.5) shows the data grouped around the Sen line and well within the bounds. The postmine data (Figure 2.6) plot most densely below the Sen line and are more scattered. On these graphs data plotting below the lines indicate that there is less sediment in transport for a given discharge. The lower sediment transport rates in the reclaimed data is probably the result of low gradient channels while low gradient channels in the premine condition are rare.

Several conclusions can be drawn from these data plots: (1) EASI model well replicates erosion and sediment transport processes at the mine site for background and reclaimed conditions, (2) all data show similar trends and are within the same bounds, (3) data trends indicate that channels are transporting sediment at or near capacity, and (4) amounts of sediment leaving the WA for postmine conditions are similar to premine conditions and within the range expected for the background conditions. Therefore, the overall conclusion is that the postmine reclaimed condition in J16 WA is not contributing additional suspended solids to receiving streams, and related impacts to the hydrologic balance have been minimized.

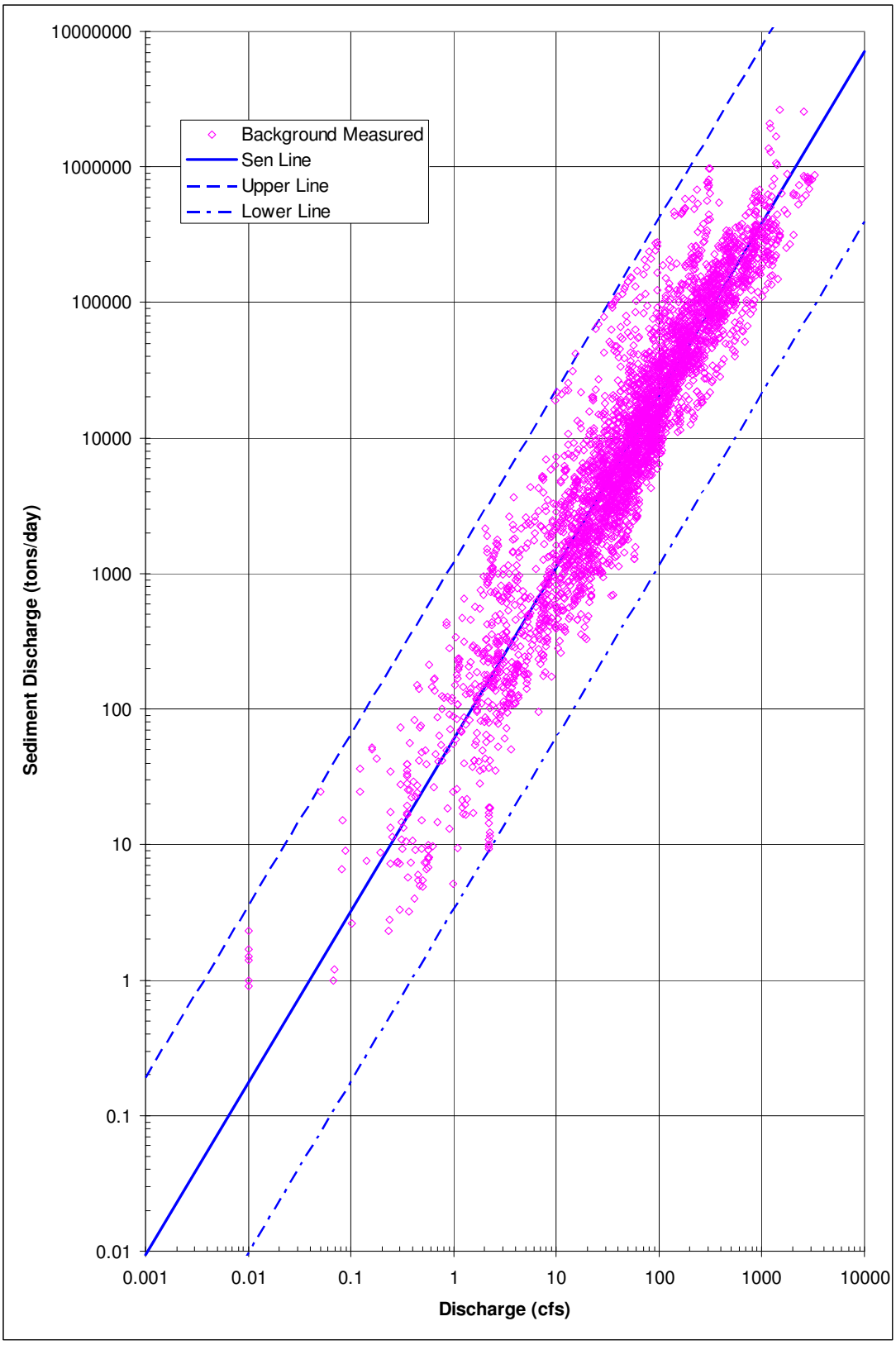


Figure 2.3. Background measured sediment and water discharge with Sen lines.

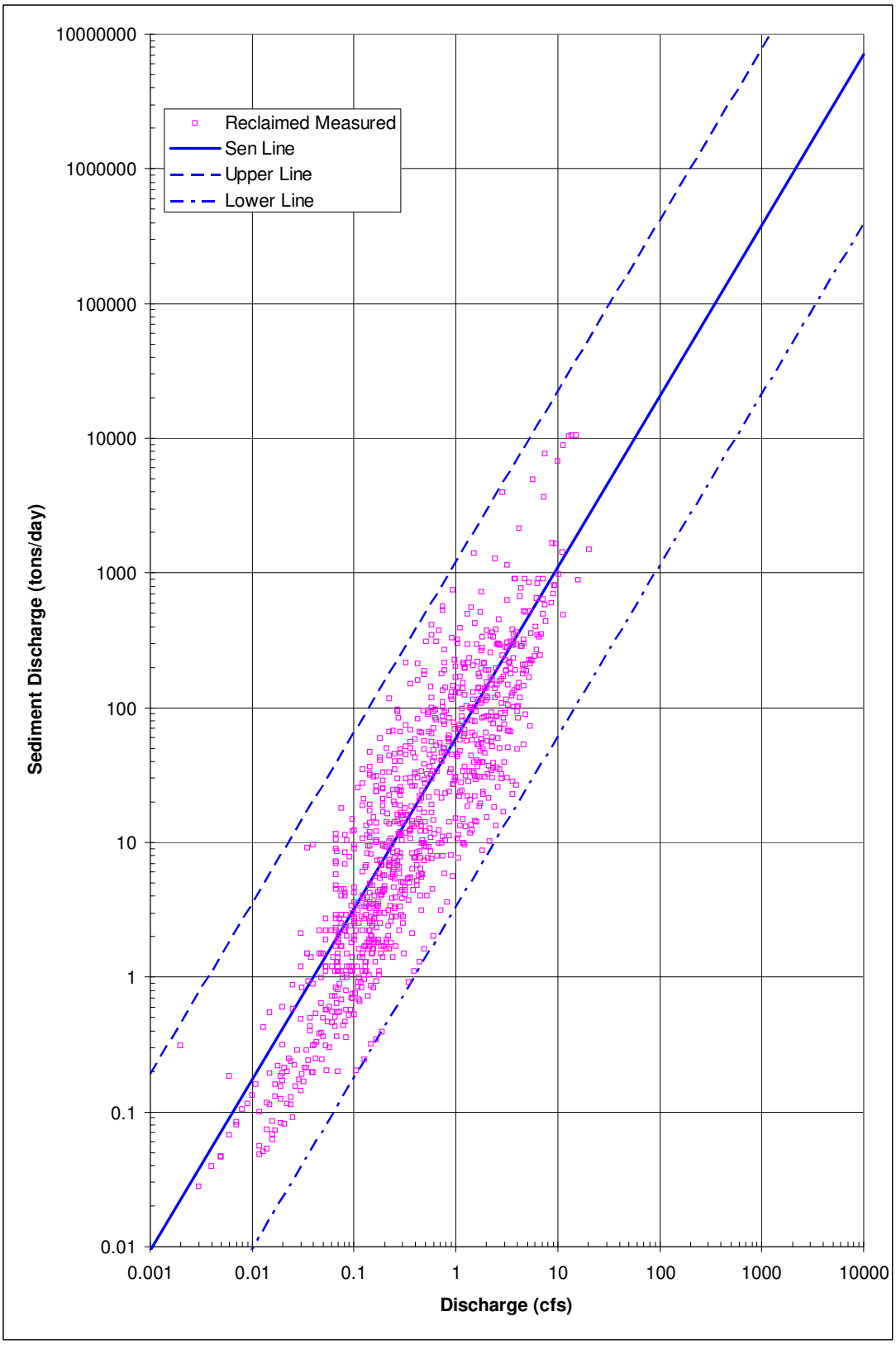


Figure 2.4. Reclaimed measured sediment and water discharge with Sen lines.

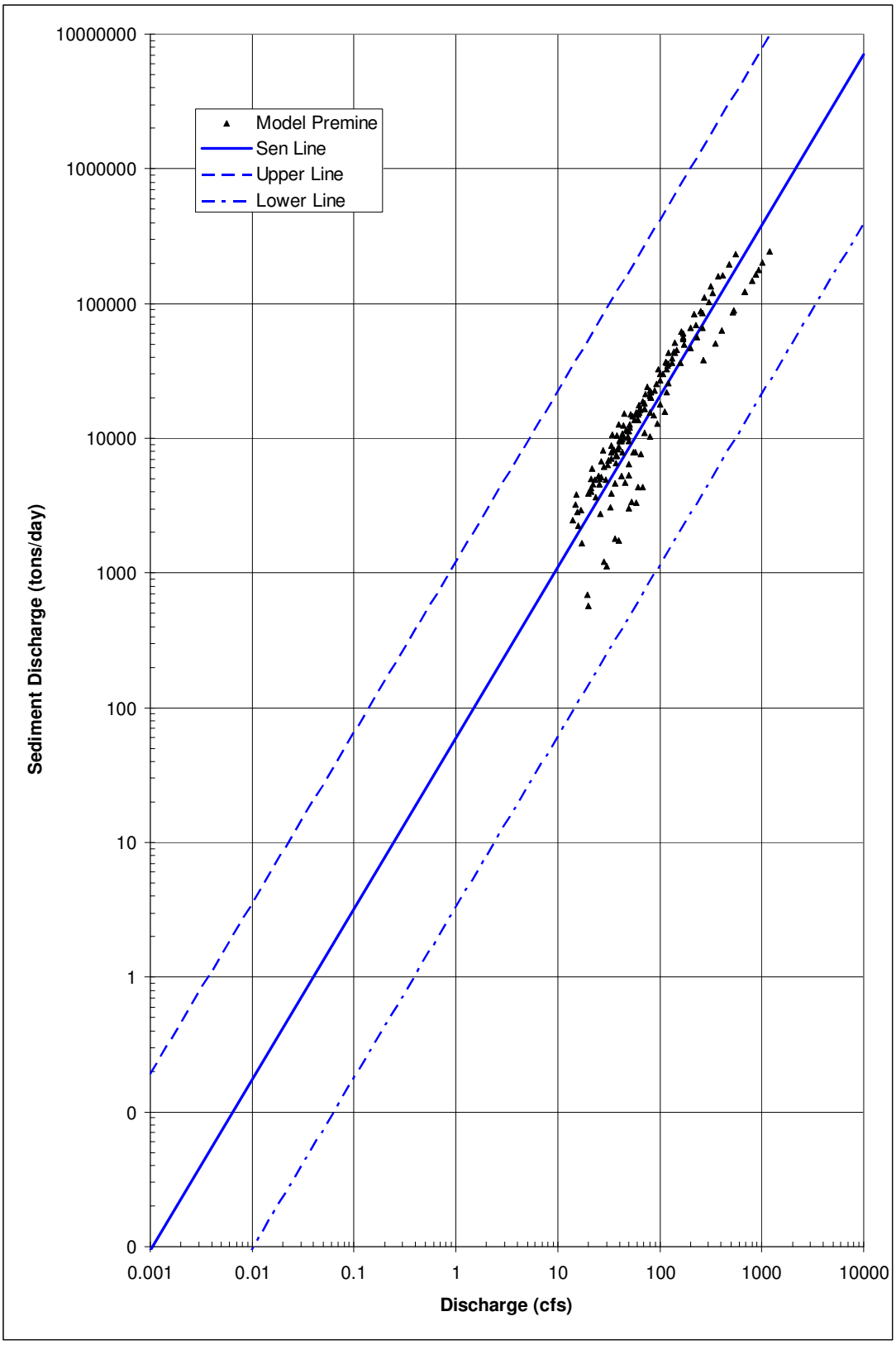


Figure 2.5. Modeled premine sediment and water discharge for the J16 WA with Sen lines.

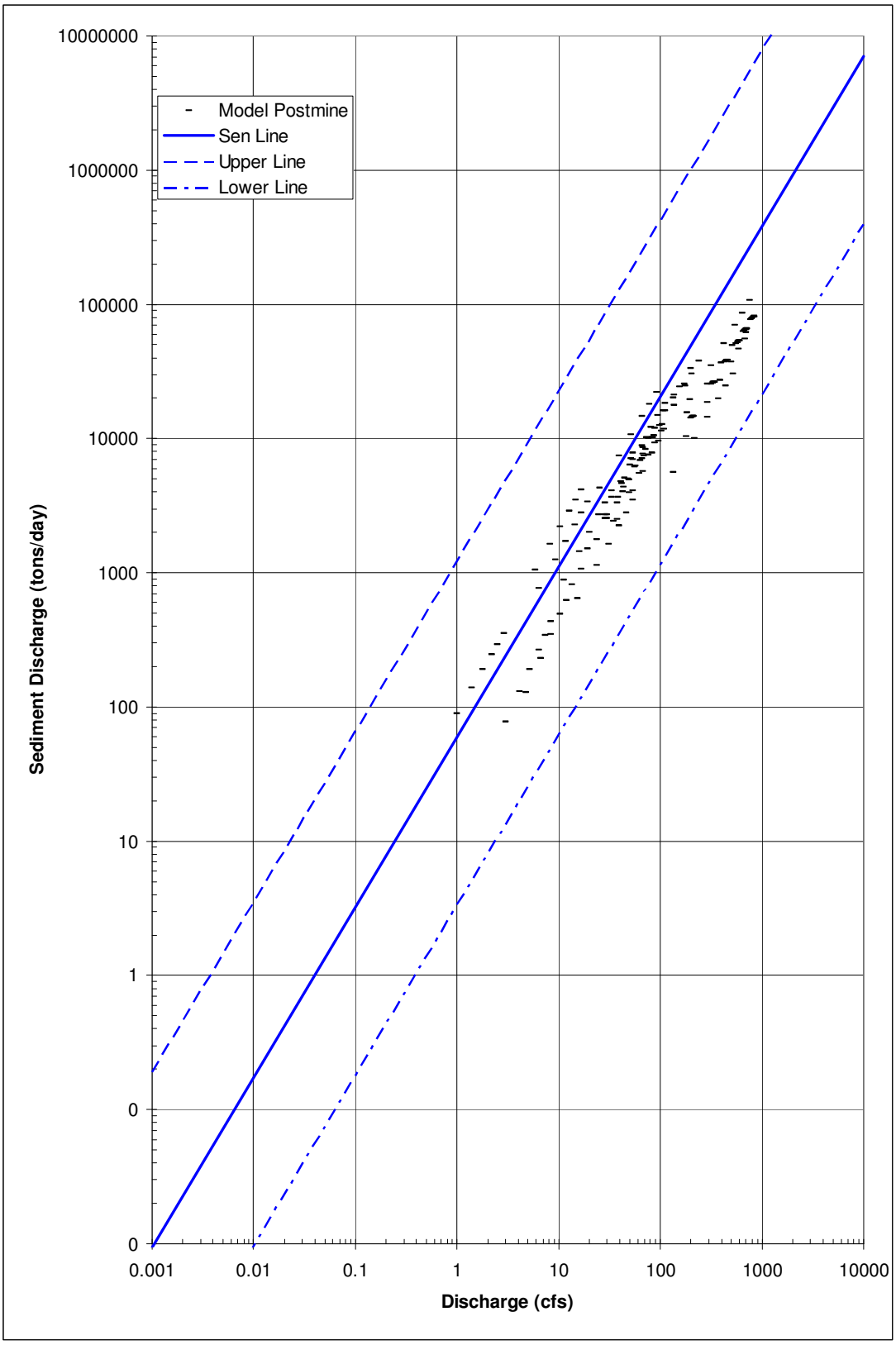


Figure 2.6. Modeled postmine sediment and water discharge for the J16 WA with Sen lines.

3. REFERENCES

Hjelmfelt, A.T., Kramer, L.A., and Spomer, R.G., 1986. Role of large events in average soil loss in Proceedings of the Fourth Federal Interagency Sedimentation Conference, March 24-27, 1986, Las Vegas, NV, p. 3-1 to 3-9.

Lagasse, P.F., Schall, J.D., and Peterson, M.R., 1985. Erosion Risk Analysis for a Southwestern Arroyo, Journal of Urban Planning and Management, American Society of Civil Engineers, v. III, no. I, November, 1985, Paper No. 20165.

Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973. "NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States," Volume VIII - Arizona, National Oceanic and Atmospheric Administration.

Renard, K.G. and Simaton, J.R., 1975. "Thunderstorm Precipitation Effects on the Rainfall-Erosion Index of the Universal Soil Loss Equation" in Volume 5 of Hydrology and Water Resources in Arizona and the Southwest, American Water Resources Assn., Arizona Section Arizona Academy of Science, Hydrology Section, Proceedings of April 11-12 meeting, Tempe AZ, v. 47-55.

Resource Consultants & Engineers, Inc. (RCE), 1993. "Surface Water Modeling of Reclaimed Parcels at the Black Mesa Complex," prepared for Peabody Western Coal Co.

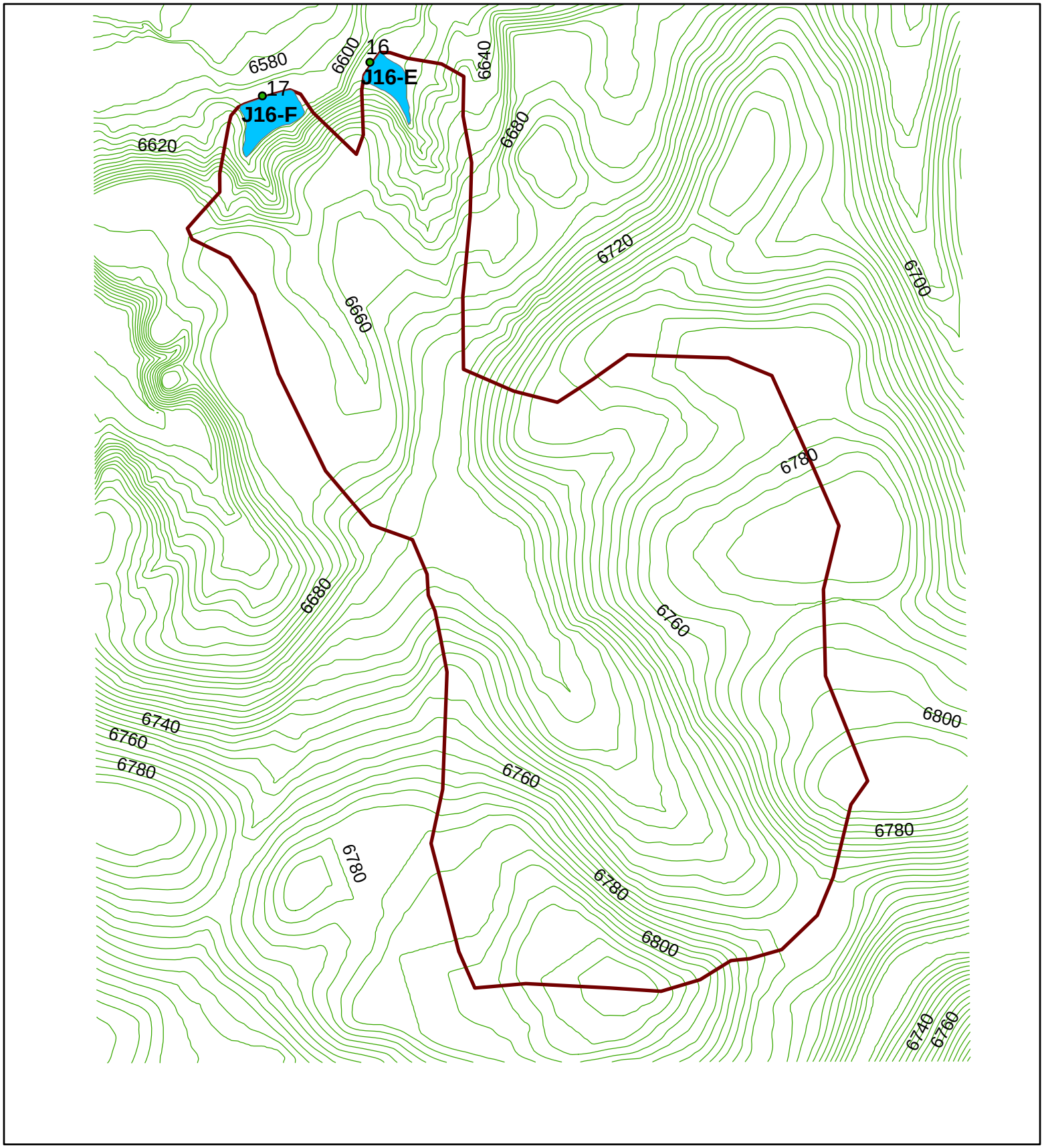
Sen, P.K., 1968. "Estimates of Regression Coefficient Based on Kendall's tau: Journal of American Statistical Association, v. 63, p. 1379-1389.

Smith, T. and Best, A., 2000. "Assessing Sedimentation and Protection of the Hydrologic Balance in Disturbed and Reclaimed Areas at the Black Mesa and Kayenta Mines, Arizona, Using Baseline Sediment Data Collected in Receiving Streams," presentation given at the Billings Mined Land Reclamation Symposium in 2001, Billings, MT.

Water Engineering & Technology, Inc. (WET), 1990. "Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control Technology at Surface Mines in the Semiarid West," prepared for Office of Surface Mining and the National Coal Association, Fort Collins, CO.

Zevenbergen, L.W., Peterson, M.R., and Watson, C.C., 1990. Computer simulation of watershed runoff and sedimentation processes, Proceedings of the Billings Symposium; Planning, Rehabilitation and Treatment of Disturbed Lands.

EXHIBIT 1
Postmine Topography



Legend

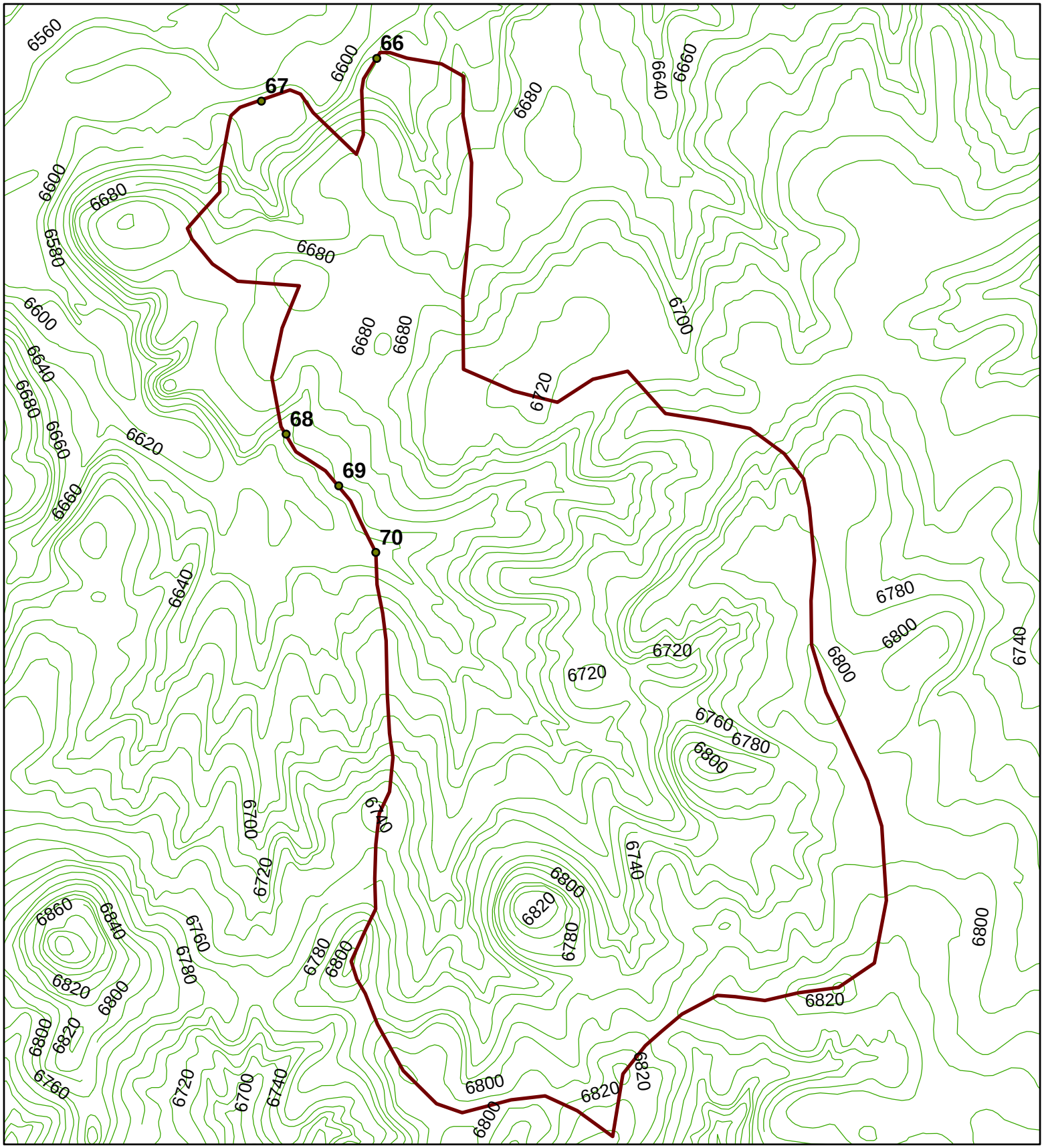
- End Points
- Ponds
- Modeling Area

N

0 300 600 1,200 1,800 Feet

Exhibit 1. Postmine Topography

EXHIBIT 2
Premine Topography



N

Legend

- End Points
- Modeling Area

0 300 600 1,200 1,800 Feet

Exhibit 2. Premine Topography

Appendix 5

Surface Water Modeling of the Reclaimed J21-A Watershed Area at Black Mesa Complex

SURFACE WATER MODELING OF THE RECLAIMED J21-A WATERSHED AREA AT BLACK MESA COMPLEX

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES

SURFACE WATER MODELING OF THE RECLAIMED J21-A WATERSHED AREA AT BLACK MESA COMPLEX

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES
P.O. Box 270460
Fort Collins, Colorado 80527
(970) 223-5556, FAX (970) 223-5578

Ayres Project No. 32-1304.00
PEA-J21A.DOC

April 2009

TABLE OF CONTENTS

1. Reclaimed Parcel Modeling 1.1

1.1 Introduction 1.1
1.2 Background 1.1
1.3 Data 1.2

1.3.1 Soils 1.2
1.3.2 Vegetation 1.2
1.3.3 Topography 1.3

1.4 Methodology 1.3

1.4.1 Synthetic Rainfall 1.8
1.4.2 Computation of Average Runoff and Sediment Yield 1.8

1.5 Results 1.8
1.6 Discussion 1.9

2. Comparisons with Measured Sediment Transport 2.1

3. References 3.1

Exhibit 1 – Postmine Topography ..... --
Exhibit 2 – Premine Topography ..... --

LIST OF FIGURES

Figure 1.1. Reclaimed area soils trilinear graph. 1.2

Figure 1.2. Spatial distribution of vegetative cover types for J21-A WA premine condition..... 1.4

Figure 1.3. J21-A postmine basin. 1.6

Figure 1.4. J21-A premine basins..... 1.7

Figure 2.1. Observed and modeled sediment and water discharge. 2.2

Figure 2.2. Observed versus modeled sediment concentration and discharge. 2.3

Figure 2.3. Background measured sediment and water discharge. 2.5

Figure 2.4. Reclaimed measured sediment and water discharge. 2.6

Figure 2.5. Modeled premine sediment and water discharge for the J21-A WA..... 2.7

Figure 2.6. Modeled postmine sediment and water discharge for the J21-A WA. 2.8

LIST OF TABLES

Table 1.1. Soils Data. 1.3

Table 1.2. Cover Sampling Data. 1.5

Table 1.3. Cover Data for J21-A Watershed..... 1.5

Table 1.4. Average Runoff and Sediment Yield Results. 1.8

Table 1.5. Average Physical Properties of the J21-A WA. 1.9

1. RECLAIMED PARCEL MODELING

1.1 Introduction

The objective defined by PWCC for this project is to use a previously calibrated and validated runoff and erosion model (EASI, Zevenbergen et al. 1990; WET 1990) for the Black Mesa and Kayenta Mines (combined as Black Mesa Complex in December 2008) to predict mean annual runoff and sediment yields from the reclaimed J21-A watershed. This objective included computation of runoff and sediment yields under premine conditions for the same area. All soils and rainfall input to the model are to be taken from models calibrated in the previous study (RCE 1993). The input variables that were calibrated to the mine areas and used in this study include soil infiltration parameters, erodibility parameters, and the grain size distribution. Parameters that are specific to this study are vegetative canopy and ground cover percentages from data collected on site.

The model calibration was conducted in a previous study (RCE 1993) using data obtained from instrumented watersheds and small hillslope plots under natural rainfall conditions. For a detailed discussion of data collection and model calibration, please refer to the previous study (RCE 1993).

1.2 Background

The J21-A Watershed Area (WA) that is the focus of this project was reclaimed between 1998 and 2003. The fundamental purpose of this study was to quantify the expected behavior and hydrologic response of the reclaimed areas above this pond relative to the conditions that existed prior to the occurrence of mining activities.

Runoff and sediment yield response from the reclaimed lands should be managed by implementing Best Management Practices (BMP's) in conjunction with an OSM approved sediment control plan in order to not adversely impact the prevailing hydrologic balance and to limit additional contributions of suspended sediment to streamflow or runoff outside the mine permit areas. BMP's include regrading, replacing salvaged topsoil, revegetation, and other controls such as riprap protected channel bottoms, check dams, and where practicable, contour terraces. The natural watersheds on the mesa contribute significant quantities of sediment to the channel system. It is expected that the postmine condition will also produce comparable amounts of sediment without adversely impacting the hydrologic balance.

This section describes the data and procedures used to evaluate the J21-A WA. This area was modeled to determine the average annual hydrologic response following the completion of reclamation activities taking into account BMP's implemented as part of the reclamation process. Infiltration, runoff, and erosion processes from both hillslopes and channels within the J21-A WA were modeled using EASI. Results were determined for a concentration point at the outlet of the reclaimed watershed, which corresponds to the embankment associated with Pond J21-A. The location of this point is shown in **Exhibit 1**. Modeling was also conducted to determine the hydrologic response under premine conditions based on the topography, soils, cover, and other conditions that typified the undisturbed watersheds draining to each concentration point. **Exhibit 2** shows the modeling endpoints for the premine J21-A WA.

1.3 Data

1.3.1 Soils

Soils data used for the current study (J21-A WA) were based on data developed from the calibration of models used in the previous study for Coal Resource Areas (CRAs) N1/N2 and J27 (RCE 1993). The composition of postmine soil in the current study is depicted along with the composition of postmine soils from the previous study in **Figure 1.1**. This figure shows that the soil composition of J21-A WA is very similar to soils evaluated during model calibration. Therefore, the soil properties developed in the previous study are valid for this modeling project. These properties include calibrated parameters, such as infiltration and erodibility coefficients, and measured soil size distributions. **Table 1.1** lists the premine and postmine soils data used during EASI modeling of J21-A WA.

1.3.2 Vegetation

Vegetative cover data representative of both pre- and postmine conditions in J21-A WA were supplied by PWCC. For the premine condition, land was characterized as being covered by sagebrush or pinon juniper. The spatial distribution of vegetative cover for the J21-A WA premine condition appears in **Figure 1.2**. Average cover properties for CRAs N1/N2 and J27 of the previous study and J21-A WA of the current study appear in **Table 1.2**. For the postmine condition, the reclaimed area was assigned the postmine cover type and the unmined area was assigned the same cover type as the premine condition. **Table 1.3** lists the pre- and postmine vegetative cover data used in the EASI model runs generated for the J21-A WA. Note that if a unit contained significant portions of both sagebrush and pinon juniper cover types, it was classified as half pinon juniper and half sagebrush.

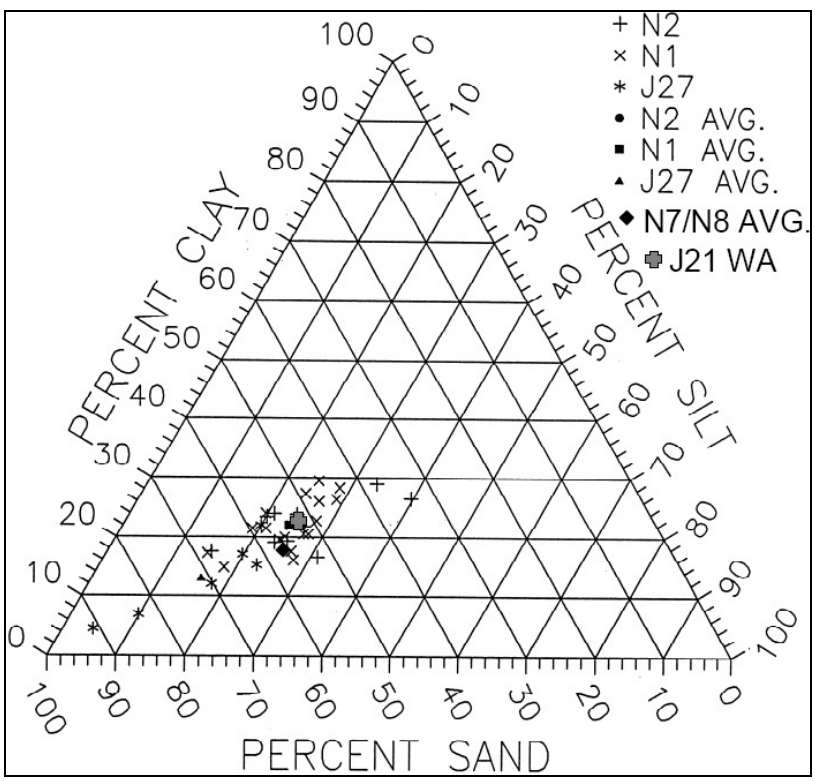


Figure 1.1. Reclaimed area soils trilinear graph.

Table 1.1. Soils Data.			
Condition	Premine	Postmine	Rock Chutes
Rainfall detachment	0.005	0.005	0
Overland flow detachment	0.44	0.44	0
Channel flow detachment	0.5	0.5	0
Initial soil moisture, %	70	70	70
Final soil moisture, %	90	90	90
Soil porosity, %	45	45	46
Temperature, *F	70	70	70
Hydraulic conductivity, in/hr	0.23	0.29	0.3
Capillary suction, in	3.7	2.6	2.6
	Particle Size Distribution (all conditions)		
	Size, mm	% Finer	
	0.001	0	
	0.004	18.0	
	0.016	27.4	
	0.062	36.6	
	0.125	56.2	
	0.250	64.3	
	0.500	72.4	
	1.000	80.5	
	2.000	88.6	
	4.000	92.4	
	16.000	100	

1.3.3 Topography

Pre- and postmine topography was supplied by PWCC in the form of ArcGIS geodatabase. Basin delineations, hillslope delineations, subwatershed delineations, as well as areas, slopes, and lengths of all units of the study area were defined and calculated using ArcGIS software. **Figures 1.3 and 1.4** show the watershed delineation and numbers assigned to the basins used in the EASI model for the post- and premine conditions, respectively. Channel dimensions input to EASI were based on the topography supplied and limited field observations.

1.4 Methodology

Runoff and sediment yield in the semiarid western United States is largely governed by the occurrence of high-intensity, short-duration rainstorms of limited areal extent (Renard and Simaton 1975). Research has indicated that relatively few events may produce the greatest erosion (e.g., Hjelmfelt et al. 1986 reported that only 3 to 4% of rainfall events accounted for 50% of long-term sediment yields). Although there is perhaps a relatively limited physical basis for definition of an "average annual" runoff or sediment yield in a semiarid environment due to the extreme variability in response and importance of single infrequent events, such a term does provide a useful basis for long-term comparison between reclaimed and undisturbed conditions.

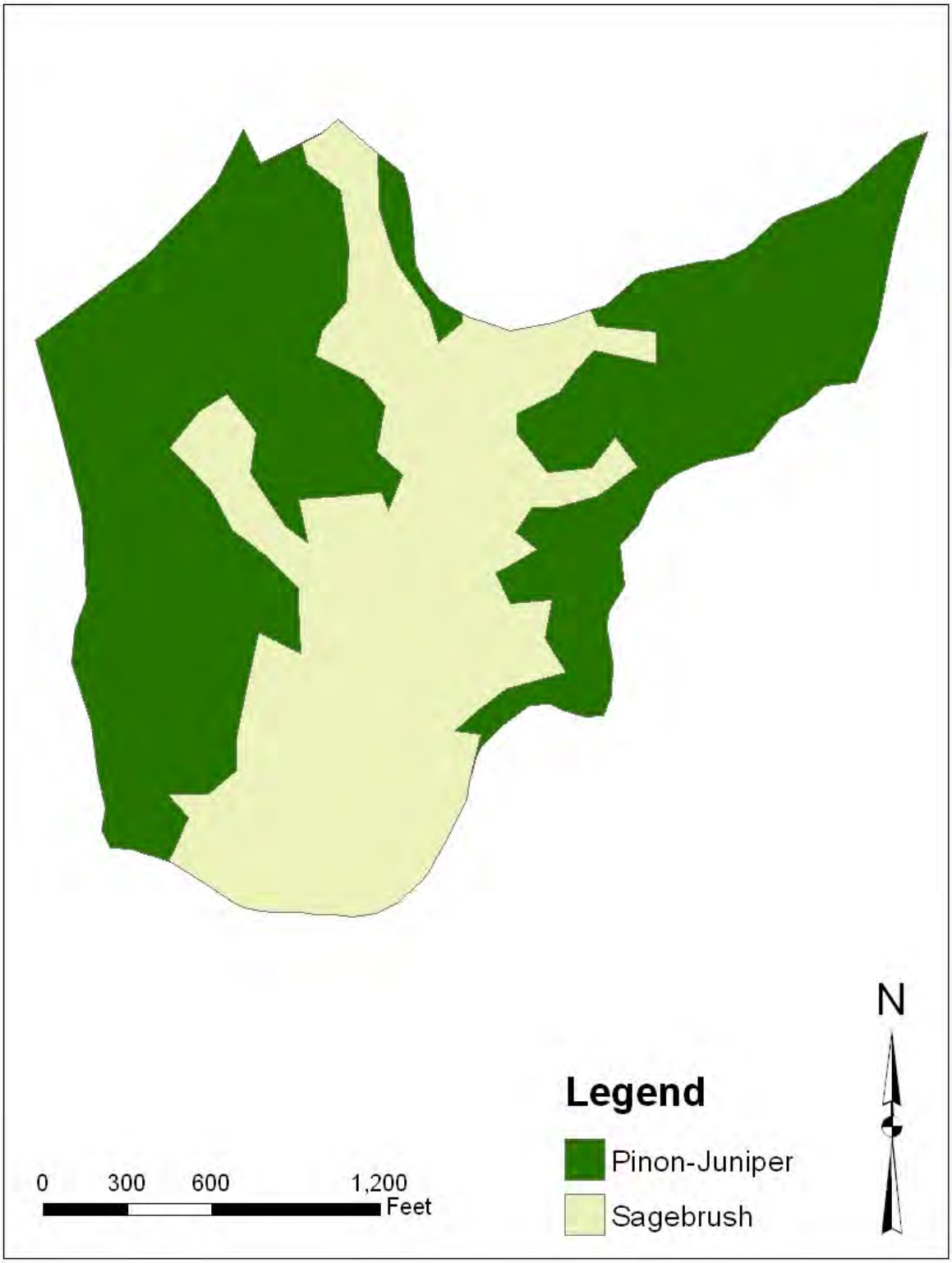


Figure 1.2. Spatial distribution of vegetative cover types for J21-A WA premine condition.

Table 1.2. Cover Sampling Data.								
Area	Condition	Cover Type	Nonstratified Vegetation Cover (%)	Vegetation Canopy Cover (%)	Vegetation Ground Cover (%)	Litter* (%)	Rock (%)	Total Ground Cover (%)
N1/N2	Postmine	Postmine	25.6	1.4	24.2	13.6	4.2	41.9
J21-A WA	Postmine	Postmine	23.0	0.3	22.8	25.3	4.6	52.7
N1/N2/J27	Premine	Pinon Juniper	32.7	31.1	3.0	44.0	19.7	66.7
J21-A WA	Premine	Pinon Juniper	20.0	16.8	3.9	28.8	16.7	49.3
N1/N2	Premine	Sagebrush	25.1	16.0	10.3	25.3	18.1	53.7
J27	Premine	Sagebrush	30.6	9.7	22.0	24.0	1.6	47.6
J21-A WA	Premine	Sagebrush	16.9	1.7	15.5	30.6	1.7	47.8
*Including standing dead litter								

Table 1.3. Cover Data for J21-A Watershed.				
Condition	Pinon Juniper	Sagebrush	Half Pinon Juniper-Half Sagebrush	Postmine
Canopy cover, %	16.8	1.7	9.3	0.3
Ground cover, %	49.3	47.8	48.5	52.7
Canopy storage, in	0.05	0.05	0.05	0.05
Ground storage, in	0.05	0.05	0.05	0.05
Depression storage, in	0.03	0.03	0.03	0.03
Impervious area, %	0	0	0	0
Manning's n	0.07	0.07	0.07	0.05

To make comparisons between reclaimed lands and associated undisturbed lands at the Black Mesa Mining Complex on the basis of average annual sediment yield, a procedure was used that considers the importance of infrequent storm events in defining sediment yield in the semiarid west. First, however, the site-specific rainfall data available for the Black Mesa Mining Complex were used to evaluate the frequency and magnitude of the measured events relative to existing predictions for rainfall depth-duration (Miller et al. 1973). The analysis of the rainfall data was performed as part of a previous study of the N1/N2 and J27 CRAs (Resource Consultants and Engineers 1993).

Comparisons between runoff and sediment yield from undisturbed and reclaimed areas in J21-A WA were developed for specific modeling endpoints shown in Exhibits 1 and 2. Mining and reclamation activities did not exactly replicate the topography, drainage network, or drainage areas that existed prior to mining. Consequently, direct comparisons of total runoff and sediment yield cannot be made between undisturbed and reclaimed response at a given point in a watershed. Comparisons were made on the basis of unit rates of runoff (inches) and sediment yield (tons/acre) at the various modeling computation endpoints. Although the same disturbance boundary was used to model extents for both pre- and postmine conditions, the topographic differences that resulted after mining and reclamation occurred in the J21-A WA dictated that some small areas would be included or excluded from the modeling. The area bounded by the modeling boundary identified by PWCC as shown in Exhibits 1 and 2 is 111.2 acres.

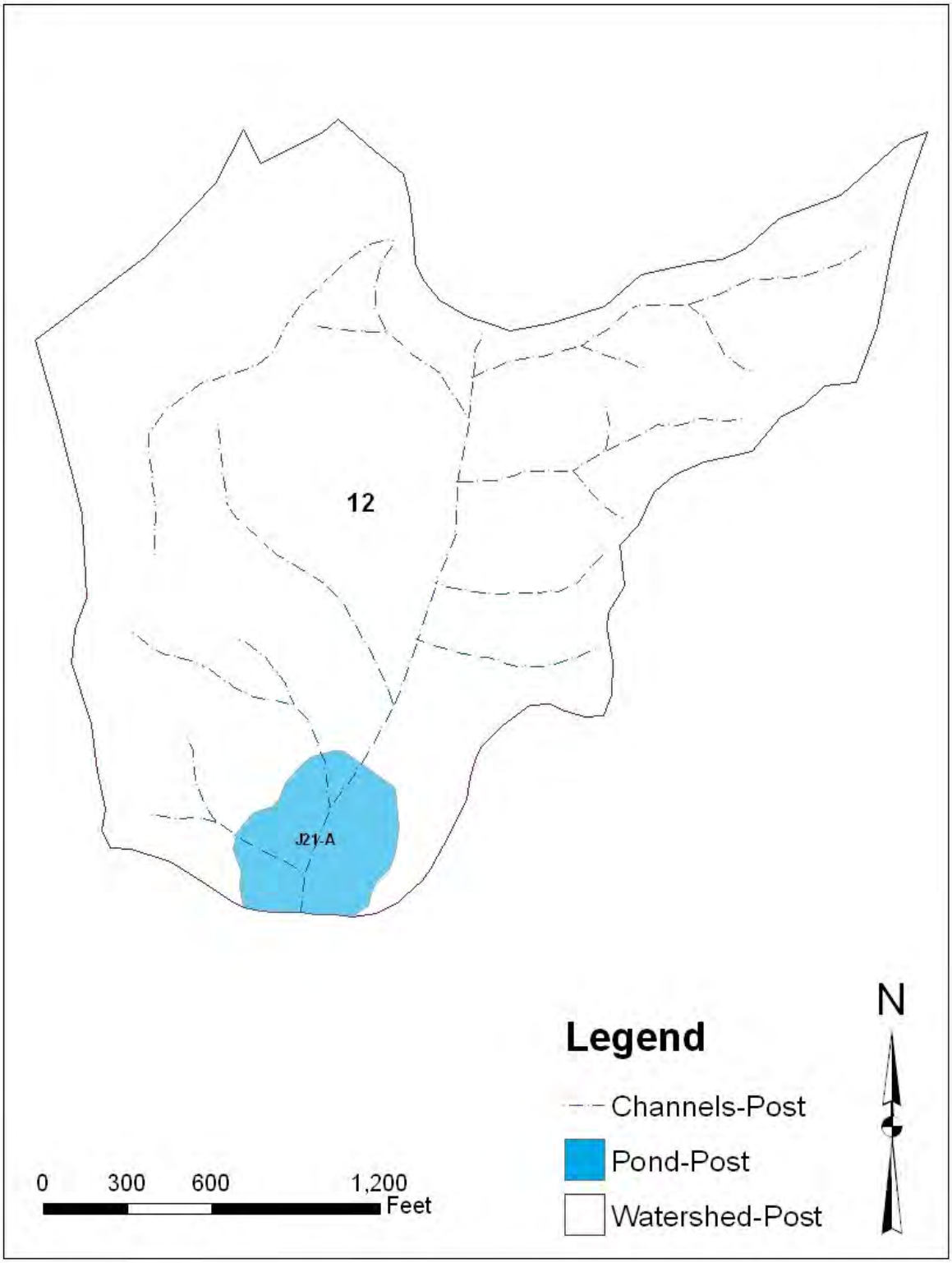


Figure 1.3. J21-A postmine basin.

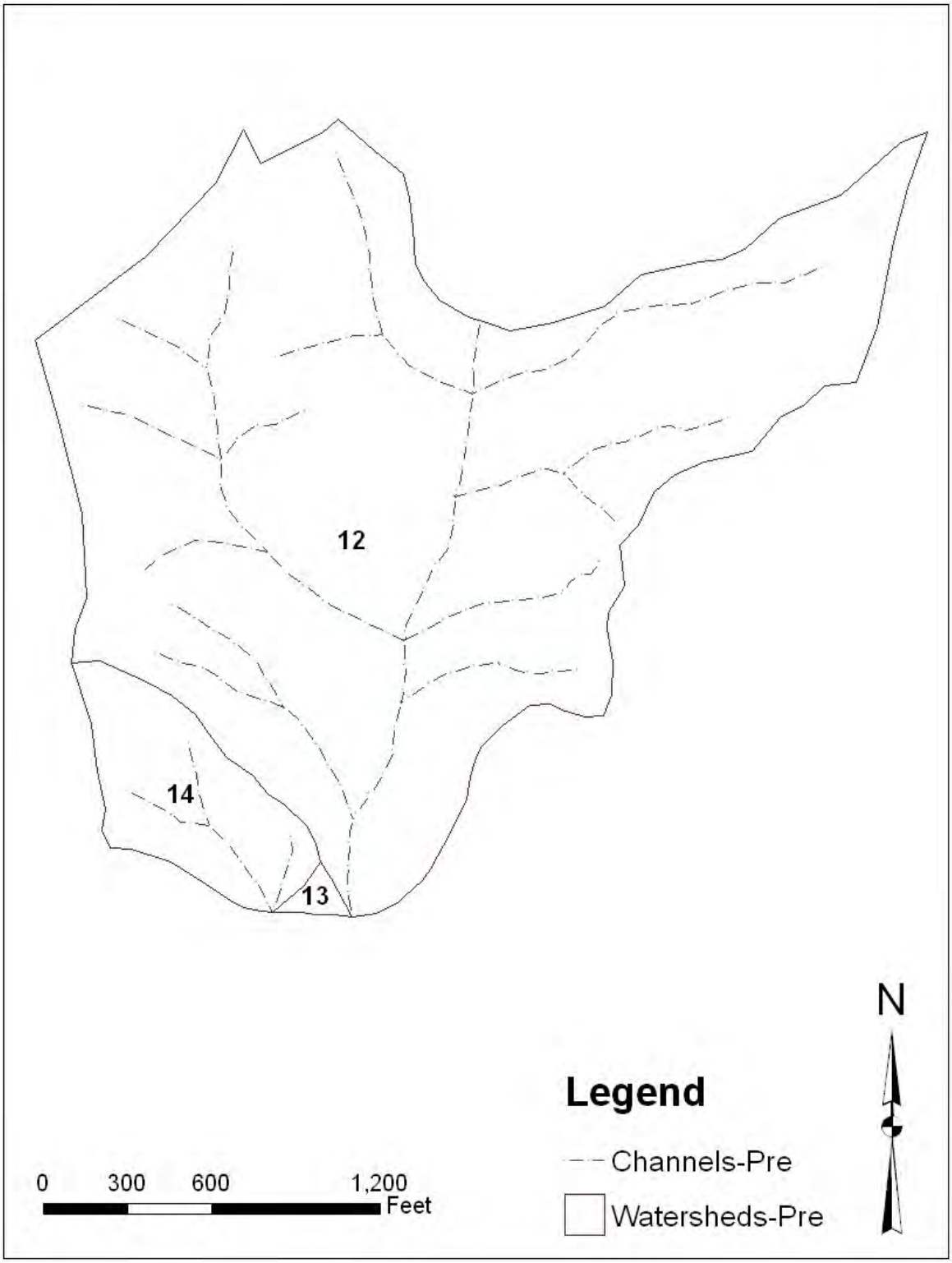


Figure 1.4. J21-A premine basins.

1.4.1 Synthetic Rainfall

Synthetic storms of 2-, 5-, 10-, 25-, 50-, and 100-year return periods were used as input to the EASI model. Actual hyetographs were taken from the previous study (RCE 1993) and are based on both local data collection and the NOAA Atlas (Miller et al. 1973).

1.4.2 Computation of Average Runoff and Sediment Yield

The EASI model was used to evaluate runoff and sediment yield from a series of storm events having recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100 years. To define average annual conditions, the average annual runoff and sediment yield generated from storm events were computed using the commonly used equation of Lagasse et al. (1985).

1.5 Results

Figures 1.3 and 1.4 show the post- and premine basin delineations. Since the individual subareas differ in number, acreage and outlet locations, a direct comparison is not possible on a subarea basis. Therefore, the best way to compare the results is on an average basis for the WA. **Table 1.4** shows pre- and postmine drainage area, runoff, and sediment yield for the J21-A WA. To consider the situation of pond removal for the postmine condition, the EASI model replaces a sediment pond with a channel, which lies near the location of the pond and discharges to the basin outlet. The channel is assumed to have a length equal to the pond's length and a slope similar to the outlet's natural slope. Runoff is defined as the total volume of water leaving the WA on an average annual basis and, therefore, does not include water stored in depression areas and ponds. For the premine condition, this is equal to the amount of water that drains off the hillslopes and subwatersheds because there are no ponds or significant depressions. For the postmine condition, this is equal to the amount of hillslope runoff less the amount stored in ponds. No ponds or significant depressions exist within the reclaimed J21-A WA that was modeled. Similarly, the sediment yield is the amount of eroded material that leaves the WA on an average annual basis computed using the equation of Lagasse et al. (1985). The sediment yield is the production from the hillslope areas and erosion from the channels. The amount of erosion is the sediment yield from the hillslopes and subwatersheds only and does not include channel erosion, channel deposition or sediment trapped in ponds. Sediment yield can be greater or less than erosion, depending on the amount of channel erosion and the capacity of the channel network to convey sediment off the leasehold.

Table 1.4. Average Runoff and Sediment Yield Results.

Area	Condition	Drainage Area (ac)	Runoff (in)	Sediment Yield (t/ac/yr)
J21-A	Premine	111.2	0.42	1.71
J21-A	Postmine	111.2	0.42	1.49

For the postmine condition, the overall sediment yield is less than the premine condition and runoff is the same as the premine amount.

1.6 Discussion

Table 1.5 gives an overview of the geometric properties of the pre- and postmine topographies for the J21-A WA. Average properties for hillslopes and channels are similar because only a small portion of J21-A WA was disturbed.

Table 1.5. Average Physical Properties of the J21-A WA.

	Premine	Postmine
Total Area (ac)	111.2	111.2
Total Channel Length (ft)	14115	13228
Mean Channel Slope	0.0761	0.0657
Drainage Density (mi/mi^2)	15.4	14.4
Mean Hillslope Length (ft)	396	261
Mean Hillslope Gradient	0.1262	0.1229

2. COMPARISONS WITH MEASURED SEDIMENT TRANSPORT

As discussed in Section 1, PWCC has monitored flow and sediment on the main channels, principal tributaries and small watersheds within the leasehold. These data, along with the runoff plots, were used to calibrate the EASI model soil erodibility and infiltration input variables. **Figures 2.1** and **2.2** show sediment transport and sediment concentration versus discharge for measured unmined (background), measured reclaimed, J21-A WA's modeled unmined (premine) and modeled reclaimed (postmine) data. Although there is significant scatter shown in the data (as is expected with any sediment transport conditions), there are several conclusions that can be drawn from this data.

The open symbols in both figures depict measured data and whether the data were collected from reclaimed areas (the small watershed study) or from unmined or background surface water monitoring stations. The range of flows is generally greater for the background data but there is significant overlap between the two data sets between 0.1 and 100 cfs. This is because the reclaimed data are from small watersheds and the unmined data are from channels draining larger basins. These data show the same trend for sediment transport and sediment concentration over the entire range of flows and very close agreement in the area of discharge overlap. This, in itself, is strong evidence that (1) the sediment yields are channel transport capacity limited, (2) overlap of model predictions for both pre- and postmine conditions with measured data strongly indicate that EASI model predictions are representative and reasonable, and (3) sediment yields from reclaimed areas will not be additive to yields on the receiving streams.

The closed symbols depict data from J21-A WA's pre- and postmine EASI model runs. They represent data generated by EASI for both subwatersheds and channels for peak discharges resulting from 2-, 5-, 10-, 25-, 50-, and 100-year storms. Using the peak flows from extreme events results in discharges that generally exceed 10 cfs. The trend of the model-derived data is similar and the ranges of concentration and sediment transport are similar to the measured data and between pre- and postmine conditions.

The sediment discharge plot (Figure 2.1) shows a stronger trend because it is plotting discharge (sediment) against discharge (flow). This is expected because the sediment discharge does depend on flow discharge. The concentration plot (Figure 2.2) shows the two separate variables and, therefore, a less significant trend. PWCC believes that data measurement may have some influence on the scatter (outliers were removed), but the process variability is probably the major influence. The majority of the data, however, fall in a group centered on 100 cfs and 100,000 mg/l, both in the observed data and in the model results. These plots support the use of the EASI model, the results of the modeling, the conclusion that sediment yields from reclaimed areas are not additive to receiving stream sediment loads, and that sediment impacts to the prevailing hydrologic balance have been minimized.

From Figures 2.1 and 2.2 it is apparent that sediment loads and concentrations are dependent on the channel sediment transport capacity for both pre- and postmine conditions. Channel sources of sediment in this arid environment are virtually unlimited. Therefore, channel transport capacity and channel derived sediment limits and governs sediment yields from the small tributaries, large channels and the WA as a whole.

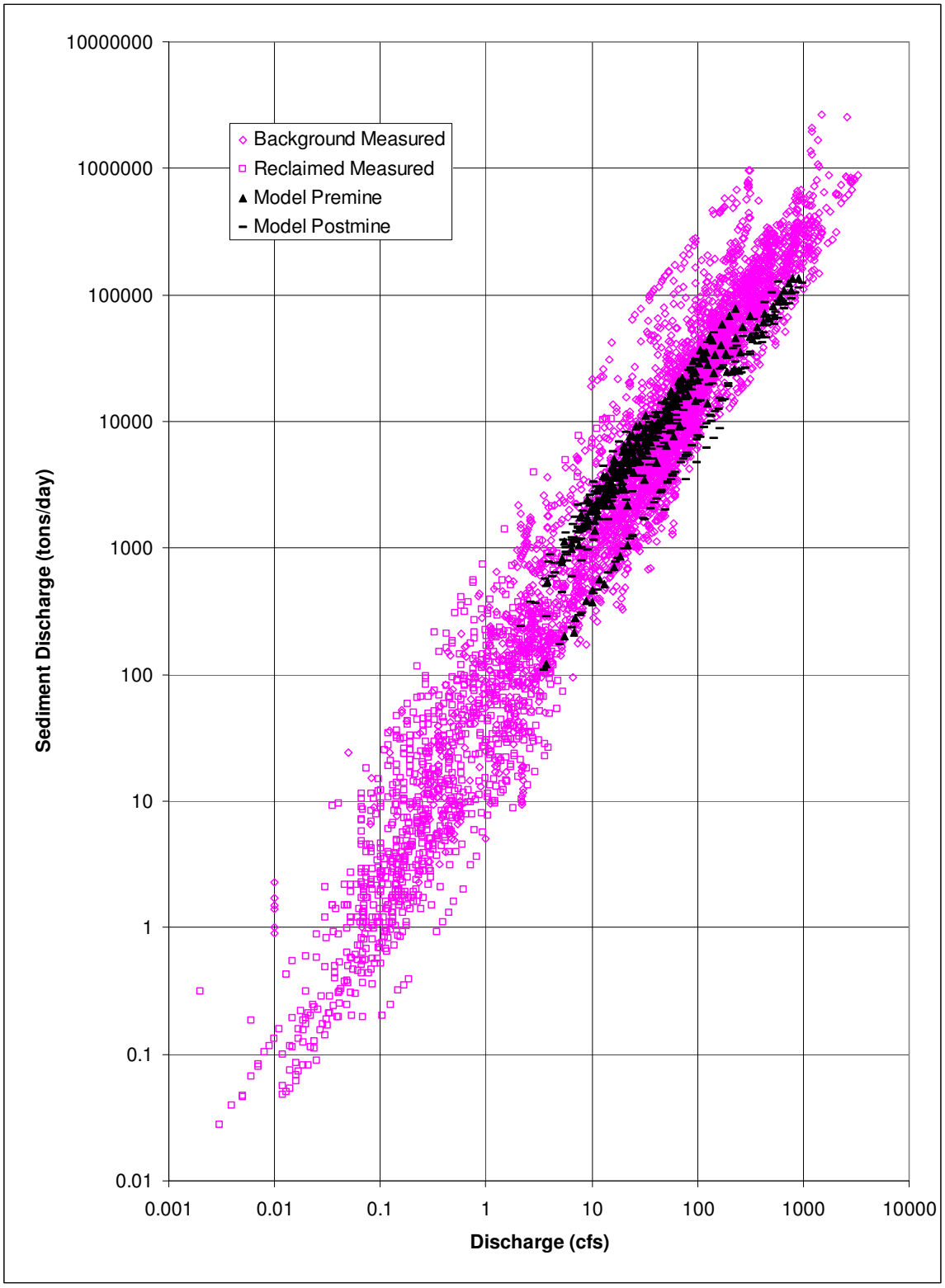


Figure 2.1. Observed and modeled sediment and water discharge.

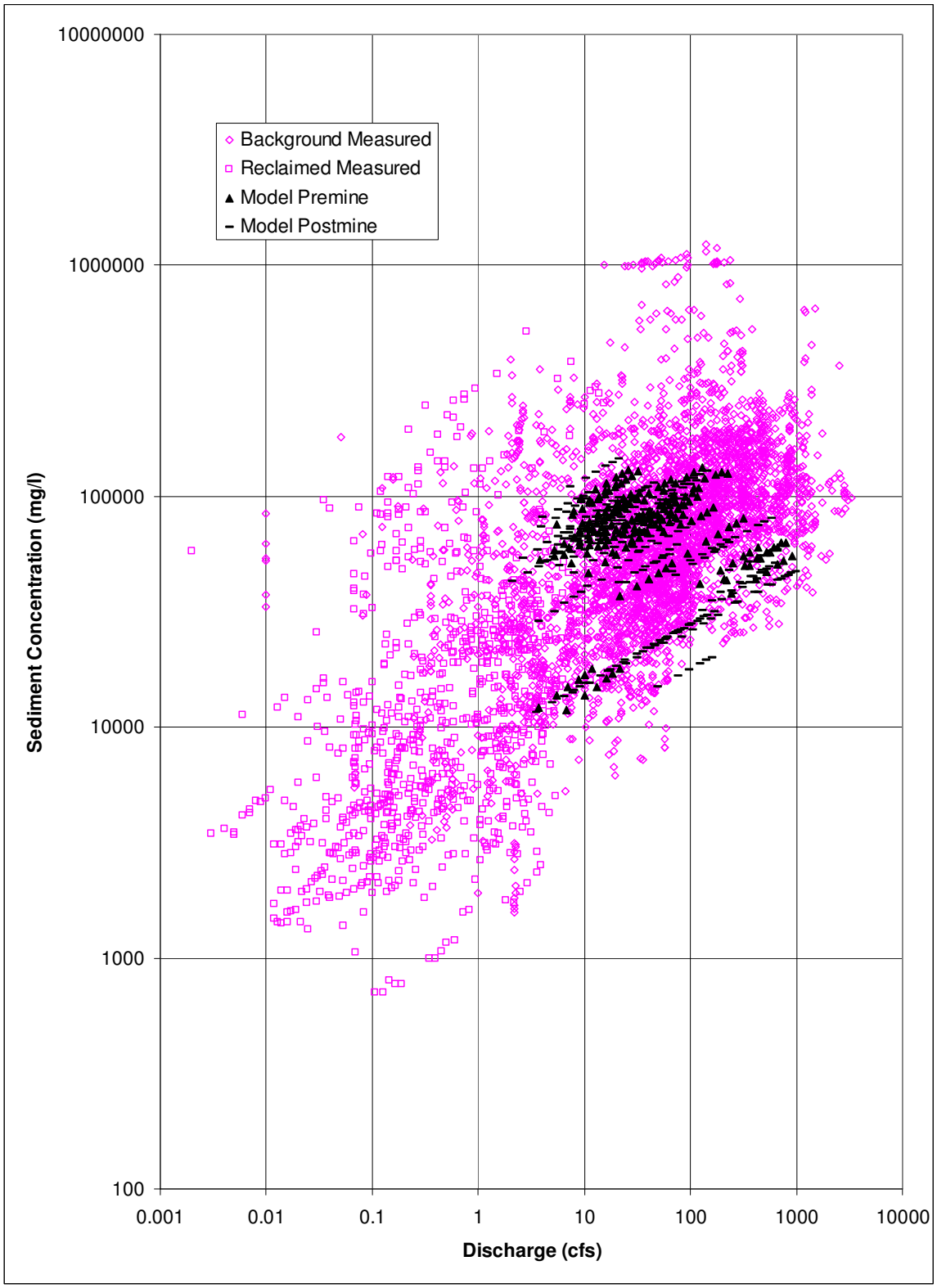


Figure 2.2. Observed versus modeled sediment concentration and discharge.

However, the sediment yield shown in Table 1.4 is the average annual amount of sediment leaving the J21-A WA whereas the sediment discharge shown in Figure 2.1 is the peak rate of sediment in transport occurring in any channel represented by the data, whether the channel is located upstream or downstream of a pond. Therefore, it should be concluded that with or without a pond left in the postmine landscape that traps sediment or stores water, the mine reclamation is not contributing additional sediment to the receiving streams and sediment impacts to the prevailing hydrologic balance have been minimized.

Smith and Best (2000) analyzed the measured data (background and reclaimed) shown in Figure 2.1 to develop an approach that can be used to determine if channels in reclaimed areas have similar sediment transport characteristics as background channels. The method that they used was to develop Sen lines (Sen 1968) and confidence intervals around the data. The slope of the Sen line is a non-parametric statistic computed as the median slope of all possible slopes determined from pairing all the data points. The Sen line is drawn through the median coordinate of the data. Smith and Best first showed that the large channel flume data (background) and the small watershed background data could be combined. They concluded that since the data from one data set fall within the Sen line bounds of the other data set then the two data sets are merely extensions of each other and could be combined. Also, because the main channel and background small watershed site data could be combined, it indicated there is an unlimited supply of sediment and the channels are conveying sediment at (or near) capacity. The Sen line and bounds are shown with the background measured data in **Figure 2.3**.

They then plotted the reclaimed measured data (**Figure 2.4**) with the Sen line and bounds from the background data to show that the reclaimed data have the same characteristics even though the flow range of the measurements is lower. The data indicate that channel flows in this environment achieve the sediment transport capacity of the channel, whether in reclaimed or background conditions.

Using the same approach with the modeled data generated for the J21-A WA, **Figures 2.5 and 2.6** show the pre- and postmine computed sediment transport rates with the Sen lines and bounds. One difference between the plots is that the measured data occur throughout the flow hydrograph whereas the modeled data are tabulated at the peak of the simulation flow hydrograph. The premine data plot (Figure 2.5) shows the data grouped above the Sen line and well within the bounds. The postmine data (Figure 2.6) plot shows the data are distributed around the Sen line and are more scattered. On these graphs data plotting above the Sen line indicate that there is more sediment in transport for a given discharge.

Several conclusions can be drawn from these data plots: (1) EASI model well replicates erosion and sediment transport processes at the mine site for background and reclaimed conditions, (2) all data show similar trends and are within the same bounds, (3) data trends indicate that channels are transporting sediment at or near capacity, and (4) amounts of sediment leaving the WA for postmine conditions are similar to premine conditions and within the range expected for the background conditions. Therefore, the overall conclusion is that the postmine reclaimed condition in J21-A WA is not contributing additional suspended solids to receiving streams, and related impacts to the hydrologic balance have been minimized.

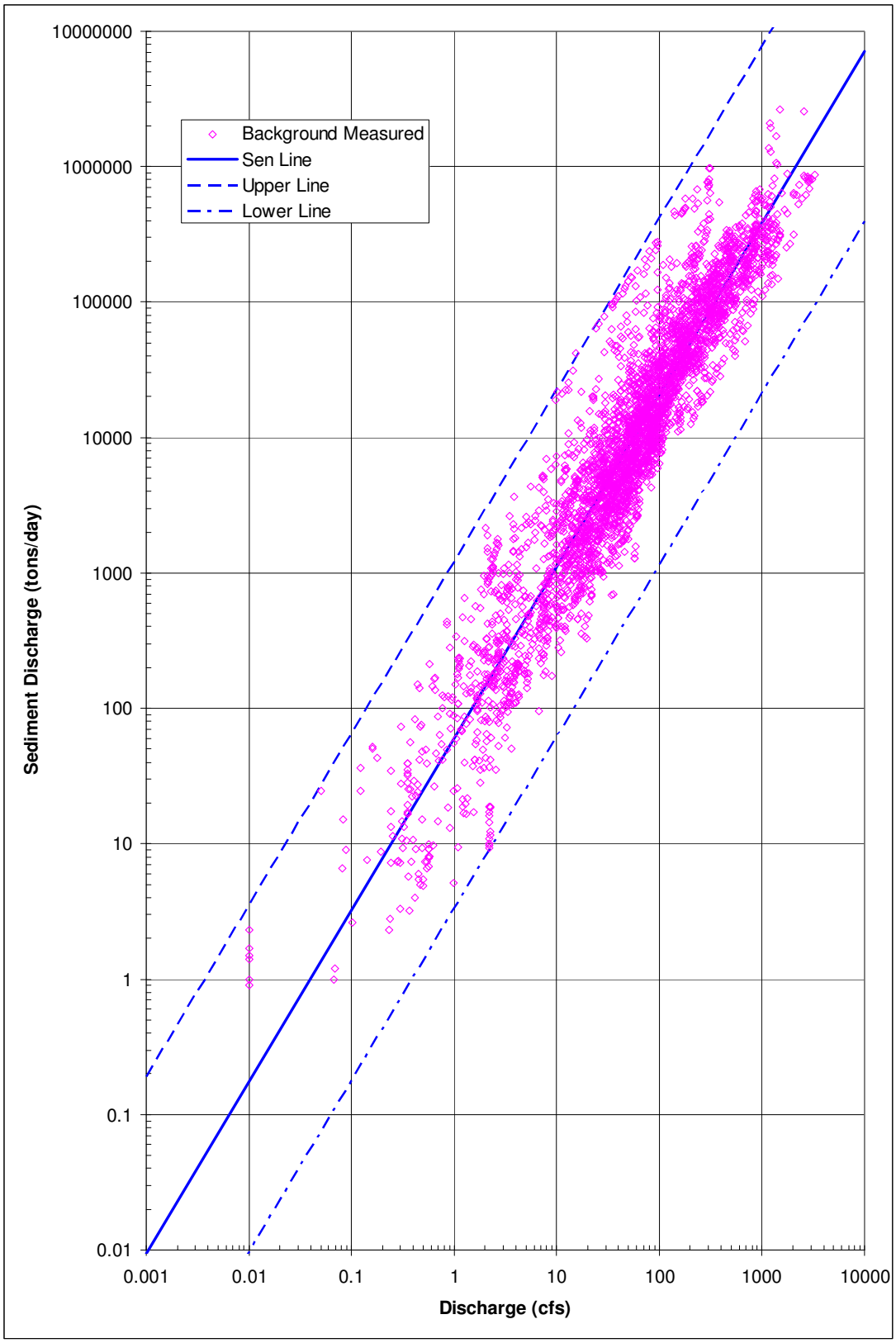


Figure 2.3. Background measured sediment and water discharge.

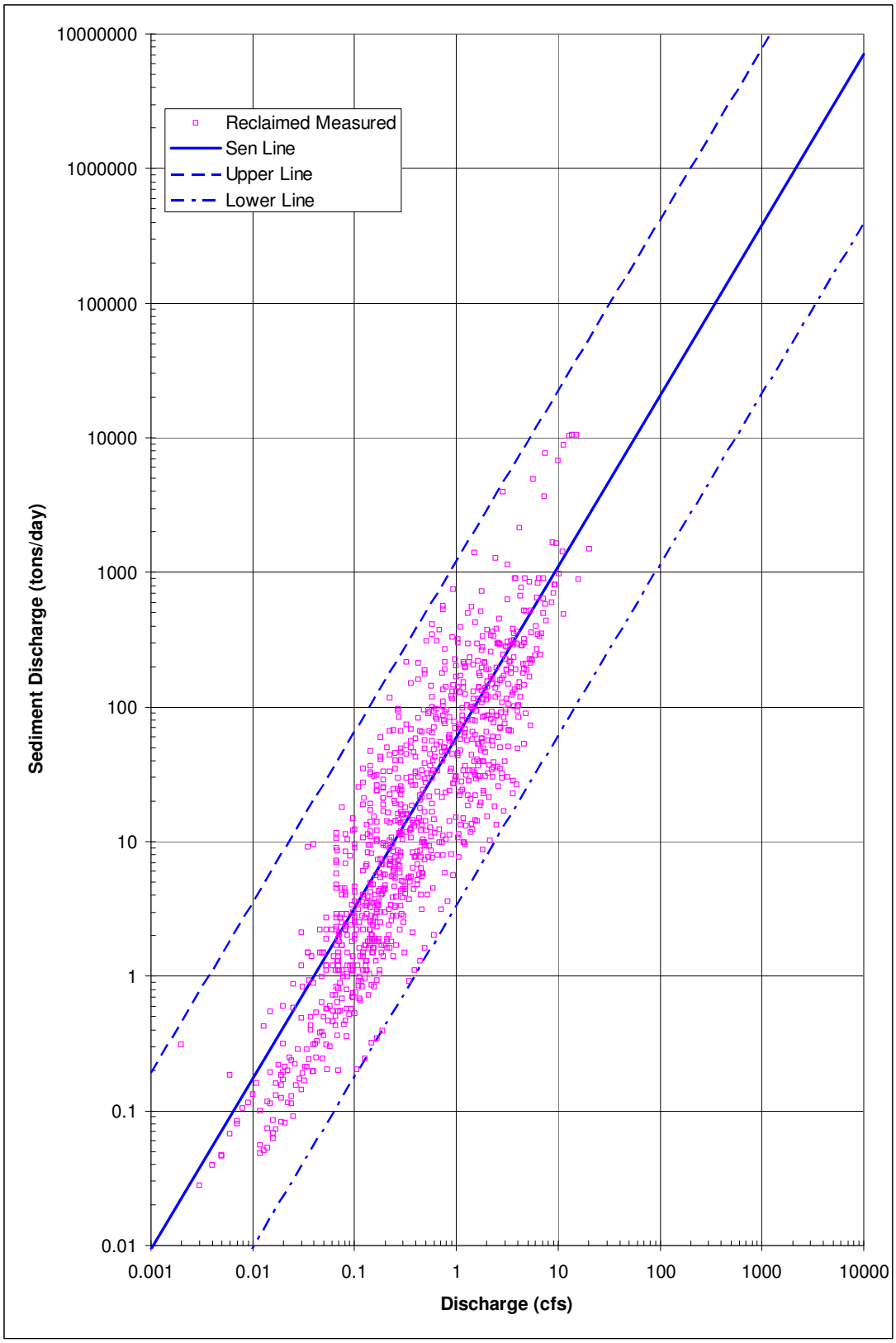


Figure 2.4. Reclaimed measured sediment and water discharge.

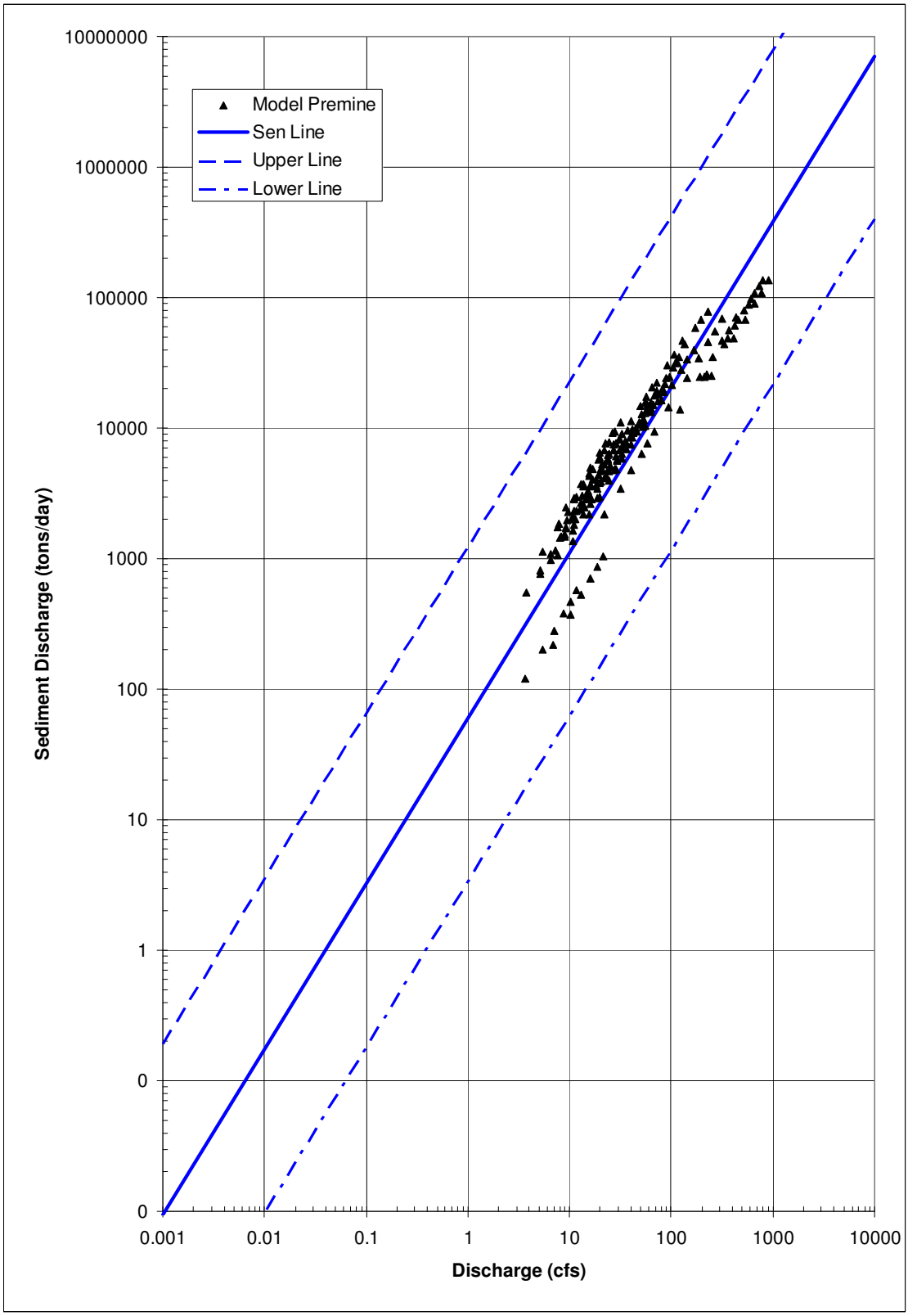


Figure 2.5. Modeled premine sediment and water discharge for the J21-A WA.

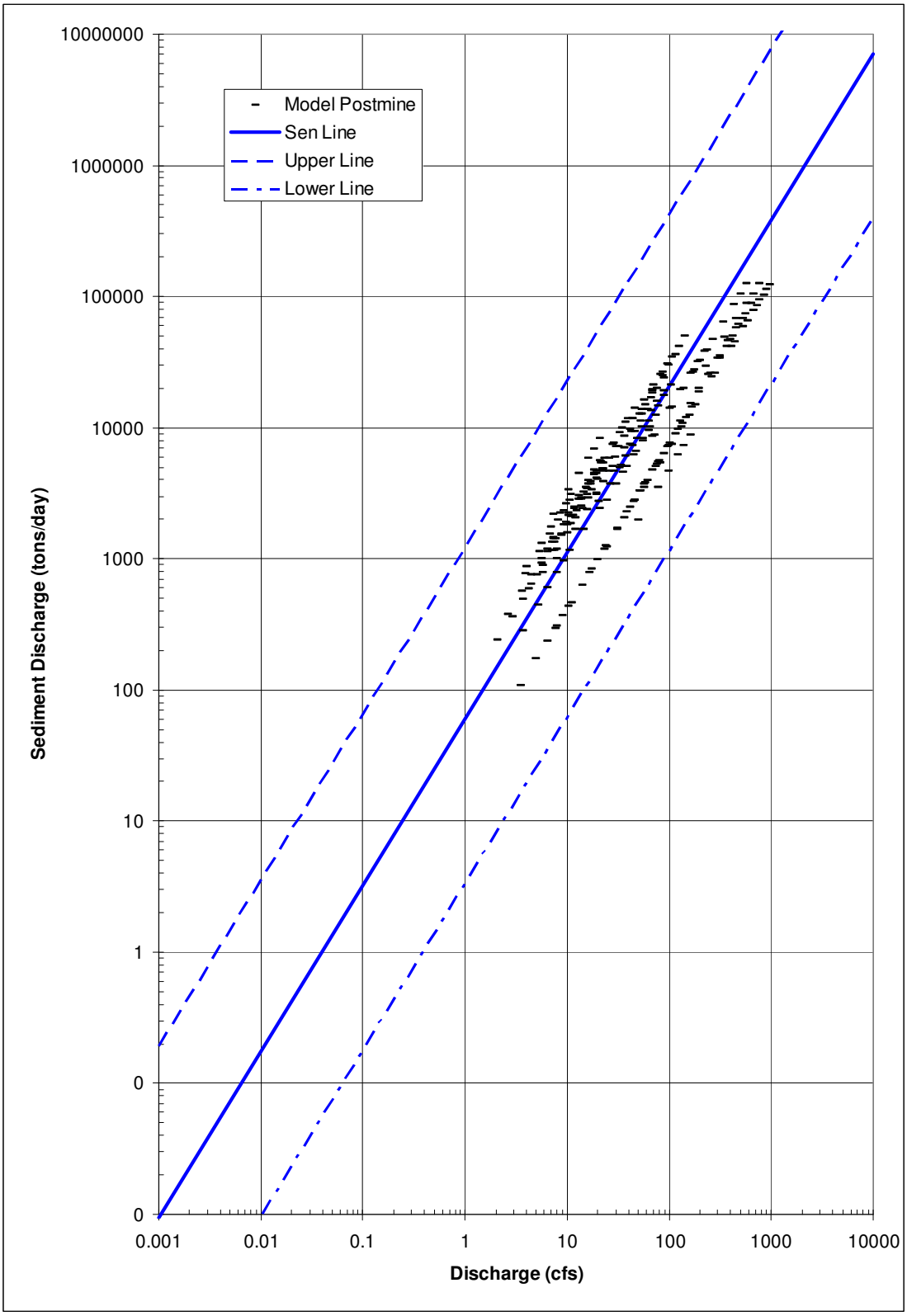


Figure 2.6. Modeled postmine sediment and water discharge for the J21-A WA.

3. REFERENCES

Hjelmfelt, A.T., Kramer, L.A., and Spomer, R.G., 1986. Role of large events in average soil loss in Proceedings of the Fourth Federal Interagency Sedimentation Conference, March 24-27, 1986, Las Vegas, NV, p. 3-1 to 3-9.

Lagasse, P.F., Schall, J.D., and Peterson, M.R., 1985. Erosion Risk Analysis for a Southwestern Arroyo, Journal of Urban Planning and Management, American Society of Civil Engineers, v. III, no. I, November, 1985, Paper No. 20165.

Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973. "NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States," Volume VIII - Arizona, National Oceanic and Atmospheric Administration.

Renard, K.G. and Simaton, J.R., 1975. "Thunderstorm Precipitation Effects on the Rainfall-Erosion Index of the Universal Soil Loss Equation" in Volume 5 of Hydrology and Water Resources in Arizona and the Southwest, American Water Resources Assn., Arizona Section Arizona Academy of Science, Hydrology Section, Proceedings of April 11-12 meeting, Tempe AZ, v. 47-55.

Resource Consultants & Engineers, Inc. (RCE), 1993. "Surface Water Modeling of Reclaimed Parcels at the Black Mesa Complex," prepared for Peabody Western Coal Co.

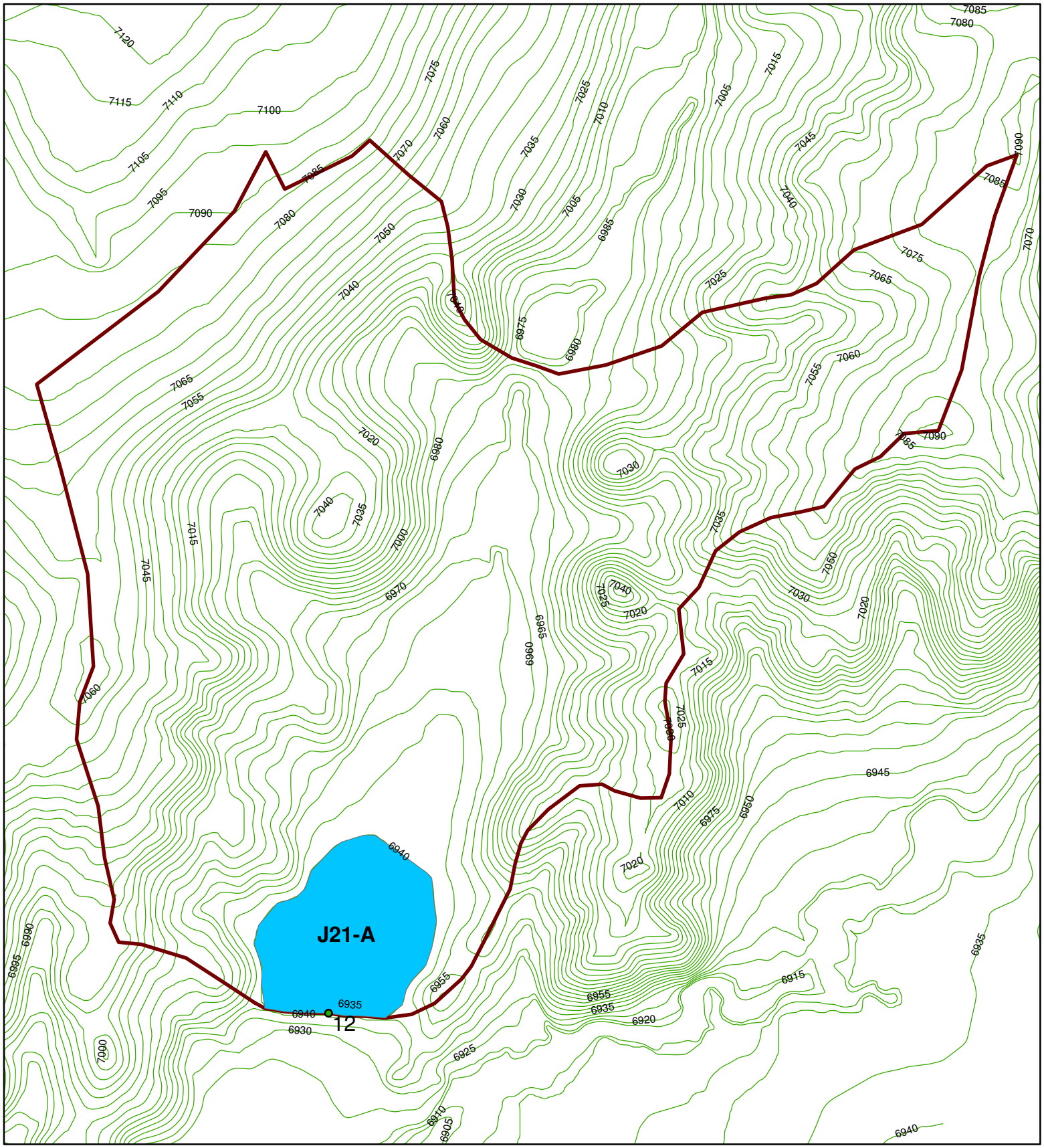
Sen, P.K., 1968. "Estimates of Regression Coefficient Based on Kendall's tau: Journal of American Statistical Association, v. 63, p. 1379-1389.

Smith, T. and Best, A., 2000. "Assessing Sedimentation and Protection of the Hydrologic Balance in Disturbed and Reclaimed Areas at the Black Mesa and Kayenta Mines, Arizona, Using Baseline Sediment Data Collected in Receiving Streams," presentation given at the Billings Mined Land Reclamation Symposium in 2001, Billings, MT.

Water Engineering & Technology, Inc. (WET), 1990. "Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control Technology at Surface Mines in the Semiarid West," prepared for Office of Surface Mining and the National Coal Association, Fort Collins, CO.

Zevenbergen, L.W., Peterson, M.R., and Watson, C.C., 1990. Computer simulation of watershed runoff and sedimentation processes, Proceedings of the Billings Symposium; Planning, Rehabilitation and Treatment of Disturbed Lands.

EXHIBIT 1
Postmine Topography



N

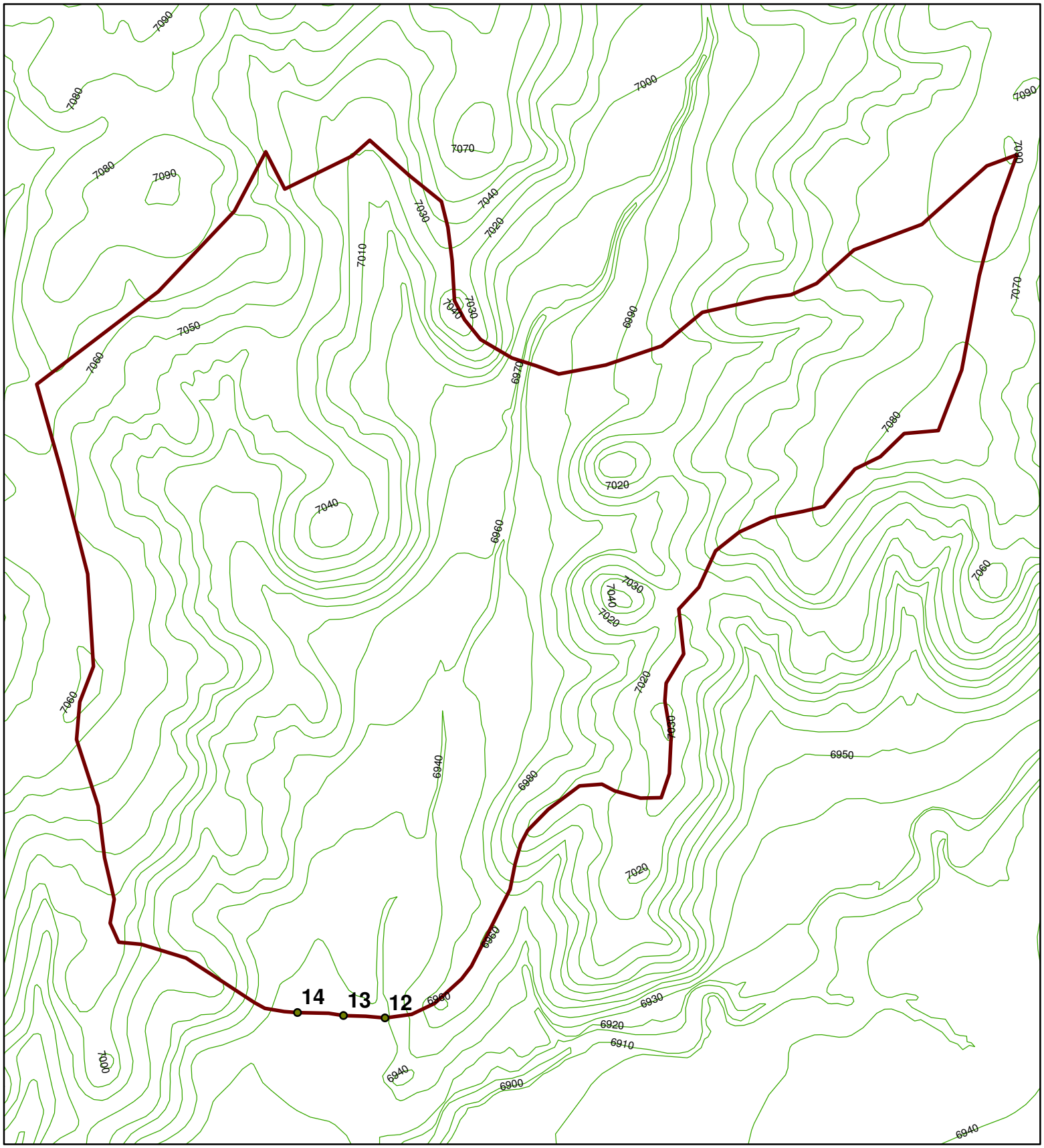
Legend

- End Points
- Ponds
- Modeling Area

0 200 400 800 1,200 Feet

Exhibit 1. Postmine Topography
(5 foot contour)

EXHIBIT 2
Premine Topography



N

Legend

- End Points
- Modeling Area

0 200 400 800 1,200 Feet

Exhibit 2. Premine Topography
(10 foot contour)

Appendix 6

Surface Water Modeling of the Reclaimed N6-G Watershed Area at Black Mesa Complex

SURFACE WATER MODELING OF THE RECLAIMED N6-G WATERSHED AREA AT BLACK MESA COMPLEX

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES

SURFACE WATER MODELING OF THE RECLAIMED N6-G WATERSHED AREA AT BLACK MESA COMPLEX

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES
P.O. Box 270460
Fort Collins, Colorado 80527
(970) 223-5556, FAX (970) 223-5578

Ayres Project No. 32-1304.00
PEAB-N6G.DOC

April 2009

TABLE OF CONTENTS

1. Reclaimed Parcel Modeling 1.1

1.1 Introduction 1.1
1.2 Background 1.1
1.3 Data 1.2

1.3.1 Soils 1.2
1.3.2 Vegetation 1.2
1.3.3 Topography 1.3

1.4 Methodology 1.3

1.4.1 Synthetic Rainfall 1.8
1.4.2 Computation of Average Runoff and Sediment Yield 1.8

1.5 Results 1.8
1.6 Discussion 1.9

2. Comparisons with Measured Sediment Transport 2.1

3. References 3.1

Exhibit 1 – Postmine Topography ..... --
Exhibit 2 – Premine Topography ..... --

LIST OF FIGURES

Figure 1.1. Reclaimed area soils trilinear graph. 1.2

Figure 1.2. Spatial distribution of vegetative cover types for N6-G WA premine condition..... 1.4

Figure 1.3. N6-G postmine basins. 1.6

Figure 1.4. N6-G premine basins. 1.7

Figure 2.1. Observed and modeled sediment and water discharge. 2.2

Figure 2.2. Observed versus modeled sediment concentration and discharge. 2.3

Figure 2.3. Background measured sediment and water discharge. 2.5

Figure 2.4. Reclaimed measured sediment and water discharge. 2.6

Figure 2.5. Modeled premine sediment and water discharge for the N6-G WA..... 2.7

Figure 2.6. Modeled postmine sediment and water discharge for the N6-G WA. 2.8

LIST OF TABLES

Table 1.1. Soils Data. 1.3

Table 1.2. Cover Sampling Data. 1.5

Table 1.3. Cover Data for N6-G Watershed. 1.5

Table 1.4. Average Runoff and Sediment Yield Results. 1.8

Table 1.5. Average Physical Properties of the N6-G WA. 1.9

1. RECLAIMED PARCEL MODELING

1.1 Introduction

The objective defined by PWCC for this project is to use a previously calibrated and validated runoff and erosion model (EASI, Zevenbergen et al. 1990; WET 1990) for the Black Mesa and Kayenta Mines (combined as Black Mesa Complex in December 2008) to predict mean annual runoff and sediment yields from the reclaimed N6-G watershed. This objective included computation of runoff and sediment yields under premine conditions for the same area. All soils and rainfall input to the model are to be taken from models calibrated in the previous study (RCE 1993). The input variables that were calibrated to the mine areas and used in this study include soil infiltration parameters, erodibility parameters, and the grain size distribution. Parameters that are specific to this study are vegetative canopy and ground cover percentages from data collected on site.

The model calibration was conducted in a previous study (RCE 1993) using data obtained from instrumented watersheds and small hillslope plots under natural rainfall conditions. For a detailed discussion of data collection and model calibration, please refer to the previous study (RCE 1993).

1.2 Background

The N6-G Watershed Area (WA) that is the focus of this project was reclaimed between 1993 and 2007. The fundamental purpose of this study was to quantify the expected behavior and hydrologic response of the reclaimed areas above this pond relative to the conditions that existed prior to the occurrence of mining activities.

Runoff and sediment yield response from the reclaimed lands should be managed by implementing Best Management Practices (BMP's) in conjunction with an OSM approved sediment control plan in order to not adversely impact the prevailing hydrologic balance and to limit additional contributions of suspended sediment to streamflow or runoff outside the mine permit areas. BMP's include regrading, replacing salvaged topsoil, revegetation, and other controls such as riprap protected channel bottoms, check dams, and where practicable, contour terraces. The natural watersheds on the mesa contribute significant quantities of sediment to the channel system. It is expected that the postmine condition will also produce comparable amounts of sediment without adversely impacting the hydrologic balance.

This section describes the data and procedures used to evaluate the N6-G WA. This area was modeled to determine the average annual hydrologic response following the completion of reclamation activities taking into account BMP's implemented as part of the reclamation process. Infiltration, runoff, and erosion processes from both hillslopes and channels within the N6-G WA were modeled using EASI. Results were determined for concentration points at the outlets of the reclaimed watersheds, several of which correspond to the embankment associated with Pond N6-G. The locations of these points are shown in **Exhibit 1**. Modeling was also conducted to determine the hydrologic response under premine conditions based on the topography, soils, cover, and other conditions that typified the undisturbed watersheds draining to each concentration point. **Exhibit 2** shows the modeling endpoints for the premine N6-G WA.

1.3 Data

1.3.1 Soils

Soils data used for the current study (N6-G WA) were based on data developed from the calibration of models used in the previous study for Coal Resource Areas (CRAs) N1/N2 and J27 (RCE 1993). The composition of postmine soil in the current study is depicted along with the composition of postmine soils from the previous study in **Figure 1.1**. This figure shows that the soil composition of N6-G WA is very similar to soils evaluated during model calibration. Therefore, the soil properties developed in the previous study are valid for this modeling project. These properties include calibrated parameters, such as infiltration and erodibility coefficients, and measured soil size distributions. **Table 1.1** lists the premine and postmine soils data used during EASI modeling of N6-G WA.

1.3.2 Vegetation

Vegetative cover data representative of both pre- and postmine conditions in N6-G WA were supplied by PWCC. For the premine condition, land was characterized as being covered by sagebrush or pinon juniper. The spatial distribution of vegetative cover for the N6-G WA premine condition appears in **Figure 1.2**. Average cover properties for CRAs N1/N2 and J27 of the previous study and N6-G WA of the current study appear in **Table 1.2**. The south-central portion of N6-G WA is covered with red rock as a postmine erosion-control measure. The red rock area is about 5.7 acres, and its cover data is also included in Table 1.2. Revegetation activities in the N6-G WA were completed from 1993-2007. The area revegetated in 2007 represents 1.7% of the reclaimed watershed and is in its second growing season. Postmine cover data in Table 1.2 reflects the current condition. For the postmine condition, the reclaimed area was assigned the postmine cover type and the unmined area was assigned the same cover type as the premine condition. **Table 1.3** lists the pre- and postmine vegetative cover data used in the EASI model runs generated for the N6-G WA. Note that if a unit contained significant portions of both sagebrush and pinon juniper cover types, it was classified as half pinon juniper and half sagebrush.

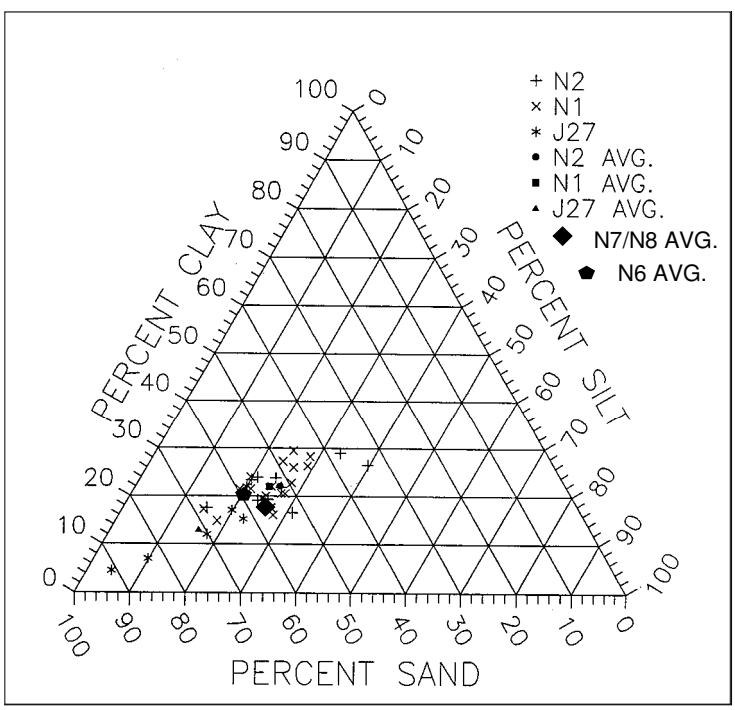


Figure 1.1. Reclaimed area soils trilinear graph.

Table 1.1. Soils Data.			
Condition	Premine	Postmine	Rock Chutes
Rainfall detachment	0.005	0.005	0
Overland flow detachment	0.44	0.44	0
Channel flow detachment	0.5	0.5	0
Initial soil moisture, %	70	70	70
Final soil moisture, %	90	90	90
Soil porosity, %	45	45	46
Temperature, *F	70	70	70
Hydraulic conductivity, in/hr	0.23	0.29	0.3
Capillary suction, in	3.7	2.6	2.6
	Particle Size Distribution (all conditions)		
	Size, mm	% Finer	
	0.001	0	
	0.004	18.0	
	0.016	27.4	
	0.062	36.6	
	0.125	56.2	
	0.250	64.3	
	0.500	72.4	
	1.000	80.5	
	2.000	88.6	
	4.000	92.4	
	16.000	100	

1.3.3 Topography

Pre- and postmine topography was supplied by PWCC in the form of ArcGIS geodatabase. Basin delineations, hillslope delineations, subwatershed delineations, as well as areas, slopes, and lengths of all units of the study area were defined and calculated using ArcGIS software. **Figures 1.3 and 1.4** show the watershed delineation and numbers assigned to the basins used in the EASI model for the post- and premine conditions, respectively. Channel dimensions input to EASI were based on the topography supplied and limited field observations. A topsoil stockpile at the southwest of N6-G WA will be removed in the near future. The postmine topography at the location of the topsoil stockpile is assumed to be similar to the premine topography.

1.4 Methodology

Runoff and sediment yield in the semiarid western United States is largely governed by the occurrence of high-intensity, short-duration rainstorms of limited areal extent (Renard and Simaton 1975). Research has indicated that relatively few events may produce the greatest erosion (e.g., Hjelmfelt et al. 1986 reported that only 3 to 4% of rainfall events accounted for 50% of long-term sediment yields). Although there is perhaps a relatively limited physical basis for definition of an "average annual" runoff or sediment yield in a semiarid environment due to the extreme variability in response and importance of single infrequent events, such a term does provide a useful basis for long-term comparison between reclaimed and undisturbed conditions.

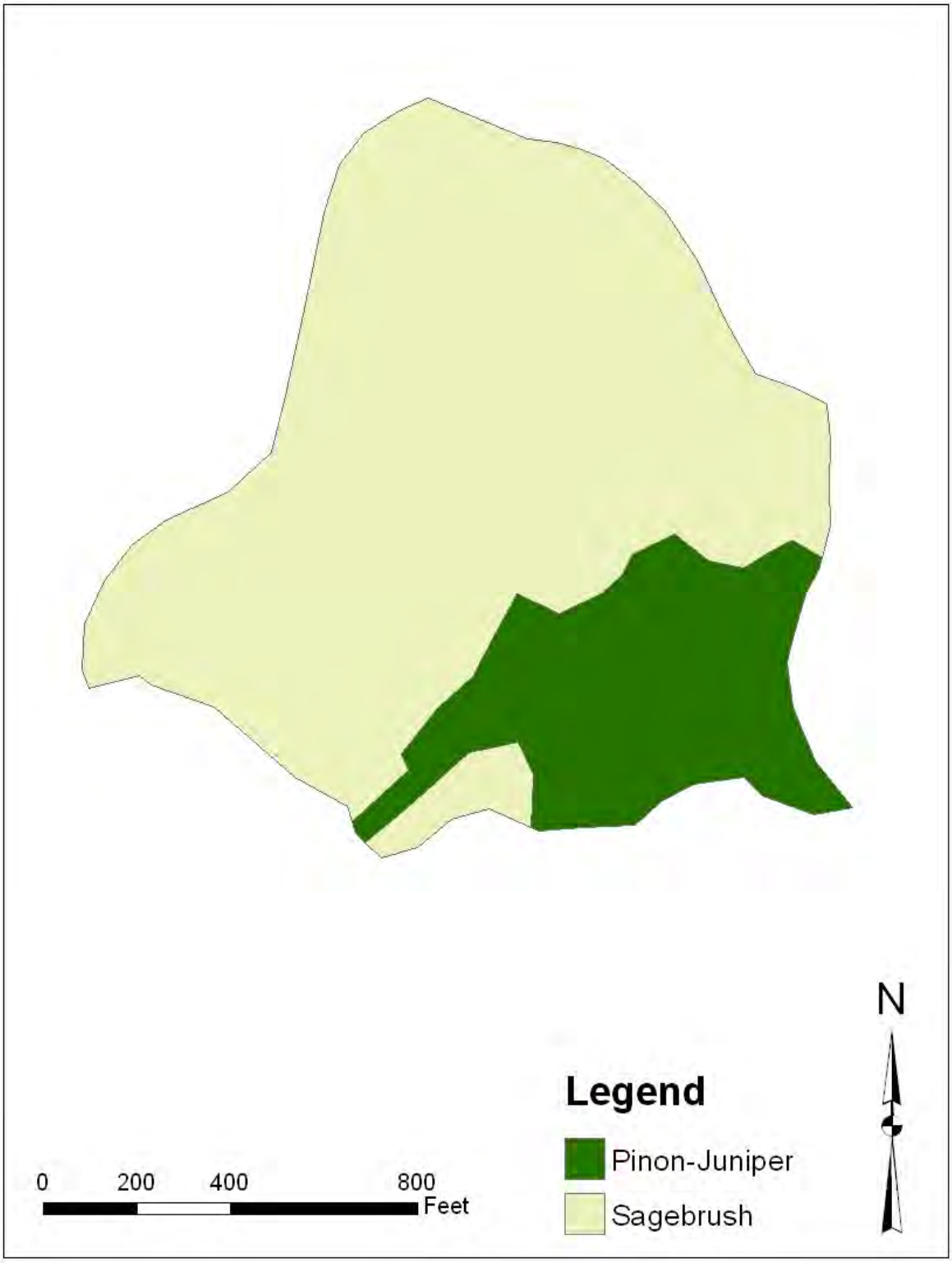


Figure 1.2. Spatial distribution of vegetative cover types for N6-G WA premine condition.

Table 1.2. Cover Sampling Data.								
Area	Condition	Cover Type	Nonstratified Vegetation Cover (%)	Vegetation Canopy Cover (%)	Vegetation Ground Cover (%)	Litter* (%)	Rock (%)	Total Ground Cover (%)
N1/N2	Postmine	Postmine	25.6	1.4	24.2	13.6	4.2	41.9
N6-G	Postmine	Postmine	31.4	0	31.4	22.5	1.8	55.6
N6-G	Postmine	Red Rock	26.3	0	26.3	11.3	51.3	88.9
N1/N2/J27	Premine	Pinon Juniper	32.7	31.1	3.0	44.0	19.7	66.7
N6-G	Premine	Pinon Juniper	16.9	14.6	2.7	18.8	17.3	38.8
N1/N2	Premine	Sagebrush	25.1	16.0	10.3	25.3	18.1	53.7
J27	Premine	Sagebrush	30.6	9.7	22.0	24.0	1.6	47.6
N6-G	Premine	Sagebrush	12.4	1.3	11.2	24.7	2.5	38.3
*Including standing dead litter								

Table 1.3. Cover Data for N6-G Watershed.					
Condition	Pinon Juniper	Sagebrush	Half Pinon Juniper-Half Sagebrush	Postmine	Postmine Red Rock
Canopy cover, %	14.6	1.3	8.0	0	0
Ground cover, %	38.8	38.3	38.5	55.6	88.9
Canopy storage, in	0.05	0.05	0.05	0.05	0.05
Ground storage, in	0.05	0.05	0.05	0.05	0.05
Depression storage, in	0.03	0.03	0.03	0.03	0.03
Impervious area, %	0	0	0	0	0
Manning's n	0.07	0.07	0.07	0.05	0.05

To make comparisons between reclaimed lands and associated undisturbed lands at the Black Mesa Mining Complex on the basis of average annual sediment yield, a procedure was used that considers the importance of infrequent storm events in defining sediment yield in the semiarid west. First, however, the site-specific rainfall data available for the Black Mesa Mining Complex were used to evaluate the frequency and magnitude of the measured events relative to existing predictions for rainfall depth-duration (Miller et al. 1973). The analysis of the rainfall data was performed as part of a previous study of the N1/N2 and J27 CRAs (Resource Consultants and Engineers 1993).

Comparisons between runoff and sediment yield from undisturbed and reclaimed areas in N6-G WA were developed for specific modeling endpoints shown in Exhibits 1 and 2. Mining and reclamation activities did not exactly replicate the topography, drainage network, or drainage areas that existed prior to mining. Consequently, direct comparisons of total runoff and sediment yield cannot be made between undisturbed and reclaimed response at a given point in a watershed. Comparisons were made on the basis of unit rates of runoff (inches) and sediment yield (tons/acre) at the various modeling computation endpoints. Although the same disturbance boundary was used to model extents for both pre- and postmine conditions, the topographic differences that resulted after mining and reclamation occurred in the N6-G WA dictated that some small areas would be included or excluded from the modeling. The area bounded by the modeling boundary identified by PWCC as shown in Exhibits 1 and 2 is 37.9 acres.

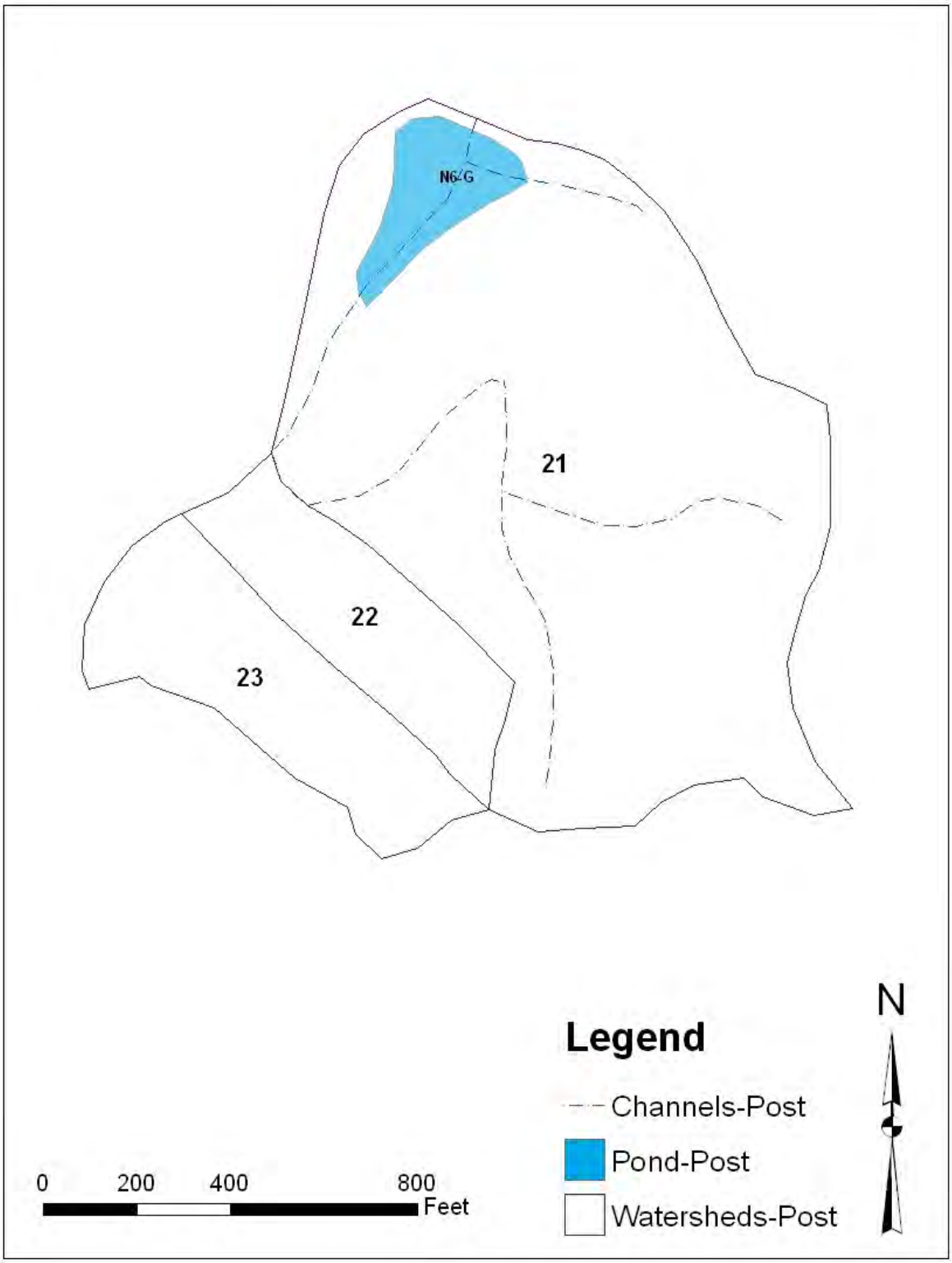


Figure 1.3. N6-G postmine basins.

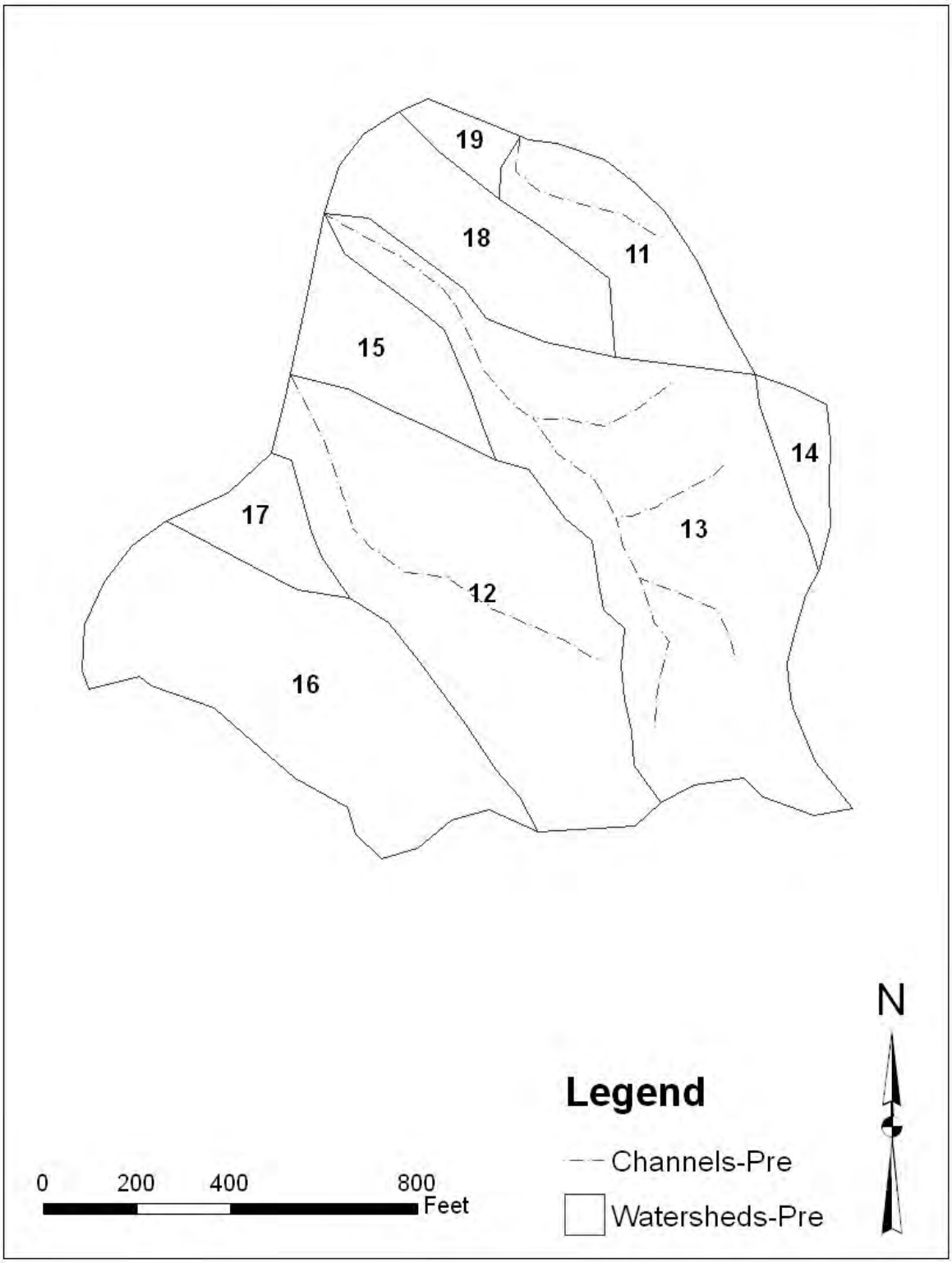


Figure 1.4. N6-G premine basins.

1.4.1 Synthetic Rainfall

Synthetic storms of 2-, 5-, 10-, 25-, 50-, and 100-year return periods were used as input to the EASI model. Actual hyetographs were taken from the previous study (RCE 1993) and are based on both local data collection and the NOAA Atlas (Miller et al. 1973).

1.4.2 Computation of Average Runoff and Sediment Yield

The EASI model was used to evaluate runoff and sediment yield from a series of storm events having recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100 years. To define average annual conditions, the average annual runoff and sediment yield generated from storm events were computed using the commonly used equation of Lagasse et al. (1985).

1.5 Results

Figures 1.3 and 1.4 show the post- and premine basin delineations. Since the individual subareas differ in number, acreage and outlet locations, a direct comparison is not possible on a subarea basis. Therefore, the best way to compare the results is on an average basis for the WA. **Table 1.4** shows pre- and postmine drainage area, runoff, and sediment yield for the N6-G WA. To consider the situation of pond removal for the postmine condition, the EASI model replaces a sediment pond with a channel, which lies near the location of the pond and discharges to the basin outlet. The channel is assumed to have a length equal to the pond's length and a slope similar to the outlet's natural slope. Runoff is defined as the total volume of water leaving the WA on an average annual basis and, therefore, does not include water stored in depression areas and ponds. For the premine condition, this is equal to the amount of water that drains off the hillslopes and subwatersheds because there are no ponds or significant depressions. For the postmine condition, this is equal to the amount of hillslope runoff less the amount stored in ponds. No ponds or significant depressions exist within the reclaimed N6-G WA that was modeled. Similarly, the sediment yield is the amount of eroded material that leaves the WA on an average annual basis computed using the equation of Lagasse et al. (1985). The sediment yield is the production from the hillslope areas and erosion from the channels. The amount of erosion is the sediment yield from the hillslopes and subwatersheds only and does not include channel erosion, channel deposition or sediment trapped in ponds. Sediment yield can be greater or less than erosion, depending on the amount of channel erosion and the capacity of the channel network to convey sediment off the leasehold.

Table 1.4. Average Runoff and Sediment Yield Results.

Area	Condition	Drainage Area (ac)	Runoff (in)	Sediment Yield (t/ac/yr)
N6-G	Premine	37.9	0.42	1.28
N6-G	Postmine	37.9	0.42	1.20

For the postmine condition, the overall sediment yield is less than the premine condition and runoff is the same as the premine amount.

1.6 Discussion

Table 1.5 gives an overview of the geometric properties of the pre- and postmine topography of the N6-G WA. Mean channel slope for the postmine topography is smaller than that for the premine topography, while mean hillslope gradient for the postmine topography is larger than that for the premine topography.

Table 1.5. Average Physical Properties of the N6-G WA.

	Premine	Postmine
Total Area (ac)	37.9	37.9
Total Channel Length (ft)	3679	3468
Mean Channel Slope	0.0733	0.0530
Drainage Density (mi/mi^2)	11.8	11.1
Mean Hillslope Length (ft)	276	238
Mean Hillslope Gradient	0.0866	0.1073

2. COMPARISONS WITH MEASURED SEDIMENT TRANSPORT

As discussed in Section 1, PWCC has monitored flow and sediment on the main channels, principal tributaries and small watersheds within the leasehold. These data, along with the runoff plots, were used to calibrate the EASI model soil erodibility and infiltration input variables. **Figures 2.1** and **2.2** show sediment transport and sediment concentration versus discharge for measured unmined (background), measured reclaimed, N6-G WA's modeled unmined (premine) and modeled reclaimed (postmine) data. Although there is significant scatter shown in the data (as is expected with any sediment transport conditions), there are several conclusions that can be drawn from this data.

The open symbols in both figures depict measured data and whether the data were collected from reclaimed areas (the small watershed study) or from unmined or background surface water monitoring stations. The range of flows is generally greater for the background data but there is significant overlap between the two data sets between 0.1 and 100 cfs. This is because the reclaimed data are from small watersheds and the unmined data are from channels draining larger basins. These data show the same trend for sediment transport and sediment concentration over the entire range of flows and very close agreement in the area of discharge overlap. This, in itself, is strong evidence that (1) the sediment yields are channel transport capacity limited, (2) overlap of model predictions for both pre- and postmine conditions with measured data strongly indicate that EASI model predictions are representative and reasonable, and (3) sediment yields from reclaimed areas will not be additive to yields on the receiving streams.

The closed symbols depict data from N6-G WA's pre- and postmine EASI model runs. They represent data generated by EASI for both subwatersheds and channels for peak discharges resulting from 2-, 5-, 10-, 25-, 50-, and 100-year storms. Using the peak flows from extreme events results in discharges that generally exceed 10 cfs. The trend of the model-derived data is similar and the ranges of concentration and sediment transport are similar to the measured data and between pre- and postmine conditions.

The sediment discharge plot (Figure 2.1) shows a stronger trend because it is plotting discharge (sediment) against discharge (flow). This is expected because the sediment discharge does depend on flow discharge. The concentration plot (Figure 2.2) shows the two separate variables and, therefore, a less significant trend. PWCC believes that data measurement may have some influence on the scatter (outliers were removed), but the process variability is probably the major influence. The majority of the data, however, fall in a group centered on 100 cfs and 100,000 mg/l, both in the observed data and in the model results. These plots support the use of the EASI model, the results of the modeling, the conclusion that sediment yields from reclaimed areas are not additive to receiving stream sediment loads, and that sediment impacts to the prevailing hydrologic balance have been minimized.

From Figures 2.1 and 2.2 it is apparent that sediment loads and concentrations are dependent on the channel sediment transport capacity for both pre- and postmine conditions. Channel sources of sediment in this arid environment are virtually unlimited. Therefore, channel transport capacity and channel derived sediment limits and governs sediment yields from the small tributaries, large channels and the WA as a whole.

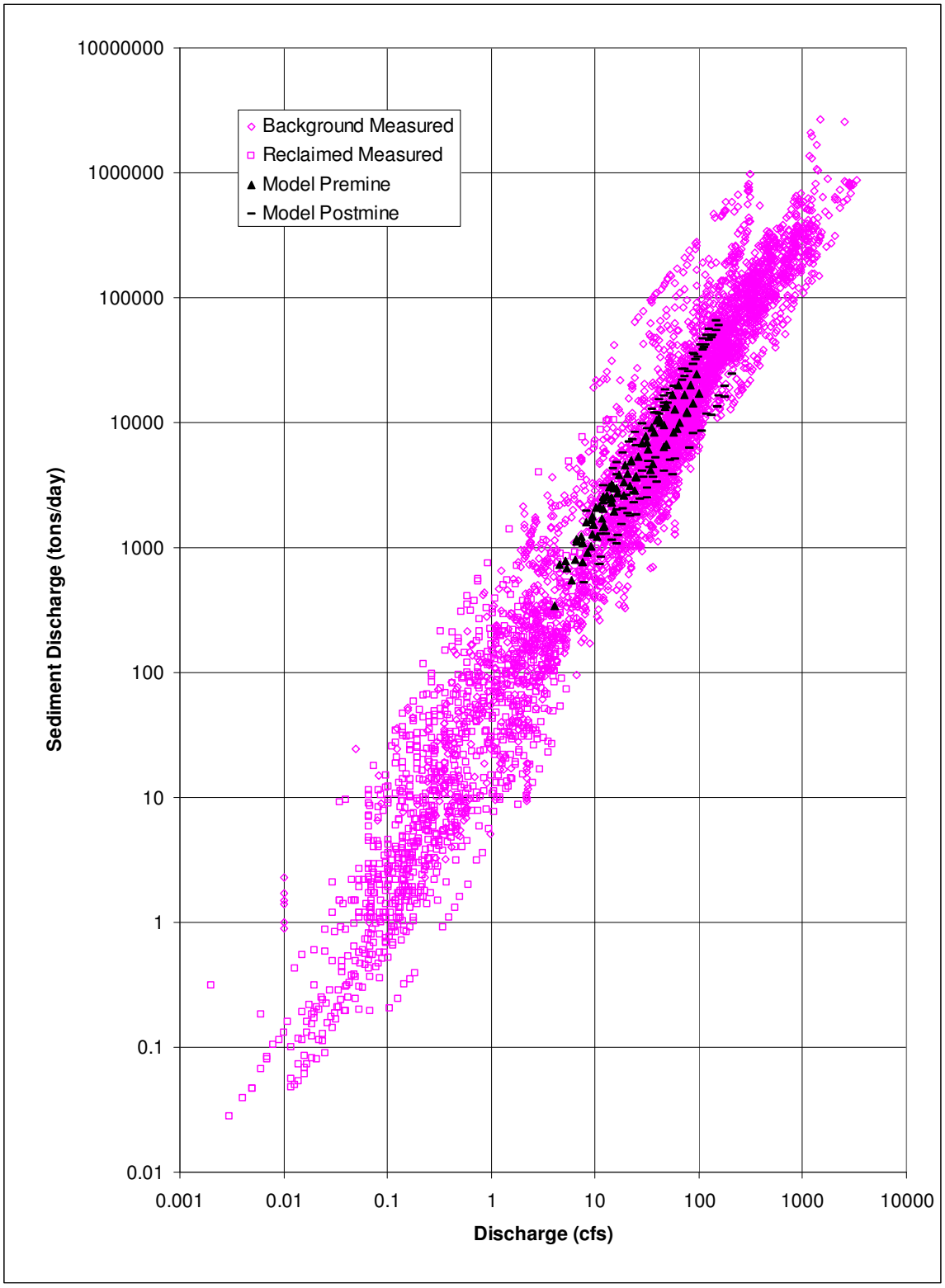


Figure 2.1. Observed and modeled sediment and water discharge.

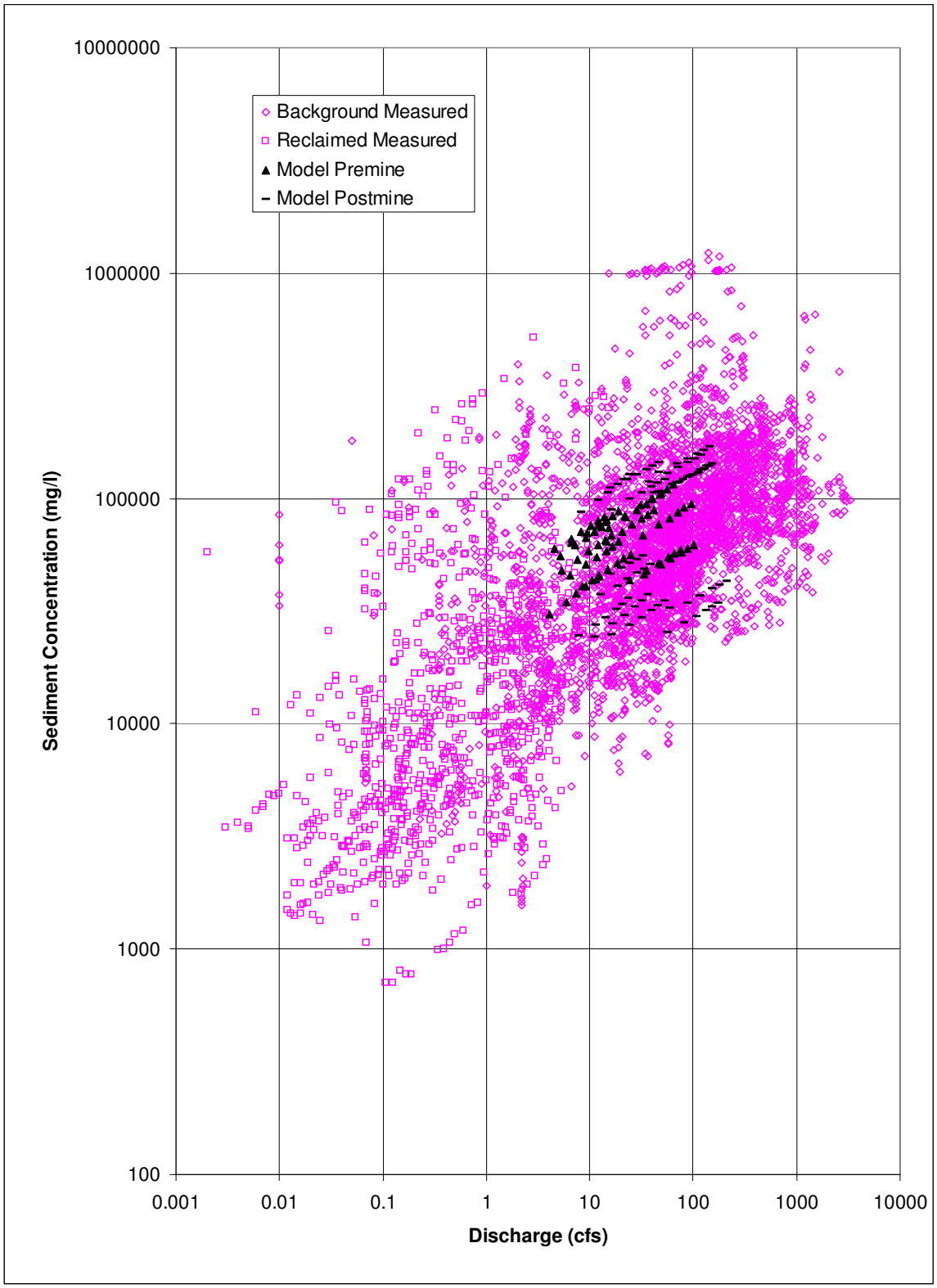


Figure 2.2. Observed versus modeled sediment concentration and discharge.

However, the sediment yield shown in Table 1.4 is the average annual amount of sediment leaving the N6-G WA whereas the sediment discharge shown in Figure 2.1 is the peak rate of sediment in transport occurring in any channel represented by the data, whether the channel is located upstream or downstream of a pond. Therefore, it should be concluded that with or without a pond left in the postmine landscape that traps sediment or stores water, the mine reclamation is not contributing additional sediment to the receiving streams and sediment impacts to the prevailing hydrologic balance have been minimized.

Smith and Best (2000) analyzed the measured data (background and reclaimed) shown in Figure 2.1 to develop an approach that can be used to determine if channels in reclaimed areas have similar sediment transport characteristics as background channels. The method that they used was to develop Sen lines (Sen 1968) and confidence intervals around the data. The slope of the Sen line is a non-parametric statistic computed as the median slope of all possible slopes determined from pairing all the data points. The Sen line is drawn through the median coordinate of the data. Smith and Best first showed that the large channel flume data (background) and the small watershed background data could be combined. They concluded that since the data from one data set fall within the Sen line bounds of the other data set then the two data sets are merely extensions of each other and could be combined. Also, because the main channel and background small watershed site data could be combined, it indicated there is an unlimited supply of sediment and the channels are conveying sediment at (or near) capacity. The Sen line and bounds are shown with the background measured data in **Figure 2.3**.

They then plotted the reclaimed measured data (**Figure 2.4**) with the Sen line and bounds from the background data to show that the reclaimed data have the same characteristics even though the flow range of the measurements is lower. The data indicate that channel flows in this environment achieve the sediment transport capacity of the channel, whether in reclaimed or background conditions.

Using the same approach with the modeled data generated for the N6-G WA, **Figures 2.5 and 2.6** show the pre- and postmine computed sediment transport rates with the Sen lines and bounds. One difference between the plots is that the measured data occur throughout the flow hydrograph whereas the modeled data are tabulated at the peak of the simulation flow hydrograph. The premine data plot (Figure 2.5) shows the data grouped above the Sen line and well within the bounds. The postmine data (Figure 2.6) plot shows the points equally distributed above or below the Sen line. On these graphs data plotting above the Sen line indicate that there is more sediment in transport for a given discharge.

Several conclusions can be drawn from these data plots: (1) EASI model well replicates erosion and sediment transport processes at the mine site for background and reclaimed conditions, (2) all data show similar trends and are within the same bounds, (3) data trends indicate that channels are transporting sediment at or near capacity, and (4) amounts of sediment leaving the WA for postmine conditions are similar to premine conditions and within the range expected for the background conditions. Therefore, the overall conclusion is that the postmine reclaimed condition in N6-G WA is not contributing additional suspended solids to receiving streams, and related impacts to the hydrologic balance have been minimized.

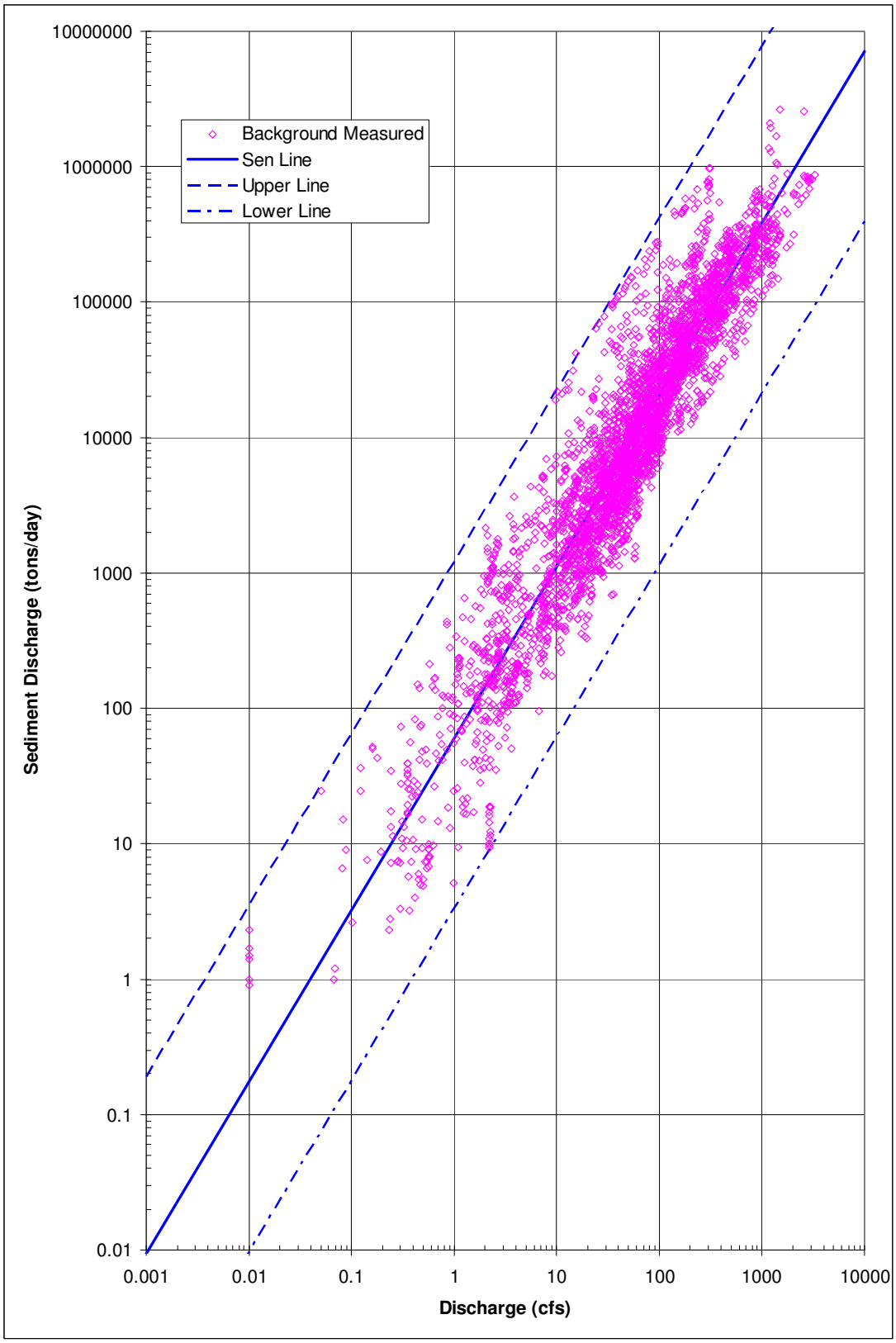


Figure 2.3. Background measured sediment and water discharge.

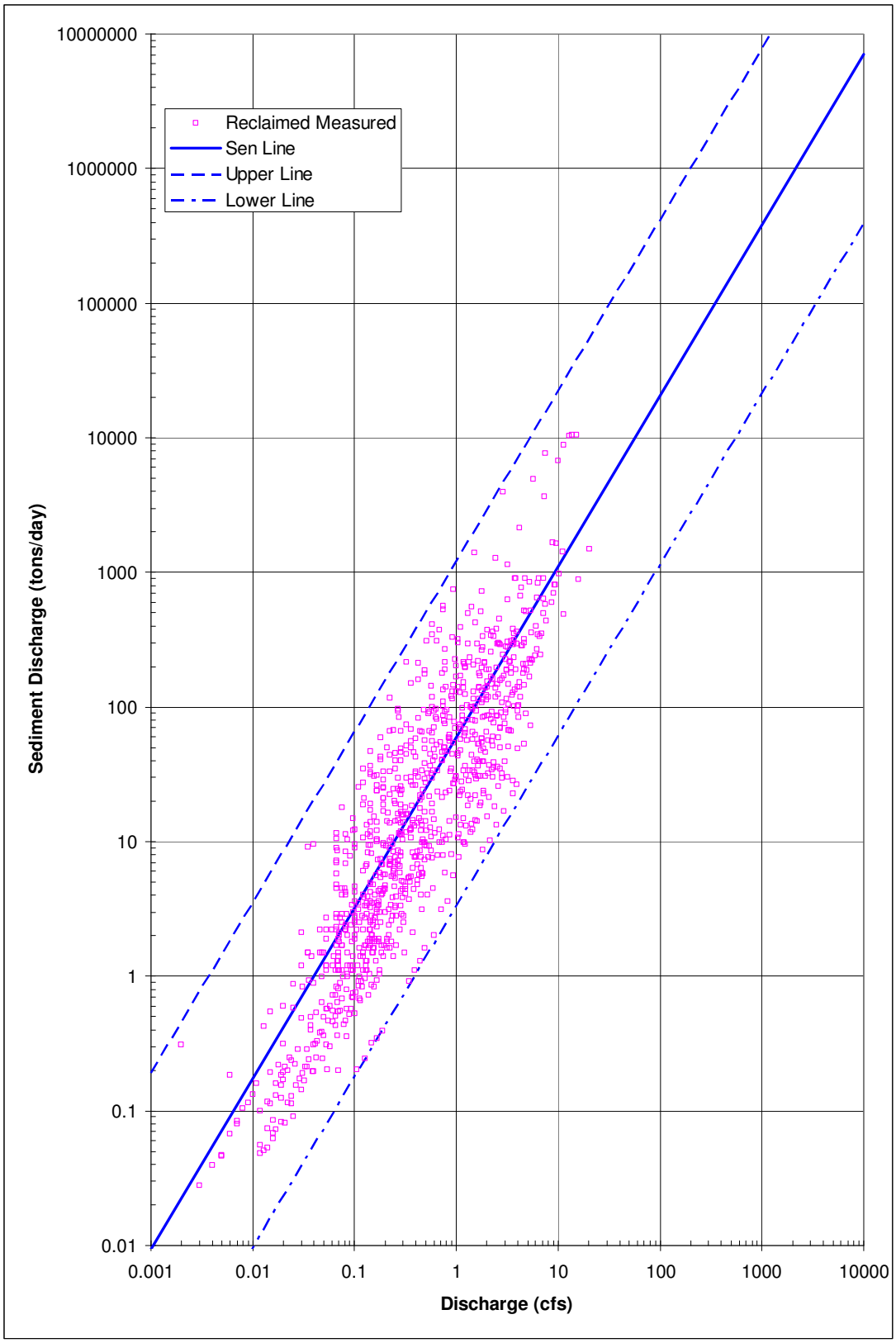


Figure 2.4. Reclaimed measured sediment and water discharge.

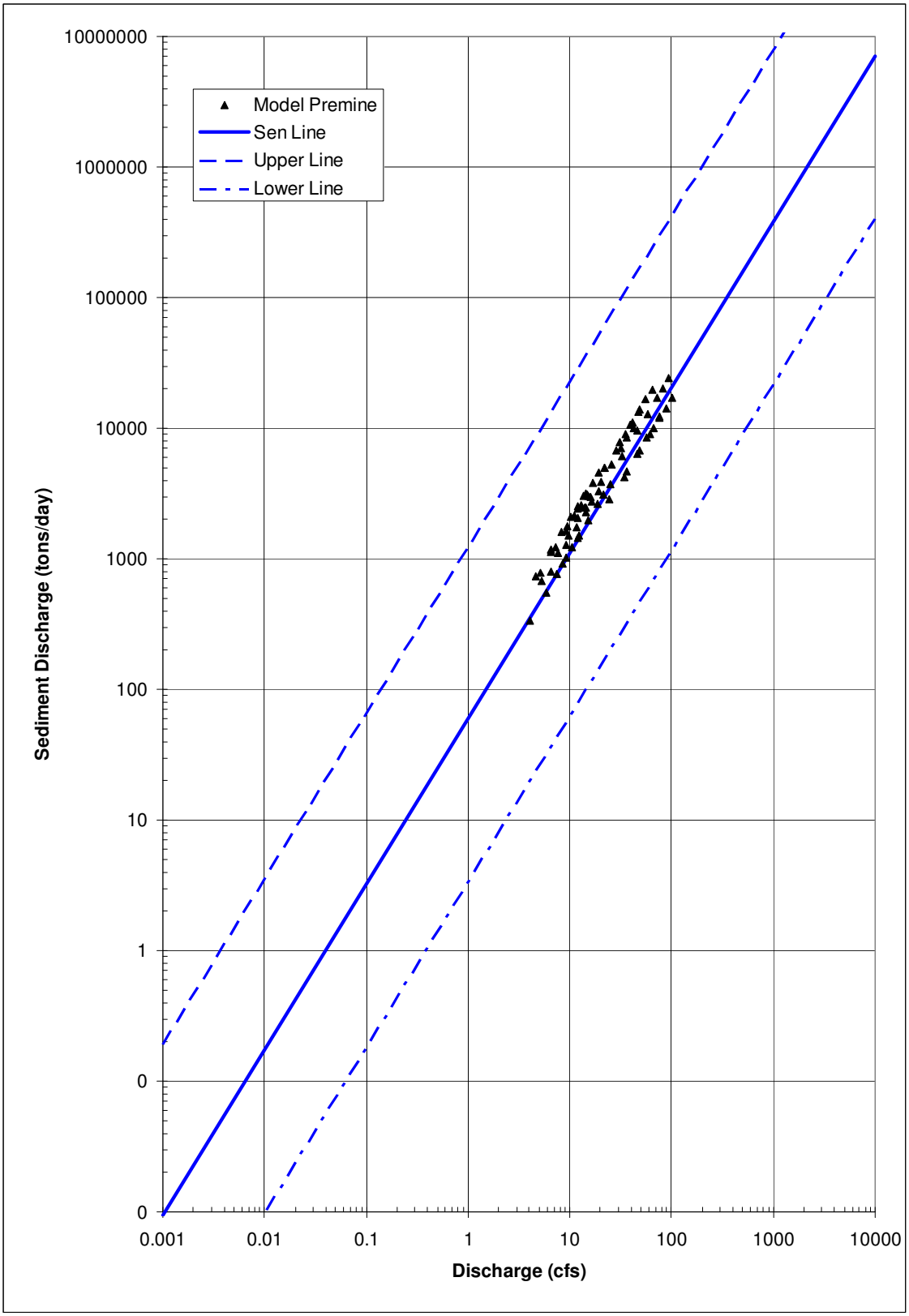


Figure 2.5. Modeled premine sediment and water discharge for the N6-G WA.

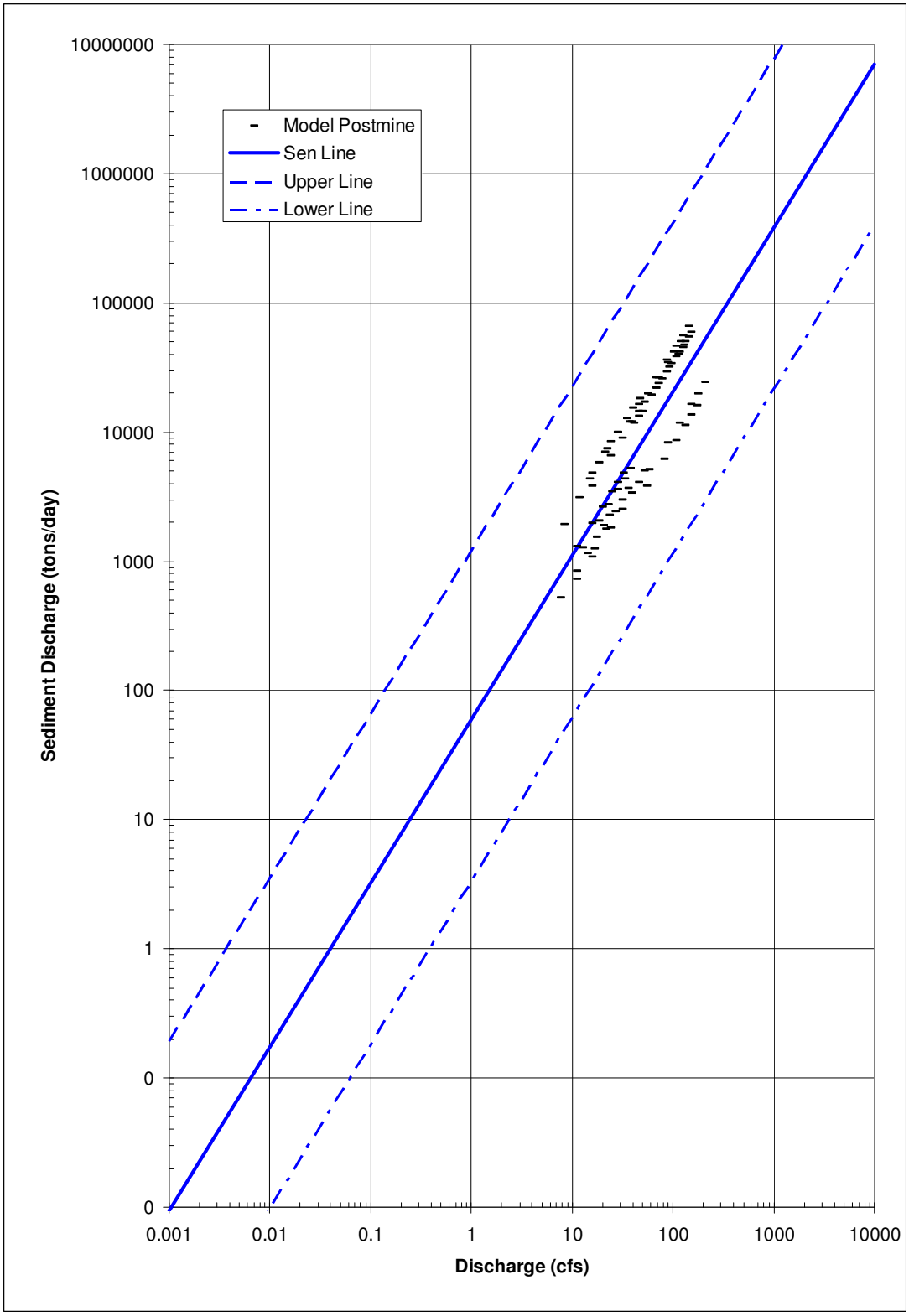


Figure 2.6. Modeled postmine sediment and water discharge for the N6-G WA.

3. REFERENCES

Hjelmfelt, A.T., Kramer, L.A., and Spomer, R.G., 1986. Role of large events in average soil loss in Proceedings of the Fourth Federal Interagency Sedimentation Conference, March 24-27, 1986, Las Vegas, NV, p. 3-1 to 3-9.

Lagasse, P.F., Schall, J.D., and Peterson, M.R., 1985. Erosion Risk Analysis for a Southwestern Arroyo, Journal of Urban Planning and Management, American Society of Civil Engineers, v. III, no. I, November, 1985, Paper No. 20165.

Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973. "NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States," Volume VIII - Arizona, National Oceanic and Atmospheric Administration.

Renard, K.G. and Simaton, J.R., 1975. "Thunderstorm Precipitation Effects on the Rainfall-Erosion Index of the Universal Soil Loss Equation" in Volume 5 of Hydrology and Water Resources in Arizona and the Southwest, American Water Resources Assn., Arizona Section Arizona Academy of Science, Hydrology Section, Proceedings of April 11-12 meeting, Tempe AZ, v. 47-55.

Resource Consultants & Engineers, Inc. (RCE), 1993. "Surface Water Modeling of Reclaimed Parcels at the Black Mesa Complex," prepared for Peabody Western Coal Co.

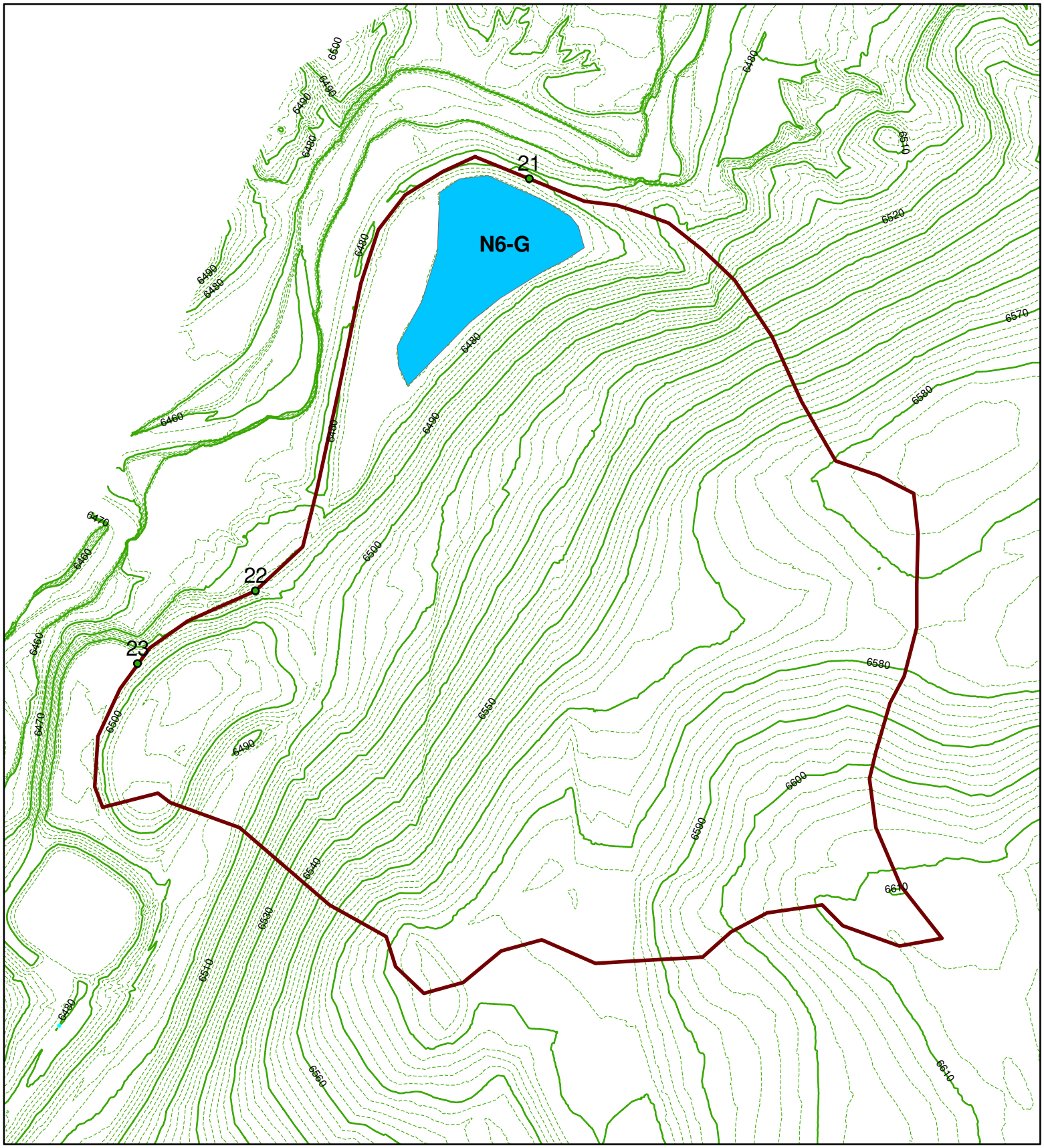
Sen, P.K., 1968. "Estimates of Regression Coefficient Based on Kendall's tau: Journal of American Statistical Association, v. 63, p. 1379-1389.

Smith, T. and Best, A., 2000. "Assessing Sedimentation and Protection of the Hydrologic Balance in Disturbed and Reclaimed Areas at the Black Mesa and Kayenta Mines, Arizona, Using Baseline Sediment Data Collected in Receiving Streams," presentation given at the Billings Mined Land Reclamation Symposium in 2001, Billings, MT.

Water Engineering & Technology, Inc. (WET), 1990. "Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control Technology at Surface Mines in the Semiarid West," prepared for Office of Surface Mining and the National Coal Association, Fort Collins, CO.

Zevenbergen, L.W., Peterson, M.R., and Watson, C.C., 1990. Computer simulation of watershed runoff and sedimentation processes, Proceedings of the Billings Symposium; Planning, Rehabilitation and Treatment of Disturbed Lands.

EXHIBIT 1
Postmine Topography



N

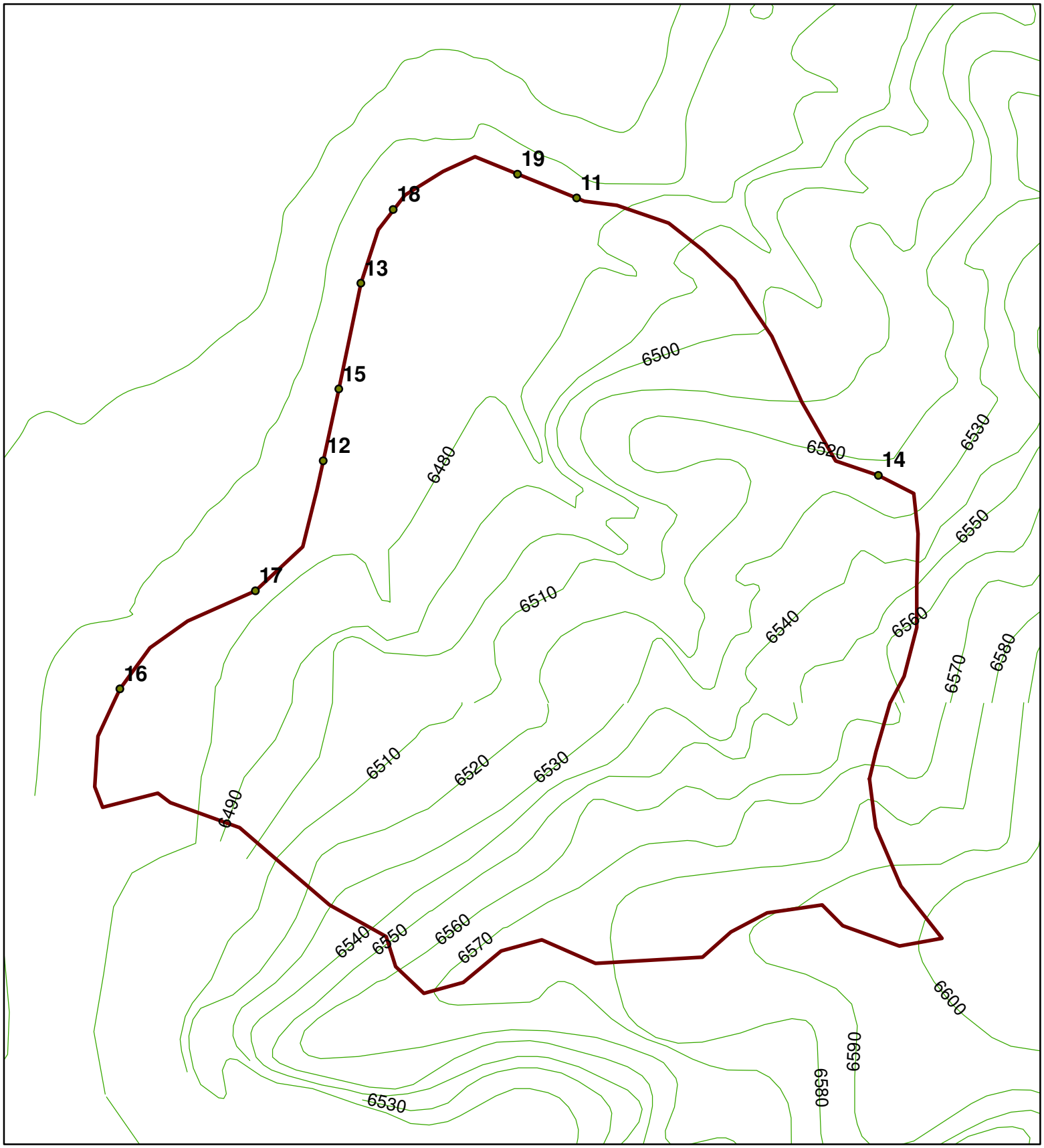
Legend

- End Points
- Ponds
- Modeling Area

0 125 250 500 750 Feet

Exhibit 1. Postmine Topography
(2 foot contour)

EXHIBIT 2
Premine Topography



N

Legend

- End Points
- Modeling Area

0 125 250 500 750 Feet

Exhibit 2. Premine Topography
(10 foot contour)

Appendix 7

Surface Water Modeling of the Reclaimed J7-K and J7-M Watershed Area at Black Mesa Complex

SURFACE WATER MODELING OF THE RECLAIMED J7-K and J7-M WATERSHED AREA AT BLACK MESA COMPLEX

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES

SURFACE WATER MODELING OF THE RECLAIMED J7-K and J7-M WATERSHED AREA AT BLACK MESA COMPLEX

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES
P.O. Box 270460
Fort Collins, Colorado 80527
(970) 223-5556, FAX (970) 223-5578

Ayres Project No. 32-1304.01
PEAB-J7K.DOC

June 2009

TABLE OF CONTENTS

1. Reclaimed Parcel Modeling 1.1

1.1 Introduction 1.1
1.2 Background 1.1
1.3 Data 1.2

1.3.1 Soils 1.2
1.3.2 Vegetation 1.2
1.3.3 Topography 1.3

1.4 Methodology 1.3

1.4.1 Synthetic Rainfall 1.8
1.4.2 Computation of Average Runoff and Sediment Yield 1.8

1.5 Results 1.8
1.6 Discussion 1.9

2. Comparisons with Measured Sediment Transport 2.1

3. References 3.1

Exhibit 1 – Postmine Topography ..... --
Exhibit 2 – Premine Topography ..... --

LIST OF FIGURES

Figure 1.1. Reclaimed area soils trilinear graph. 1.2

Figure 1.2. Spatial distribution of vegetative cover types for WA J7 premine condition 1.4

Figure 1.3. J7-K and J7-M postmine basins. 1.6

Figure 1.4. J7-K and J7-M premine basins. 1.7

Figure 2.1. Observed and modeled sediment and water discharge. 2.2

Figure 2.2. Observed versus modeled sediment concentration and discharge. 2.3

Figure 2.3. Background measured sediment and water discharge. 2.5

Figure 2.4. Reclaimed measured sediment and water discharge. 2.6

Figure 2.5. Modeled premine sediment and water discharge for the J7 WA. 2.7

Figure 2.6. Modeled postmine sediment and water discharge for the J7 WA 2.8

LIST OF TABLES

Table 1.1. Soils Data. 1.3

Table 1.2. Cover Sampling Data. 1.5

Table 1.3. Cover Data for J7-K and J7-M Watersheds. 1.5

Table 1.4. Average Runoff and Sediment Yield Results. 1.8

Table 1.5. Average Physical Properties of the J7 WA. 1.9

1. RECLAIMED PARCEL MODELING

1.1 Introduction

The objective defined by PWCC for this project is to use a previously calibrated and validated runoff and erosion model (EASI, Zevenbergen et al. 1990; WET 1990) for the Black Mesa and Kayenta Mines (combined as Black Mesa Complex in December 2008) to predict mean annual runoff and sediment yields from the reclaimed J7-K and J7-M watersheds. This objective included computation of runoff and sediment yields under premine conditions for the same area. All soils and rainfall input to the model are to be taken from models calibrated in the previous study (RCE 1993). The input variables that were calibrated to the mine areas and used in this study include soil infiltration parameters, erodibility parameters, and the grain size distribution. Parameters that are specific to this study are vegetative canopy and ground cover percentages from data collected on site.

The model calibration was conducted in a previous study (RCE 1993) using data obtained from instrumented watersheds and small hillslope plots collected under natural rainfall conditions. For a detailed discussion of data collection and model calibration, please refer to the previous study (RCE 1993).

1.2 Background

The J7-K and J7-M Watershed Area (WA) that is the focus of this project was reclaimed between 1990 and 2006. The fundamental purpose of this study was to quantify the expected behavior and hydrologic response of the reclaimed areas above each pond relative to the conditions that existed prior to the occurrence of mining activities.

Runoff and sediment yield response from the reclaimed lands should be managed by implementing Best Management Practices (BMP's) in conjunction with an OSM approved sediment control plan in order to not adversely impact the prevailing hydrologic balance and to limit additional contributions of suspended sediment to streamflow or runoff outside the mine permit areas. BMP's include regrading, replacing salvaged topsoil, revegetation, and other controls such as riprapped channel bottoms, check dams, and where practicable, contour terraces. The natural watersheds on the mesa contribute significant quantities of sediment to the channel system. It is expected that the postmine condition will also produce comparable amounts of sediment without adversely impacting the hydrologic balance.

This section describes the data and procedures used to evaluate the J7 WA. This area was modeled to determine the average annual hydrologic response following the completion of reclamation activities taking into account BMP's implemented as part of the reclamation process. Infiltration, runoff, and erosion processes from both hillslopes and channels within the J7 WA were modeled using EASI. Results were determined for concentration points at the outlets of the reclaimed watersheds, which correspond to the embankments associated with Ponds J7-K and J7-M. The locations of these points are shown in **Exhibit 1**. Modeling was also conducted to determine hydrologic response under premine conditions based on the topography, soils, cover, and other conditions that typified the undisturbed watersheds draining to each concentration point. **Exhibit 2** shows the modeling endpoints for the premine J7 WA.

1.3 Data

1.3.1 Soils

Soils data used for the current study (J7 WA) were based on data developed from the calibration of models used in the previous study for Coal Resource Areas (CRAs) N1/N2 and J27 (RCE 1993). The composition of postmine soil in the current study is depicted along with the composition of postmine soils from the previous study in **Figure 1.1**. This figure shows that the soil composition of WA J7 is very similar to soils evaluated during model calibration. Therefore, the soil properties developed in the previous study are valid for this modeling project. These properties include calibrated parameters, such as infiltration and erodibility coefficients, and measured soil size distributions. **Table 1.1** lists the premine and postmine soils data used during EASI modeling of WA J7.

1.3.2 Vegetation

Vegetative cover data representative of both pre- and postmine conditions in WA J7 were supplied by PWCC. For the premine condition, land was characterized as being covered by sagebrush or pinon juniper. The spatial distribution of vegetative cover for the J7 WA premine condition appears in **Figure 1.2**. Average cover properties for CRAs N1/N2 and J27 of the previous study and WA J7 of the current study appear in **Table 1.2**. For the postmine condition, the reclaimed area was assigned the postmine cover type and the unmined area was assigned the same cover type as the premine condition. **Table 1.3** lists the pre- and postmine vegetative cover data used in the EASI model runs generated for the J7 WA. Note that if a unit contained significant portions of both sagebrush and pinon juniper cover types, it was classified as half pinon juniper and half sagebrush.

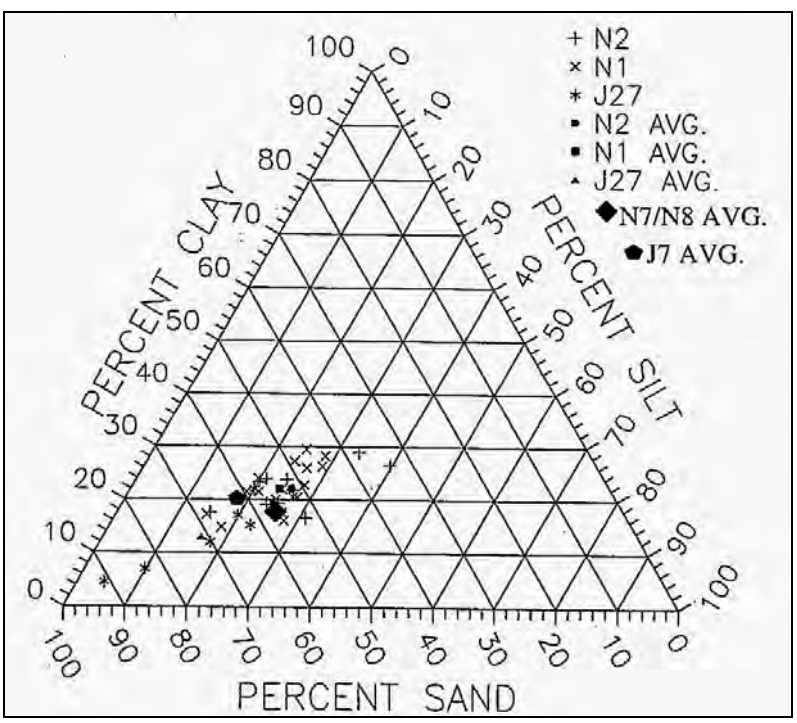


Figure 1.1. Reclaimed area soils trilinear graph.

Table 1.1. Soils Data.			
Condition	Premine	Postmine	Rock Chutes
Rainfall detachment	0.005	0.005	0
Overland flow detachment	0.44	0.44	0
Channel flow detachment	0.5	0.5	0
Initial soil moisture, %	70	70	70
Final soil moisture, %	90	90	90
Soil porosity, %	45	45	46
Temperature, *F	70	70	70
Hydraulic conductivity, in/hr	0.23	0.29	0.3
Capillary suction, in	3.7	2.6	2.6
	Particle Size Distribution (all conditions)		
	Size, mm	% Finer	
	0.001	0	
	0.004	18.0	
	0.016	27.4	
	0.062	36.6	
	0.125	56.2	
	0.250	64.3	
	0.500	72.4	
	1.000	80.5	
	2.000	88.6	
	4.000	92.4	
	16.000	100	

1.3.3 Topography

Pre- and postmine topography was supplied by PWCC in the form of ArcGIS geodatabase. Basin delineations, hillslope delineations, subwatershed delineations, as well as areas, slopes, and lengths of all units of the study area were defined and calculated using ArcGIS software. **Figures 1.3 and 1.4** show the watershed delineation and numbers assigned to the basins used in the EASI model for the post- and premine conditions, respectively. Channel dimensions input to EASI were based on the topography supplied and limited field observations.

1.4 Methodology

Runoff and sediment yield in the semiarid western United States is largely governed by the occurrence of high-intensity, short-duration rainstorms of limited areal extent (Renard and Simaton 1975). Research has indicated that relatively few events may produce the greatest erosion (e.g., Hjelmfelt et al. 1986 reported that only 3 to 4% of rainfall events accounted for 50% of long-term sediment yields). Although there is perhaps a relatively limited physical basis for definition of an "average annual" runoff or sediment yield in a semiarid environment due to the extreme variability in response and importance of single infrequent events, such a term does provide a useful basis for long-term comparison between reclaimed and undisturbed conditions.

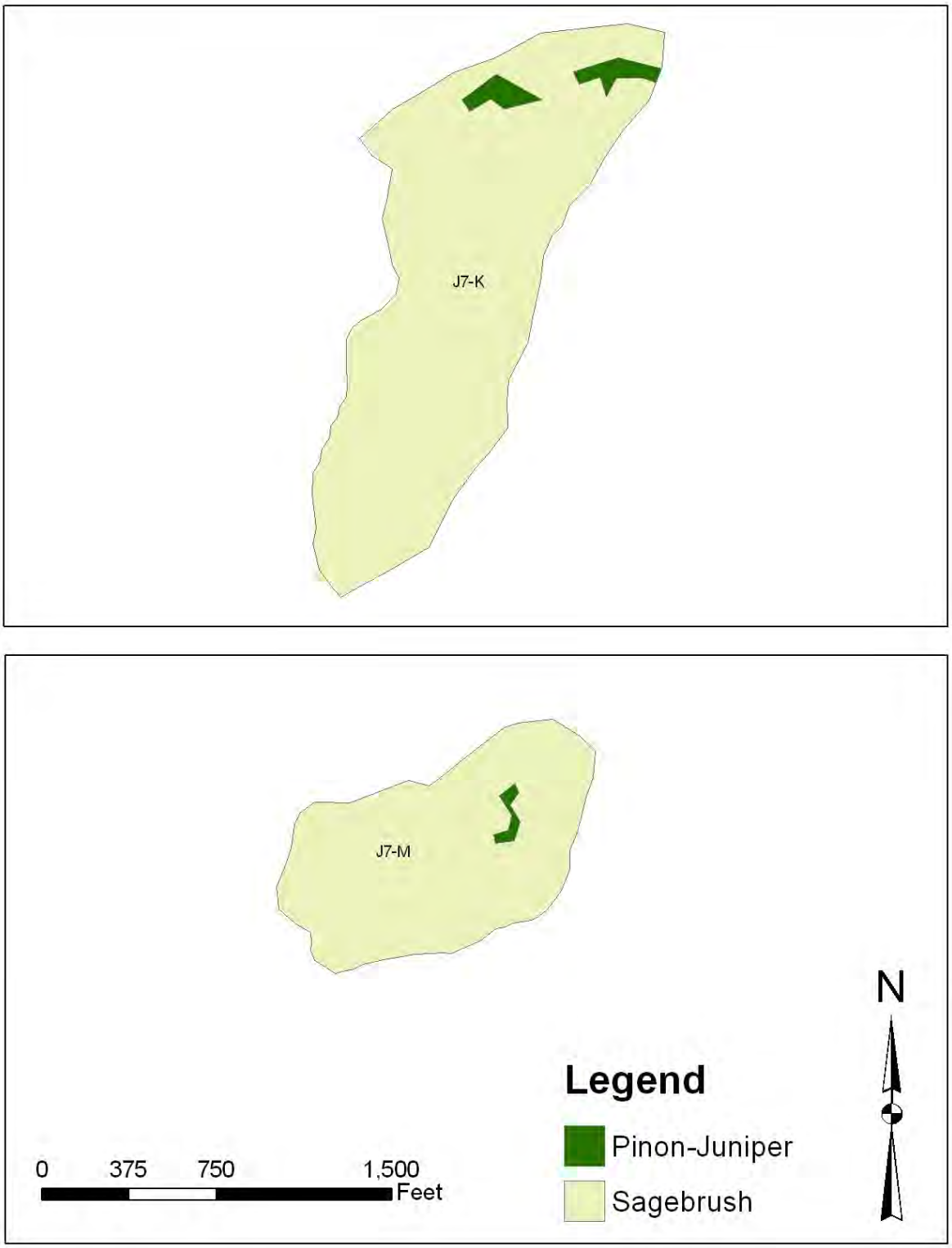


Figure 1.2. Spatial distribution of vegetative cover types for WA J7 premine condition.

Table 1.2. Cover Sampling Data.								
Area	Condition	Cover Type	Nonstratified Vegetation Cover (%)	Vegetation Canopy Cover (%)	Vegetation Ground Cover (%)	Litter* (%)	Rock (%)	Total Ground Cover (%)
N1/N2	Postmine	Postmine	25.6	1.4	24.2	13.6	4.2	41.9
J7 WA	Postmine	Postmine	21.3	0.3	21.1	31.5	2.6	55.2
N1/N2/J27	Premine	Pinon Juniper	32.7	31.1	3.0	44.0	19.7	66.7
J7 WA	Premine	Pinon Juniper	14.5	11.7	3.2	19.1	18.5	40.8
N1/N2	Premine	Sagebrush	25.1	16.0	10.3	25.3	18.1	53.7
J27	Premine	Sagebrush	30.6	9.7	22.0	24.0	1.6	47.6
J7 WA	Premine	Sagebrush	7.9	0.6	7.3	21.7	6.8	35.8
*Including standing dead litter								

Table 1.3. Cover Data for J7-K and J7-M Watersheds.				
Condition	Pinon Juniper	Sagebrush	Half Pinon Juniper-Half Sagebrush	Postmine
Canopy cover, %	11.7	0.6	6.1	0.3
Ground cover, %	40.8	35.8	38.3	55.2
Canopy storage, in	0.05	0.05	0.05	0.05
Ground storage, in	0.05	0.05	0.05	0.05
Depression storage, in	0.03	0.03	0.03	0.03
Impervious area, %	0	0	0	0
Manning n	0.07	0.07	0.07	0.05

To make comparisons between reclaimed lands and associated undisturbed lands at the Black Mesa Mining Complex on the basis of average annual sediment yield, a procedure was used that considers the importance of infrequent storm events in defining sediment yield in the semiarid west. First, however, the site-specific rainfall data available for the Black Mesa Mining Complex were used to evaluate the frequency and magnitude of the measured events relative to existing predictions for rainfall depth-duration (Miller et al. 1973). The analysis of the rainfall data was performed as part of a previous study of the N1/N2 and J27 CRAs (Resource Consultants and Engineers 1993).

Comparisons between runoff and sediment yield from undisturbed and reclaimed areas in WA J7 were developed for specific modeling endpoints shown in Exhibits 1 and 2. Mining and reclamation activities did not exactly replicate the topography, drainage network, or drainage areas that existed prior to mining. Consequently, direct comparisons of total runoff and sediment yield cannot be made between undisturbed and reclaimed response at a given point in a watershed. Comparisons were made on the basis of unit rates of runoff (inches) and sediment yield (tons/acre) at the various modeling computation endpoints. Although the same disturbance boundary was used to define the extent of both pre- and postmine conditions, the topographic differences that resulted after mining and reclamation occurred in the J7 WA dictated that some areas would be included or excluded from the modeling. The total area modeled (combined area for J7-K and J7-M watersheds) for premine conditions is 61.6 acres (Exhibit 2) and for postmine conditions is 37.3 acres (Exhibit 1).

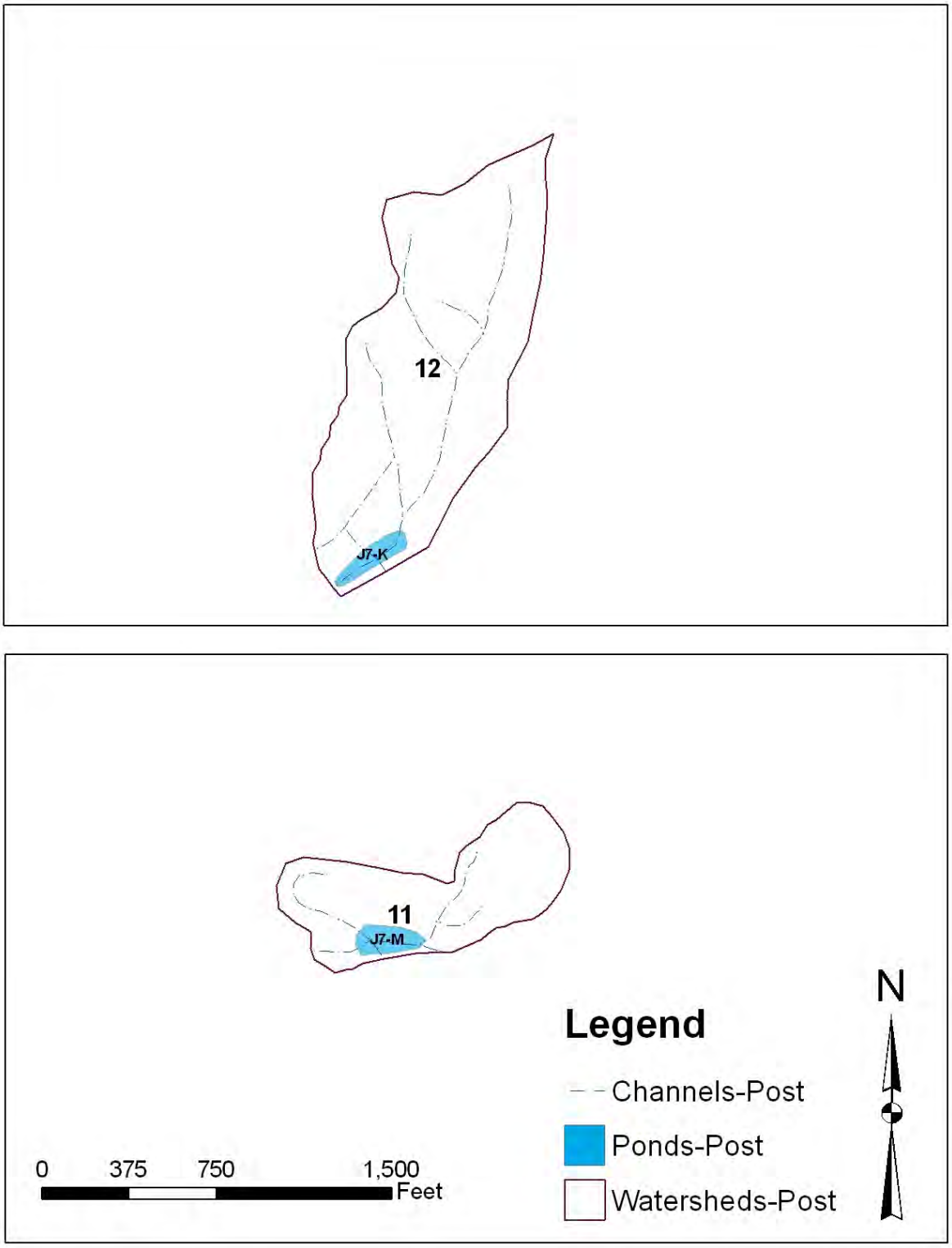


Figure 1.3. J7-K and J7-M postmine basins.

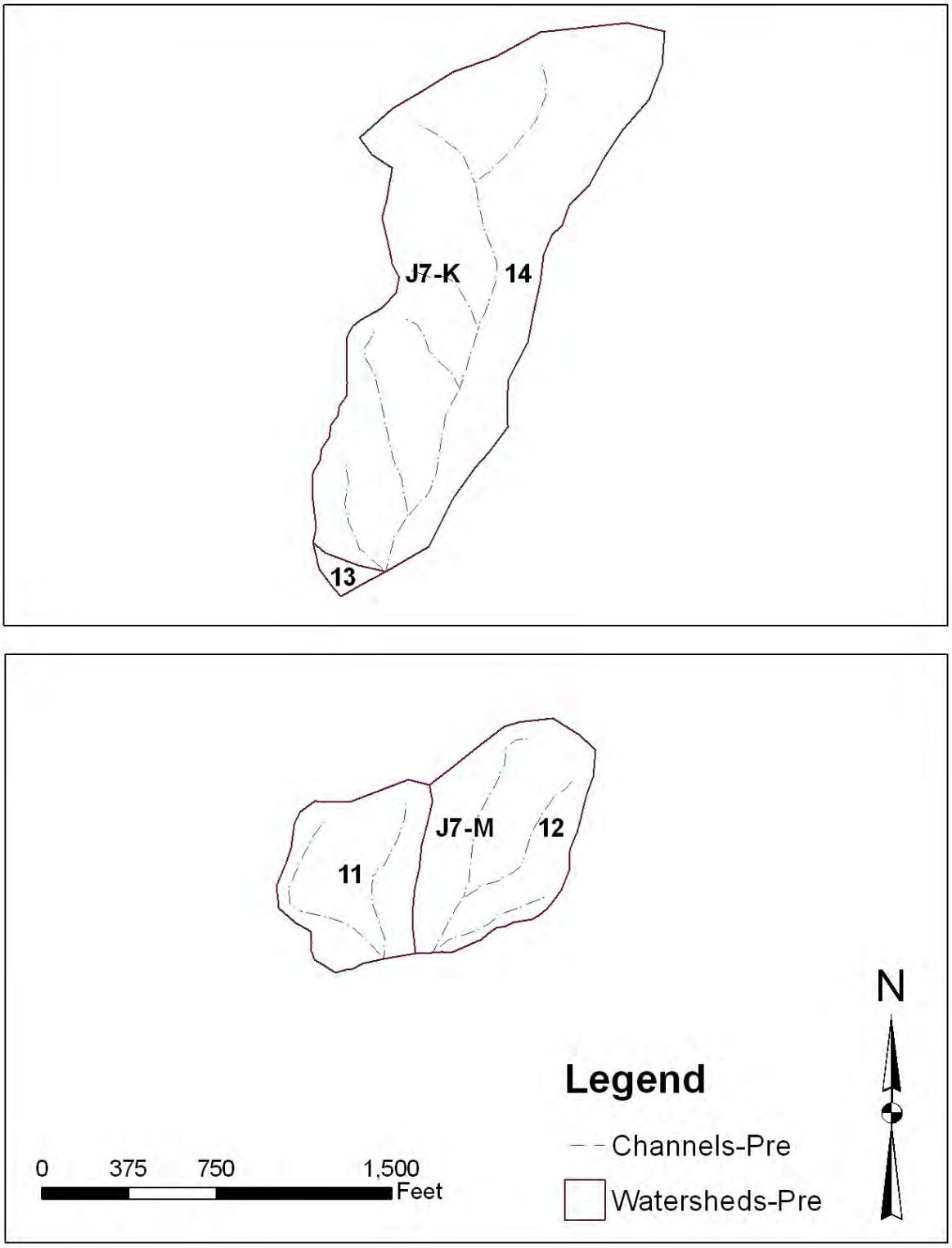


Figure 1.4. J7-K and J7-M premine basins.

1.4.1 Synthetic Rainfall

Synthetic storms of 2-, 5-, 10-, 25-, 50-, and 100-year return periods were used as input to the EASI model. Actual hyetographs were taken from the previous study (RCE 1993) and are based on both local data collection and the NOAA Atlas (Miller et al. 1973).

1.4.2 Computation of Average Runoff and Sediment Yield

The EASI model was used to evaluate runoff and sediment yield from a series of storm events having recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100 years. To define average annual conditions, the average annual runoff and sediment yield generated from storm events were computed using the commonly used equation of Lagasse et al. (1985).

1.5 Results

Figures 1.3 and 1.4 show the post- and premine basin delineations. Since the individual subareas differ in number, acreage and outlet locations, a direct comparison is not possible on a subarea basis. Therefore, the best way to compare the results is on an average basis for the WA. **Table 1.4** shows pre- and postmine drainage area, runoff, and sediment yield for the J7 WA. For the postmine condition, the overall sediment yield is less than the premine condition and runoff is the same as the premine amount.

To consider the situation of pond removal for the postmine condition, the EASI model replaces a sediment pond with a channel, which lies near the location of the pond and discharges to the basin outlet. The channel is assumed to have a length equal to the pond's length and a slope similar to the outlet's natural slope. Runoff is defined as the total volume of water leaving the WA on an average annual basis and, therefore, does not include water stored in depression areas and ponds. For the premine condition, this is equal to the amount of water that drains off the hillslopes and subwatersheds because there are no ponds or significant depressions. For the postmine condition, this is equal to the amount of hillslope runoff less the amount stored in ponds. No ponds or significant depressions exist within the reclaimed J7 WA that was modeled. Similarly, the sediment yield is the amount of eroded material that leaves the WA on an average annual basis computed using the equation of Lagasse et al. (1985). The sediment yield is the production from the hillslope areas and erosion from the channels. The amount of erosion is the sediment yield from the hillslopes and subwatersheds only and does not include channel erosion, channel deposition or sediment trapped in ponds. Sediment yield can be greater or less than erosion, depending on the amount of channel erosion and the capacity of the channel network to convey sediment off the leasehold.

Table 1.4. Average Runoff and Sediment Yield Results.

Area	Condition	Drainage Area (ac)	Runoff (in)	Sediment Yield (t/ac/yr)
J7 WA	Premine	61.6	0.42	1.56
J7 WA	Postmine	37.3	0.42	1.21
J7-K	Premine	40.0	0.42	1.34
J7-K	Postmine	26.1	0.42	1.02
J7-M	Premine	21.6	0.42	1.98
J7-M	Postmine	11.2	0.42	1.64

1.6 Discussion

Table 1.5 gives an overview of the geometric properties of the pre- and postmine topographies for the J7 WA. Postmine hillslopes are as steep as premine hillslopes, while postmine channels are gentler than premine channels.

Table 1.5. Average Physical Properties of the J7 WA.

	Premine	Postmine
Total Area (ac)	61.6	37.3
Total Channel Length (ft)	8839	6387
Mean Channel Slope	0.0548	0.0458
Drainage Density (mi/mi^2)	17.4	20.8
Mean Hillslope Length (ft)	160	156
Mean Hillslope Gradient	0.0667	0.0623

2. COMPARISONS WITH MEASURED SEDIMENT TRANSPORT

As discussed in Section 1, PWCC has monitored flow and sediment on the main channels, principal tributaries and small watersheds within the leasehold. These data, along with the runoff plots, were used to calibrate the EASI model soil erodibility and infiltration input variables. **Figures 2.1** and **2.2** show sediment transport and sediment concentration versus discharge for measured unmined (background), measured reclaimed, WA J7's modeled unmined (premine) and modeled reclaimed (postmine) data. Although there is significant scatter shown in the data (as is expected with any sediment transport conditions), there are several conclusions that can be drawn from this data.

The open symbols in both figures depict measured data and whether the data were collected from reclaimed areas (the small watershed study) or from unmined or background surface water monitoring stations. The range of flows is generally greater for the background data but there is significant overlap between the two data sets between 0.1 and 100 cfs. This is because the reclaimed data are from small watersheds and the unmined data are from channels draining larger basins. These data show the same trend for sediment transport and sediment concentration over the entire range of flows and very close agreement in the area of discharge overlap. This, in itself, is strong evidence that (1) the sediment yields are channel transport capacity limited, (2) overlap of model predictions for both pre- and postmine conditions with measured data strongly indicate that EASI model predictions are representative and reasonable, and (3) sediment yields from reclaimed areas will not be additive to yields on the receiving streams.

The closed symbols depict data from WA J7's pre- and postmine EASI model runs. They represent data generated by EASI for both subwatersheds and channels for peak discharges resulting from 2-, 5-, 10-, 25-, 50-, and 100-year storms. Using the peak flows from extreme events results in discharges that generally exceed 10 cfs. The trend of the model-derived data is similar and the ranges of concentration and sediment transport are similar to the measured data and between pre- and postmine conditions.

The sediment discharge plot (Figure 2.1) shows a stronger trend because it is plotting discharge (sediment) against discharge (flow). This is expected because the sediment discharge does depend on flow discharge. The concentration plot (Figure 2.2) shows the two separate variables and, therefore, a less significant trend. PWCC believes that data measurement may have some influence on the scatter (outliers were removed), but the process variability is probably the major influence. The majority of the data, however, fall in a group centered on 100 cfs and 100,000 mg/l, both in the observed data and in the model results. These plots support the use of the EASI model, the results of the modeling, the conclusion that sediment yields from reclaimed areas are not additive to receiving stream sediment loads, and that sediment impacts to the prevailing hydrologic balance have been minimized.

From Figures 2.1 and 2.2 it is apparent that sediment loads and concentrations are dependent on the channel sediment transport capacity for both pre- and postmine conditions. Channel sources of sediment in this arid environment are virtually unlimited. Therefore, channel transport capacity and channel derived sediment limits and governs sediment yields from the small tributaries, large channels and the WA as a whole. The similarity of sediment discharge (or concentration) between pre- and postmine conditions appears to be inconsistent with the lower rates of sediment yield shown in Table 1.4.

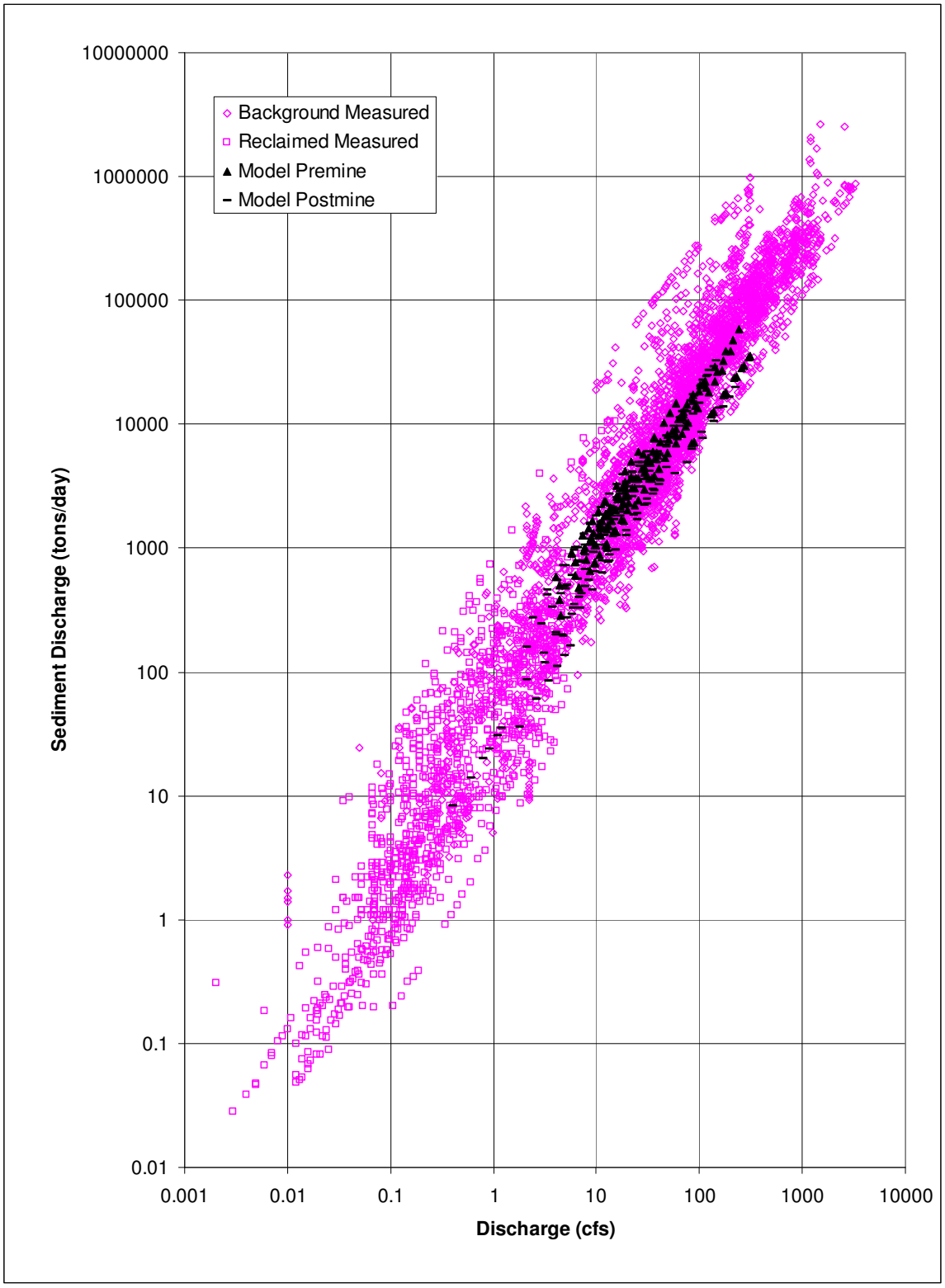


Figure 2.1. Observed and modeled sediment and water discharge.

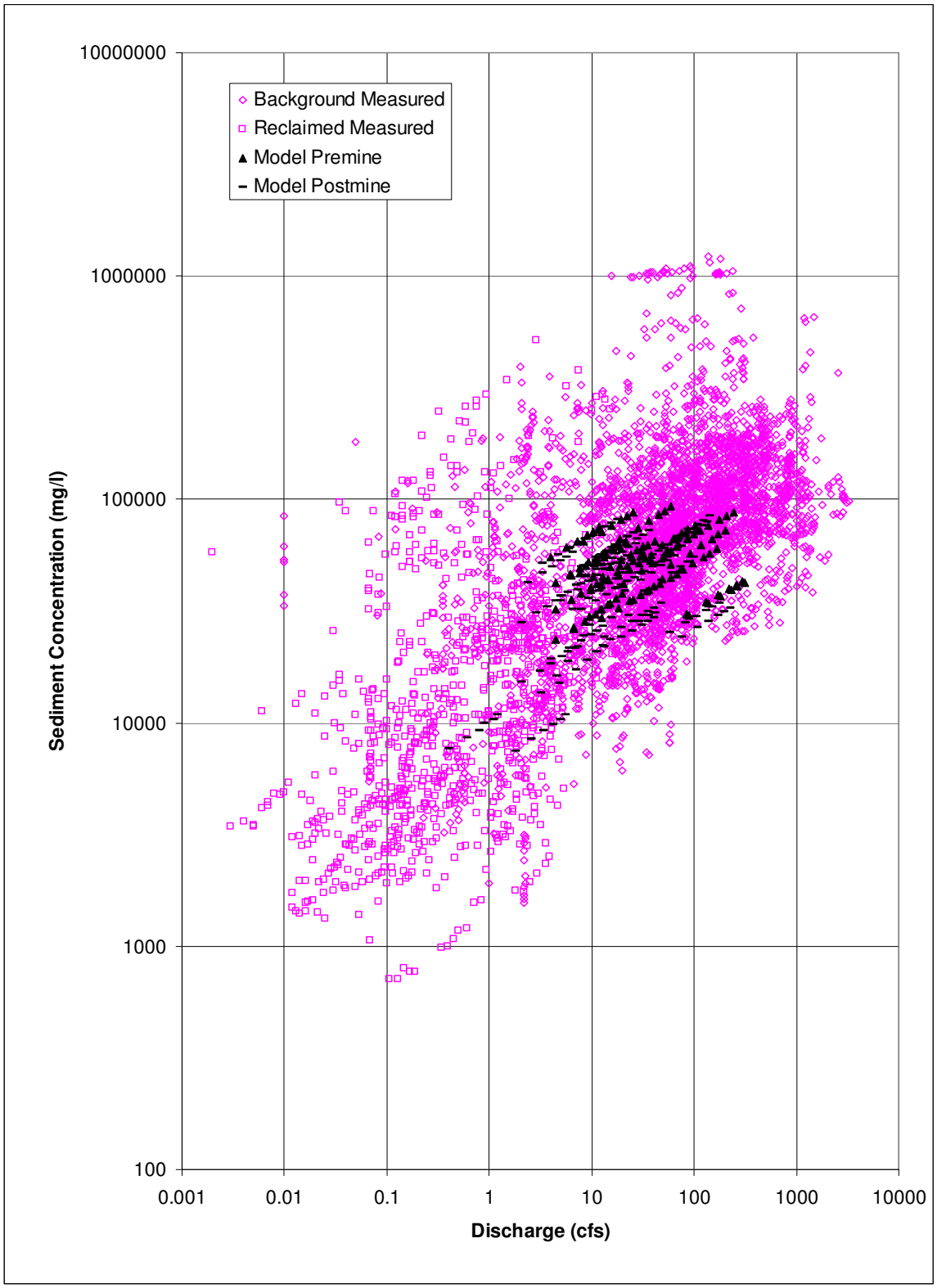


Figure 2.2. Observed versus modeled sediment concentration and discharge.

However, the sediment yield shown in Table 1.4 is the average annual amount of sediment leaving the J7 WA whereas the sediment discharge shown in Figure 2.1 is the peak rate of sediment in transport occurring in any channel represented by the data, whether the channel is located upstream or downstream of a pond. Therefore, it should be concluded that with or without a pond left in the postmine landscape that traps sediment or stores water, the mine reclamation is not contributing additional sediment to the receiving streams and sediment impacts to the prevailing hydrologic balance have been minimized.

Smith and Best (2000) analyzed the measured data (background and reclaimed) shown in Figure 2.1 to develop an approach that can be used to determine if channels in reclaimed areas have similar sediment transport characteristics as background channels. The method that they used was to develop Sen lines (Sen 1968) and confidence intervals around the data. The slope of the Sen line is a non-parametric statistic computed as the median slope of all possible slopes determined from pairing all the data points. The Sen line is drawn through the median coordinate of the data. Smith and Best first showed that the large channel flume data (background) and the small watershed background data could be combined. They concluded that since the data from one data set fall within the Sen line bounds of the other data set then the two data sets are merely extensions of each other and could be combined. Also, because the main channel and background small watershed site data could be combined, it indicated there is an unlimited supply of sediment and the channels are conveying sediment at (or near) capacity. The Sen line and bounds are shown with the background measured data in **Figure 2.3**.

They then plotted the reclaimed measured data (**Figure 2.4**) with the Sen line and bounds from the background data to show that the reclaimed data have the same characteristics even though the flow range of the measurements is lower. The data indicate that channel flows in this environment achieve the sediment transport capacity of the channel, whether in reclaimed or background conditions.

Using the same approach with the modeled data generated for the J7 WA, **Figures 2.5 and 2.6** show the pre- and postmine computed sediment transport rates with the Sen lines and bounds. One difference between the plots is that the measured data occur throughout the flow hydrograph whereas the modeled data are tabulated at the peak of the simulation flow hydrograph. The premine data plot (Figure 2.5) shows the data grouped densely around the Sen line and well within the bounds. The postmine data (Figure 2.6) plot slightly below the Sen line. On these graphs data plotting below the Sen line indicate that there is less sediment in transport for a given discharge.

Several conclusions can be drawn from these data plots: (1) EASI model well replicates erosion and sediment transport processes at the mine site for background and reclaimed conditions, (2) all data show similar trends and are within the same bounds, (3) data trends indicate that channels are transporting sediment at or near capacity, and (4) amounts of sediment leaving the WA for postmine conditions are similar to premine conditions and within the range expected for the background conditions. Therefore, the overall conclusion is that the postmine reclaimed condition in J7 WA is not contributing additional suspended solids to receiving streams, and related impacts to the hydrologic balance have been minimized.

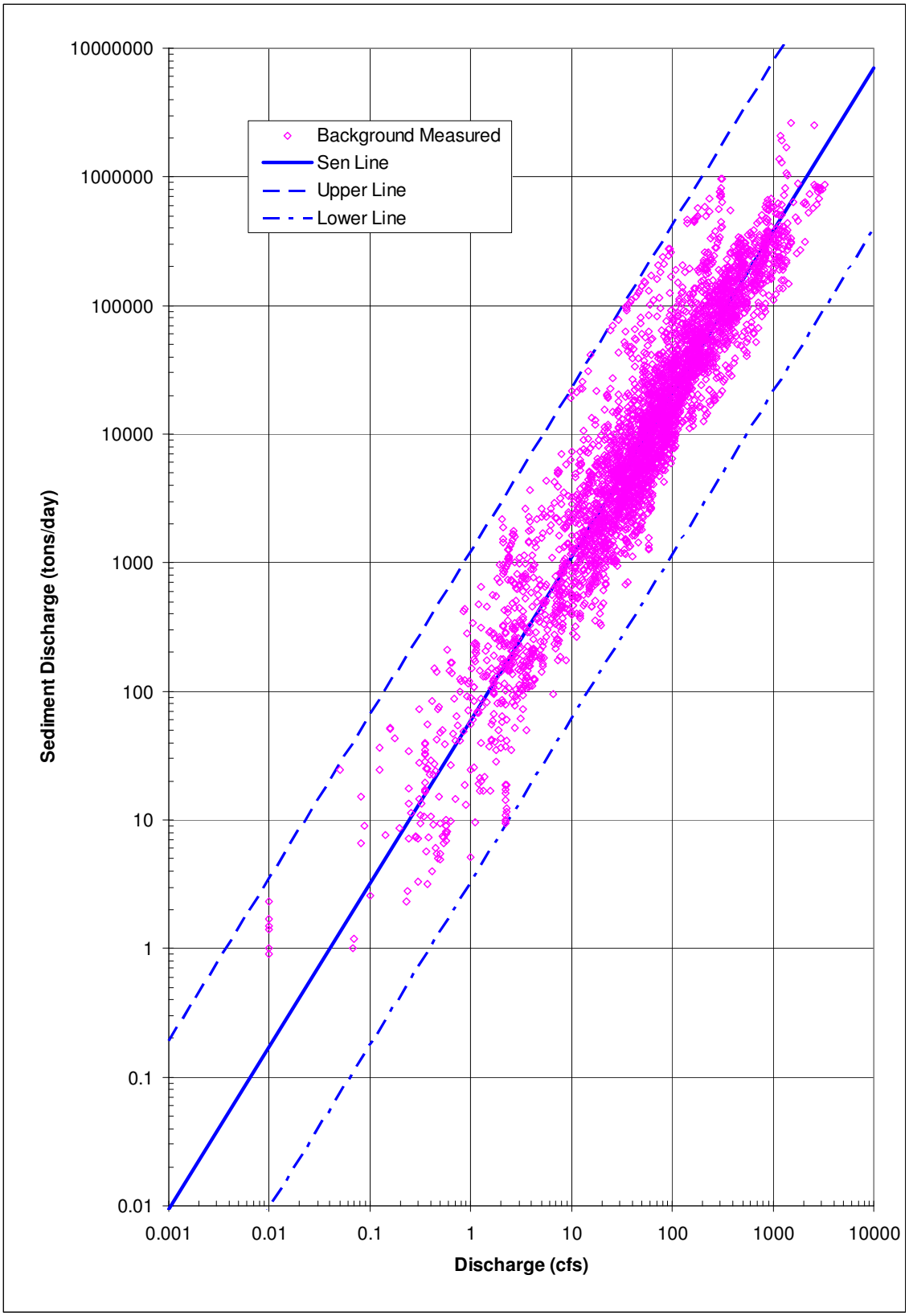


Figure 2.3. Background measured sediment and water discharge.

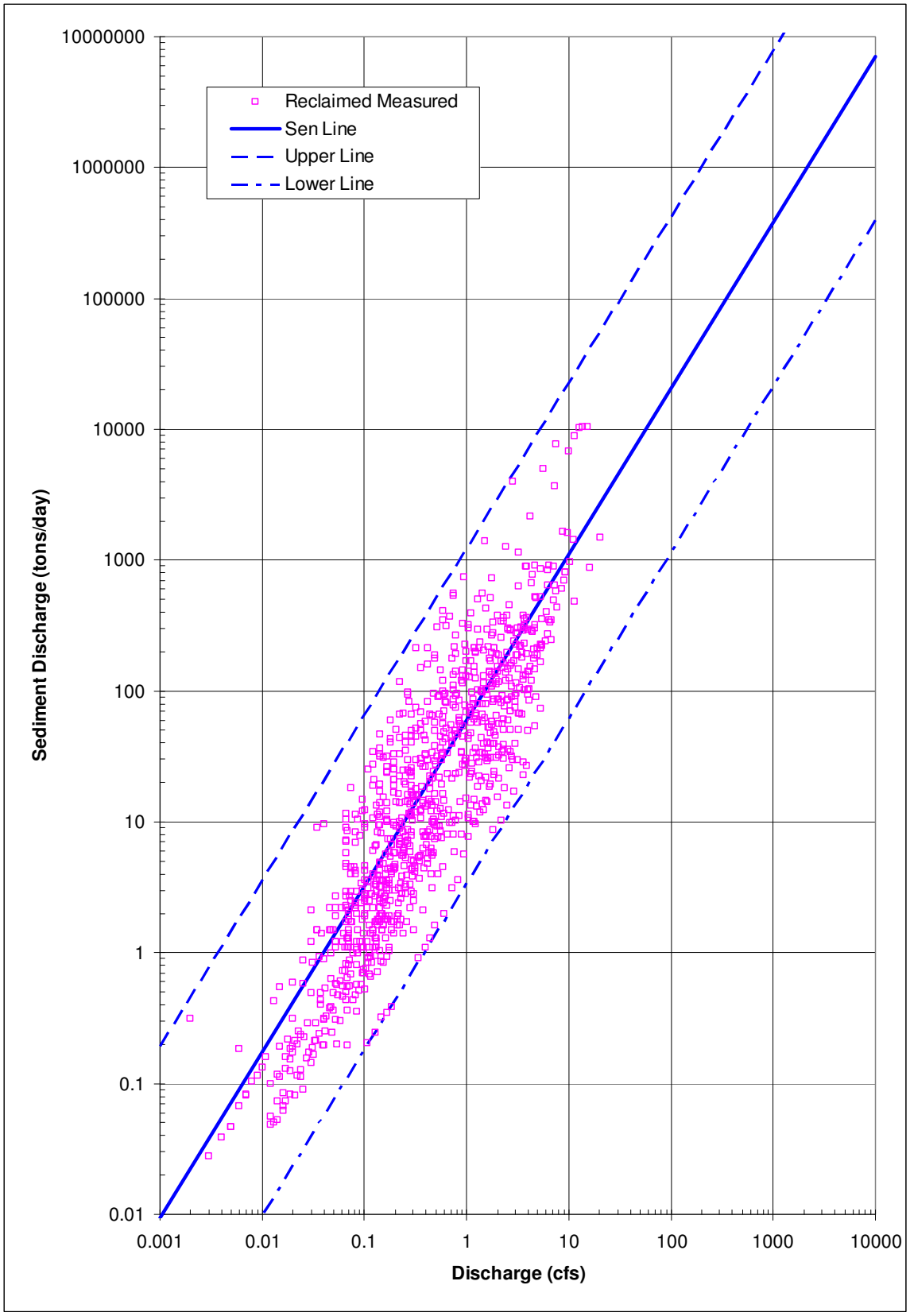


Figure 2.4. Reclaimed measured sediment and water discharge.

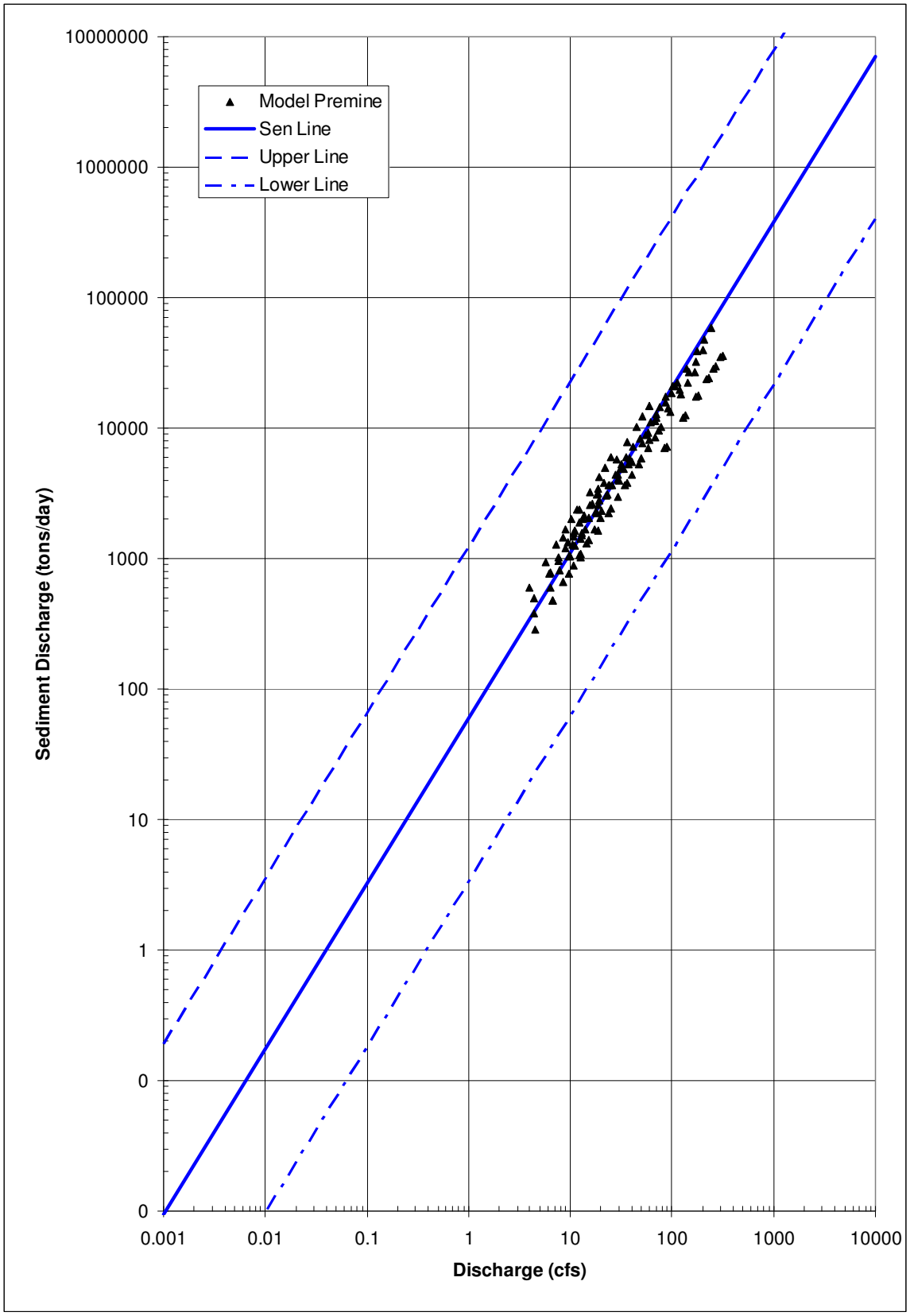


Figure 2.5. Modeled premine sediment and water discharge for the J7 WA.

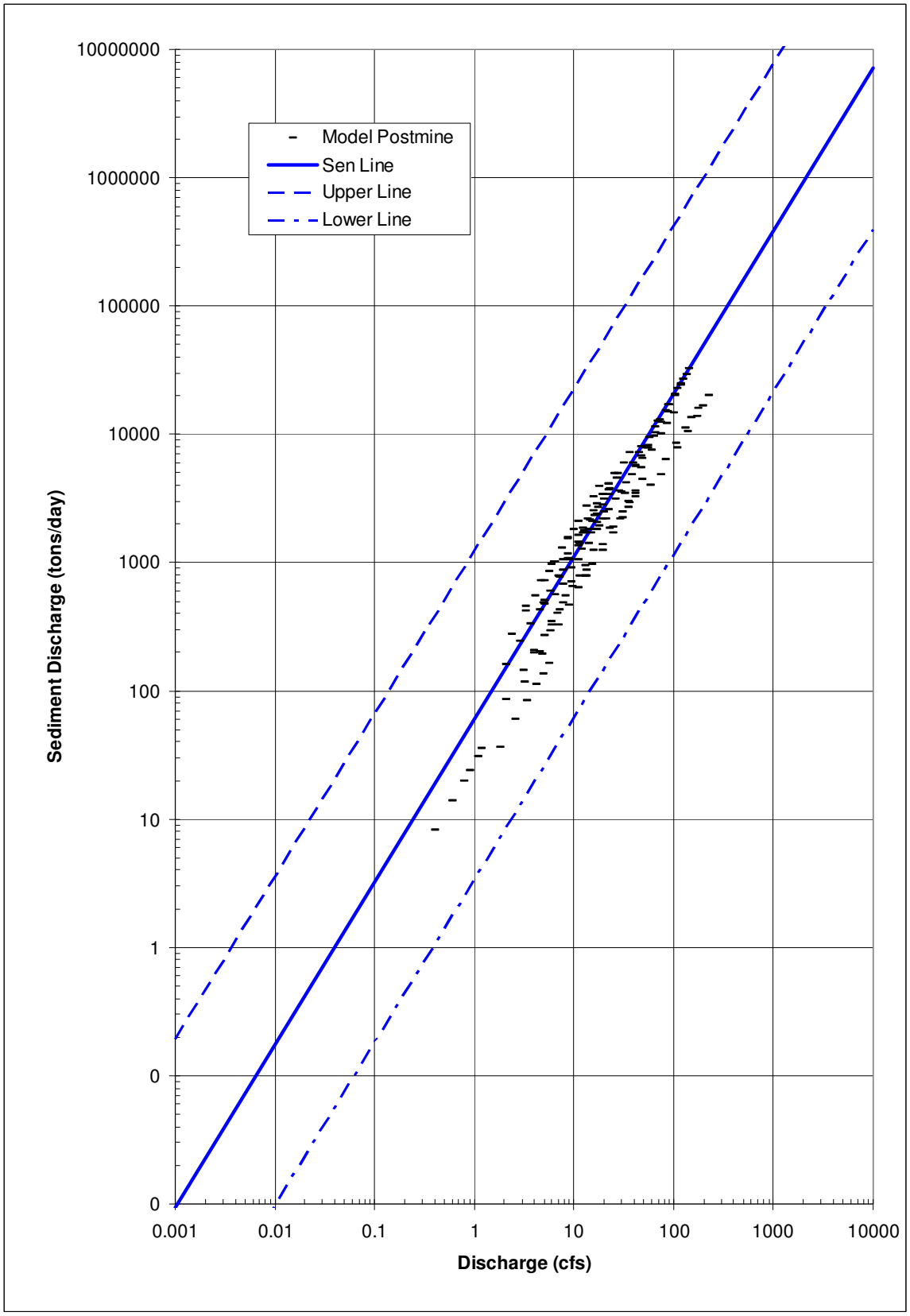


Figure 2.6. Modeled postmine sediment and water discharge for the J7 WA.

3. REFERENCES

Hjelmfelt, A.T., Kramer, L.A., and Spomer, R.G., 1986. Role of large events in average soil loss in Proceedings of the Fourth Federal Interagency Sedimentation Conference, March 24-27, 1986, Las Vegas, NV, p. 3-1 to 3-9.

Lagasse, P.F., Schall, J.D., and Peterson, M.R., 1985. Erosion Risk Analysis for a Southwestern Arroyo, Journal of Urban Planning and Management, American Society of Civil Engineers, v. III, no. I, November, 1985, Paper No. 20165.

Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973. "NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States," Volume VIII - Arizona, National Oceanic and Atmospheric Administration.

Renard, K.G. and Simaton, J.R., 1975. "Thunderstorm Precipitation Effects on the Rainfall-Erosion Index of the Universal Soil Loss Equation" in Volume 5 of Hydrology and Water Resources in Arizona and the Southwest, American Water Resources Assn., Arizona Section Arizona Academy of Science, Hydrology Section, Proceedings of April 11-12 meeting, Tempe AZ, v. 47-55.

Resource Consultants & Engineers, Inc. (RCE), 1993. "Surface Water Modeling of Reclaimed Parcels at the Black Mesa Complex," prepared for Peabody Western Coal Co.

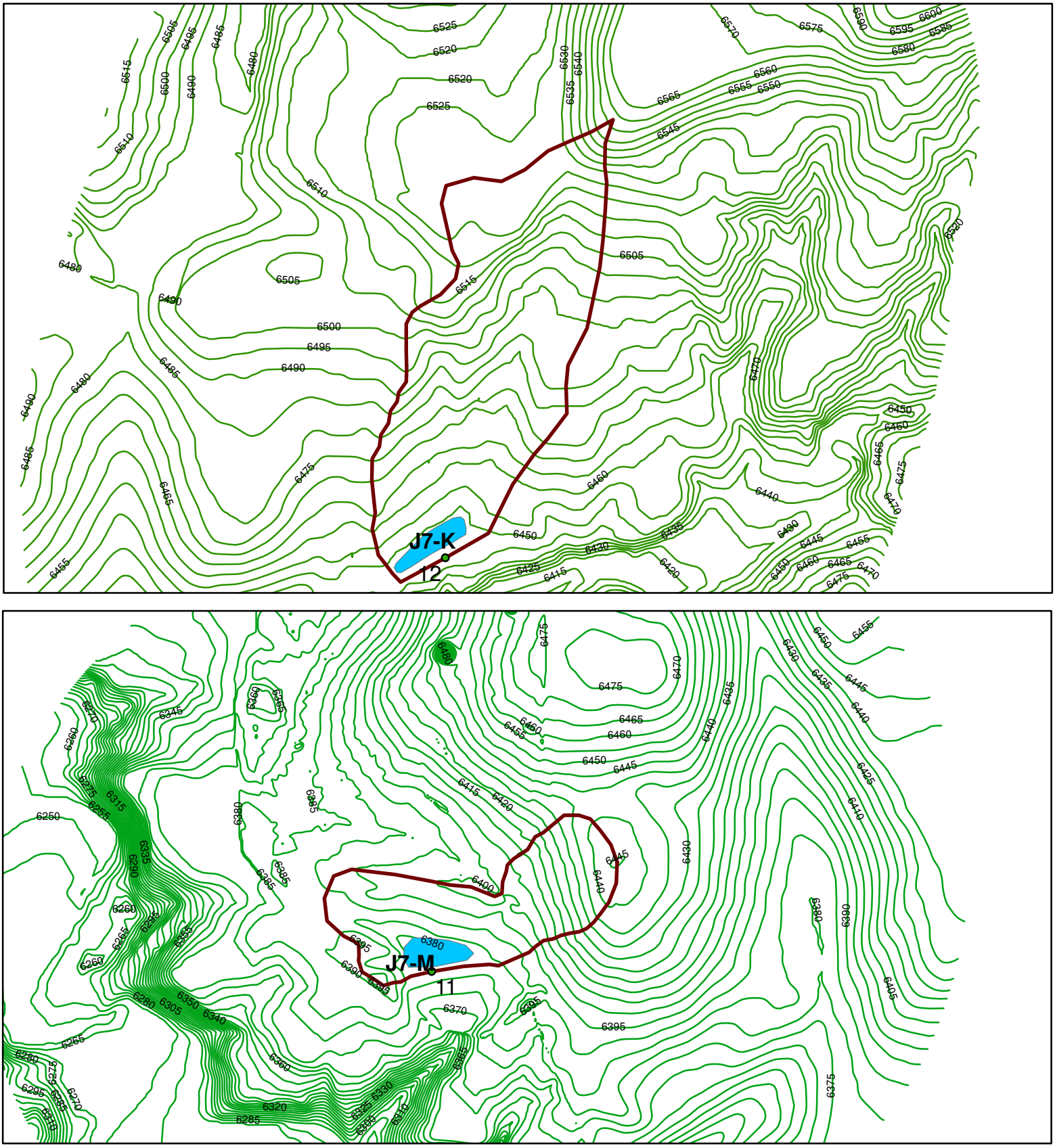
Sen, P.K., 1968. "Estimates of Regression Coefficient Based on Kendall's tau: Journal of American Statistical Association, v. 63, p. 1379-1389.

Smith, T. and Best, A., 2000. "Assessing Sedimentation and Protection of the Hydrologic Balance in Disturbed and Reclaimed Areas at the Black Mesa and Kayenta Mines, Arizona, Using Baseline Sediment Data Collected in Receiving Streams," presentation given at the Billings Mined Land Reclamation Symposium in 2001, Billings, MT.

Water Engineering & Technology, Inc. (WET), 1990. "Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control Technology at Surface Mines in the Semiarid West," prepared for Office of Surface Mining and the National Coal Association, Fort Collins, CO.

Zevenbergen, L.W., Peterson, M.R., and Watson, C.C., 1990. Computer simulation of watershed runoff and sedimentation processes, Proceedings of the Billings Symposium; Planning, Rehabilitation and Treatment of Disturbed Lands.

EXHIBIT 1
Postmine Topography



N

Legend

- End Points
- Ponds
- Modeling Area

0 300 600 1,200 1,800 Feet

Exhibit 1. Postmine Topography
(5 foot contour)

EXHIBIT 2
Premine Topography

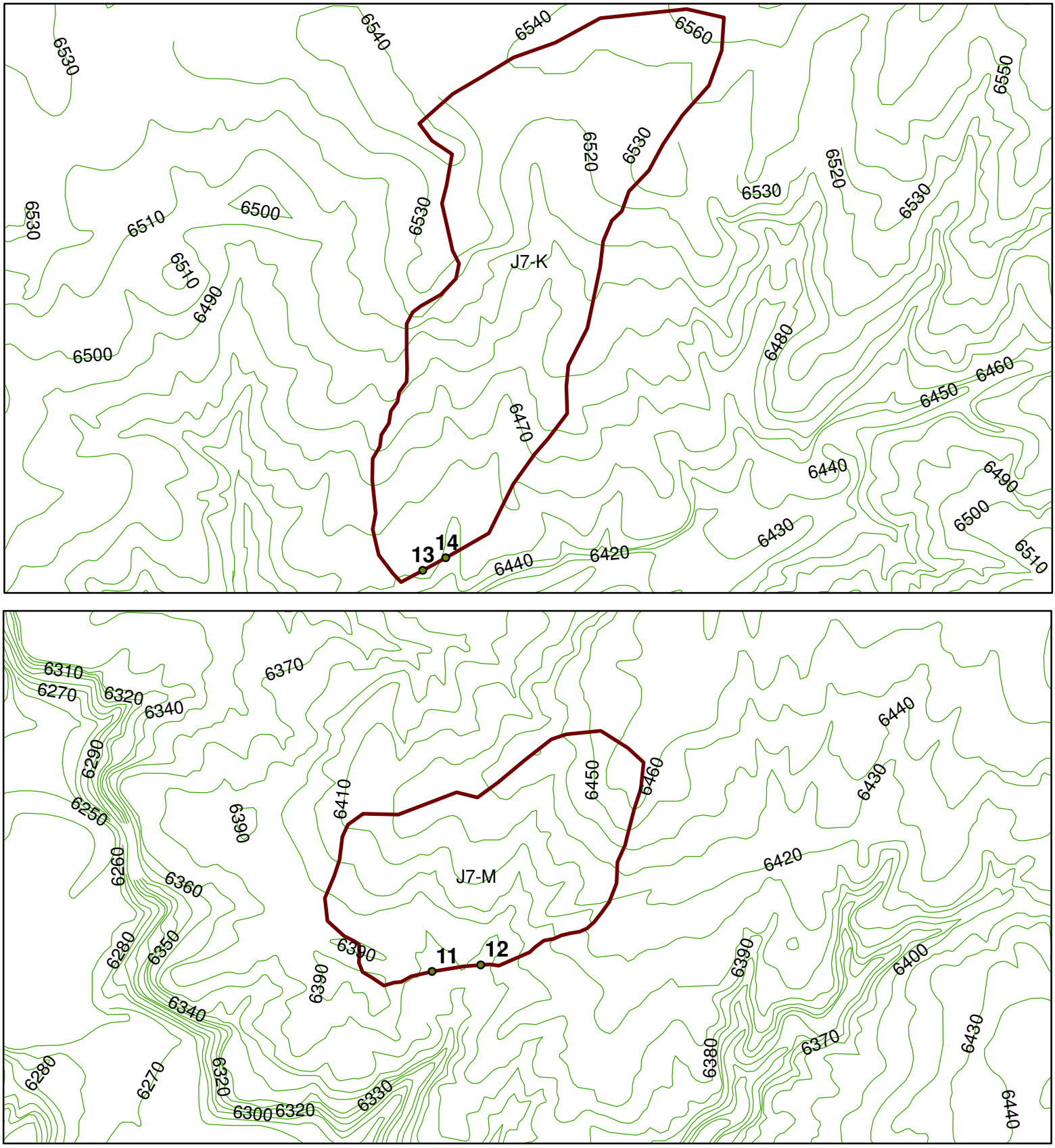


Exhibit 2. Premine Topography
(10 foot contour)

Appendix 8

Surface Water Modeling of the Reclaimed N5-D and N5-E Watershed Area at Black Mesa Complex

SURFACE WATER MODELING OF THE RECLAIMED N5-D and N5-E WATERSHED AREA AT BLACK MESA COMPLEX

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES

SURFACE WATER MODELING OF THE RECLAIMED N5-D and N5-E WATERSHED AREA AT BLACK MESA COMPLEX

Prepared for

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES
P.O. Box 270460
Fort Collins, Colorado 80527
(970) 223-5556, FAX (970) 223-5578

Ayres Project No. 32-1304.01
PEA-N5DE.DOC

August 2009

TABLE OF CONTENTS

1. Reclaimed Parcel Modeling 1.1

1.1 Introduction 1.1
1.2 Background 1.1
1.3 Data 1.2

1.3.1 Soils 1.2
1.3.2 Vegetation 1.2
1.3.3 Topography 1.3

1.4 Methodology 1.3

1.4.1 Synthetic Rainfall 1.8
1.4.2 Computation of Average Runoff and Sediment Yield 1.8

1.5 Results 1.8
1.6 Discussion 1.9

2. Comparisons with Measured Sediment Transport 2.1

3. References 3.1

Exhibit 1 – Postmine Topography ..... --
Exhibit 2 – Premine Topography ..... --

LIST OF FIGURES

Figure 1.1. Reclaimed area soils trilinear graph. 1.2

Figure 1.2. Spatial distribution of vegetative cover types for WA N5 premine condition. .. 1.4

Figure 1.3. N5-D and N5-E postmine basins. 1.6

Figure 1.4. N5-D and N5-E premine basin..... 1.7

Figure 2.1. Observed and modeled sediment and water discharge. 2.2

Figure 2.2. Observed versus modeled sediment concentration and discharge. 2.3

Figure 2.3. Background measured sediment and water discharge. 2.5

Figure 2.4. Reclaimed measured sediment and water discharge. 2.6

Figure 2.5. Modeled premine sediment and water discharge for the N5 WA. 2.7

Figure 2.6. Modeled postmine sediment and water discharge for the N5 WA. 2.8

LIST OF TABLES

Table 1.1. Soils Data. 1.3

Table 1.2. Cover Sampling Data. 1.5

Table 1.3. Cover Data for N5-D and N5-E Watersheds. 1.5

Table 1.4. Average Runoff and Sediment Yield Results. 1.8

Table 1.5. Average Physical Properties of the N5 WA. 1.9

1. RECLAIMED PARCEL MODELING

1.1 Introduction

The objective defined by PWCC for this project is to use a previously calibrated and validated runoff and erosion model (EASI, Zevenbergen et al. 1990; WET 1990) for the Black Mesa and Kayenta Mines (combined as Black Mesa Complex in December 2008) to predict mean annual runoff and sediment yields from the reclaimed N5-D and N5-E watersheds. This objective included computation of runoff and sediment yields under premine conditions for the same area. All soils and rainfall input to the model are to be taken from models calibrated in the previous study (RCE 1993). The input variables that were calibrated to the mine areas and used in this study include soil infiltration parameters, erodibility parameters, and the grain size distribution. Parameters that are specific to this study are vegetative canopy and ground cover percentages from data collected on site.

The model calibration was conducted in a previous study (RCE 1993) using data obtained from instrumented watersheds and small hillslope plots collected under natural rainfall conditions. For a detailed discussion of data collection and model calibration, please refer to the previous study (RCE 1993).

1.2 Background

The N5-D and N5-E Watershed Area (WA) that is the focus of this project was reclaimed between 1993 and 1996. The fundamental purpose of this study was to quantify the expected behavior and hydrologic response of the reclaimed areas above each pond relative to the conditions that existed prior to the occurrence of mining activities.

Runoff and sediment yield response from the reclaimed lands should be managed by implementing Best Management Practices (BMP's) in conjunction with an OSM approved sediment control plan in order to not adversely impact the prevailing hydrologic balance and to limit additional contributions of suspended sediment to streamflow or runoff outside the mine permit areas. BMP's include regrading, replacing salvaged topsoil, revegetation, and other controls such as riprapped channel bottoms, check dams, and where practicable, contour terraces. The natural watersheds on the mesa contribute significant quantities of sediment to the channel system. It is expected that the postmine condition will also produce comparable amounts of sediment without adversely impacting the hydrologic balance.

This section describes the data and procedures used to evaluate the N5 WA. This area was modeled to determine the average annual hydrologic response following the completion of reclamation activities taking into account BMP's implemented as part of the reclamation process. Infiltration, runoff, and erosion processes from both hillslopes and channels within the N5 WA were modeled using EASI. Results were determined for the concentration point at the outlet of the reclaimed watershed, which corresponds to the embankment associated with Pond N5-E. Only one concentration point results from the two ponds because Pond N5-D drains through Pond N5-E. The location of this point is shown in **Exhibit 1**. Modeling was also conducted to determine hydrologic response under premine conditions based on the topography, soils, cover, and other conditions that typified the undisturbed watersheds draining to the concentration point. **Exhibit 2** shows the modeling endpoints for the premine N5 WA.

1.3 Data

1.3.1 Soils

Soils data used for the current study (N5 WA) were based on data developed from the calibration of models used in the previous study for Coal Resource Areas (CRAs) N1/N2 and J27 (RCE 1993). The composition of postmine soil in the current study is depicted along with the composition of postmine soils from the previous study in **Figure 1.1**. Note that the postmine soil data for the N5 WA is included in the entire data set for the J1/N6 CRA. This figure shows that the soil composition of WA N5 is very similar to soils evaluated during model calibration. Therefore, the soil properties developed in the previous study are valid for this modeling project. These properties include calibrated parameters, such as infiltration and erodibility coefficients, and measured soil size distributions. **Table 1.1** lists the premine and postmine soils data used during EASI modeling of WA N5.

1.3.2 Vegetation

Vegetative cover data representative of both pre- and postmine conditions in WA N5 were supplied by PWCC. For the premine condition, land was characterized as being covered by sagebrush or pinon juniper. The spatial distribution of vegetative cover for the N5 WA premine condition appears in **Figure 1.2**. Average cover properties for CRAs N1/N2 and J27 of the previous study and WA N5 of the current study appear in **Table 1.2**. For the postmine condition, the reclaimed area was assigned the postmine cover type and the unmined area was assigned the same cover type as the premine condition. **Table 1.3** lists the pre- and postmine vegetative cover data used in the EASI model runs generated for the N5 WA. Note that if a unit contained significant portions of both sagebrush and pinon juniper cover types, it was classified as half pinon juniper and half sagebrush.

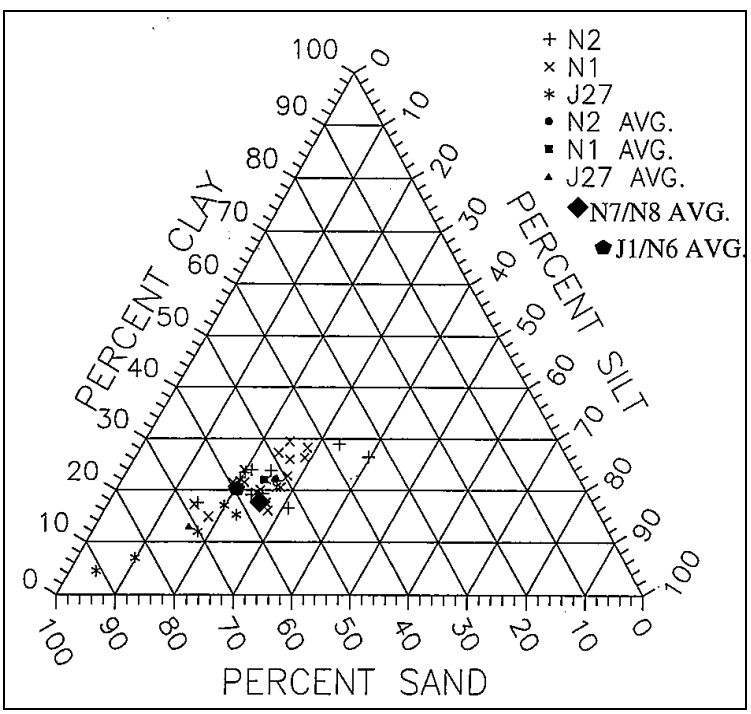


Figure 1.1. Reclaimed area soils trilinear graph.

Table 1.1. Soils Data.			
Condition	Premine	Postmine	Rock Chutes
Rainfall detachment	0.005	0.005	0
Overland flow detachment	0.44	0.44	0
Channel flow detachment	0.5	0.5	0
Initial soil moisture, %	70	70	70
Final soil moisture, %	90	90	90
Soil porosity, %	45	45	46
Temperature, *F	70	70	70
Hydraulic conductivity, in/hr	0.23	0.29	0.3
Capillary suction, in	3.7	2.6	2.6
	Particle Size Distribution (all conditions)		
	Size, mm	% Finer	
	0.001	0	
	0.004	18.0	
	0.016	27.4	
	0.062	36.6	
	0.125	56.2	
	0.250	64.3	
	0.500	72.4	
	1.000	80.5	
	2.000	88.6	
	4.000	92.4	
	16.000	100	

1.3.3 Topography

Pre- and postmine topography was supplied by PWCC in the form of ArcGIS geodatabase. Basin delineations, hillslope delineations, subwatershed delineations, as well as areas, slopes, and lengths of all units of the study area were defined and calculated using ArcGIS software. **Figures 1.3 and 1.4** show the watershed delineation and numbers assigned to the basins used in the EASI model for the post- and premine conditions, respectively. Channel dimensions input to EASI were based on the topography supplied and limited field observations.

1.4 Methodology

Runoff and sediment yield in the semiarid western United States is largely governed by the occurrence of high-intensity, short-duration rainstorms of limited areal extent (Renard and Simaton 1975). Research has indicated that relatively few events may produce the greatest erosion (e.g., Hjelmfelt et al. 1986 reported that only 3 to 4% of rainfall events accounted for 50% of long-term sediment yields). Although there is perhaps a relatively limited physical basis for definition of an "average annual" runoff or sediment yield in a semiarid environment due to the extreme variability in response and importance of single infrequent events, such a term does provide a useful basis for long-term comparison between reclaimed and undisturbed conditions.

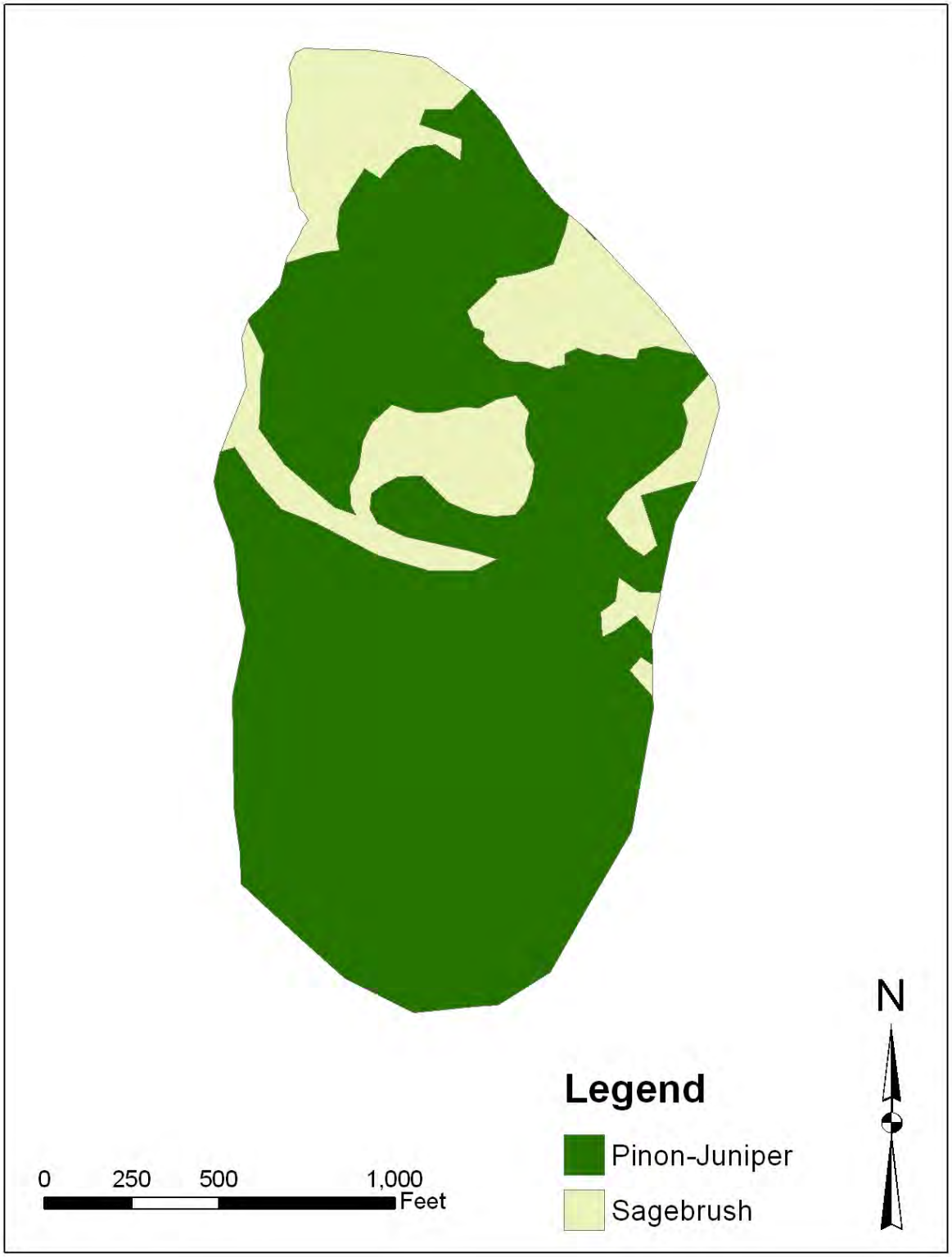


Figure 1.2. Spatial distribution of vegetative cover types for WA N5 premine condition.

Table 1.2. Cover Sampling Data.								
Area	Condition	Cover Type	Nonstratified Vegetation Cover (%)	Vegetation Canopy Cover (%)	Vegetation Ground Cover (%)	Litter* (%)	Rock (%)	Total Ground Cover (%)
N1/N2	Postmine	Postmine	25.6	1.4	24.2	13.6	4.2	41.9
N5 WA	Postmine	Postmine	16.9	0.6	16.4	30.3	2.2	48.9
N1/N2/J27	Premine	Pinon Juniper	32.7	31.1	3.0	44.0	19.7	66.7
N5 WA	Premine	Pinon Juniper	16.9	14.6	2.7	18.8	17.3	38.8
N1/N2	Premine	Sagebrush	25.1	16.0	10.3	25.3	18.1	53.7
J27	Premine	Sagebrush	30.6	9.7	22.0	24.0	1.6	47.6
N5 WA	Premine	Sagebrush	12.4	1.3	11.2	24.7	2.5	38.3
*Including standing dead litter								

Table 1.3. Cover Data for N5-D and N5-E Watersheds.				
Condition	Pinon Juniper	Sagebrush	Half Pinon Juniper-Half Sagebrush	Postmine
Canopy cover, %	14.6	1.3	8.0	0.6
Ground cover, %	38.8	38.3	38.5	48.9
Canopy storage, in	0.05	0.05	0.05	0.05
Ground storage, in	0.05	0.05	0.05	0.05
Depression storage, in	0.03	0.03	0.03	0.03
Impervious area, %	0	0	0	0
Manning n	0.07	0.07	0.07	0.05

To make comparisons between reclaimed lands and associated undisturbed lands at the Black Mesa Mining Complex on the basis of average annual sediment yield, a procedure was used that considers the importance of infrequent storm events in defining sediment yield in the semiarid west. First, however, the site-specific rainfall data available for the Black Mesa Mining Complex were used to evaluate the frequency and magnitude of the measured events relative to existing predictions for rainfall depth-duration (Miller et al. 1973). The analysis of the rainfall data was performed as part of a previous study of the N1/N2 and J27 CRAs (Resource Consultants and Engineers 1993).

Comparisons between runoff and sediment yield from undisturbed and reclaimed areas in WA N5 were developed for specific modeling endpoints shown in Exhibits 1 and 2. Mining and reclamation activities did not exactly replicate the topography, drainage network, or drainage areas that existed prior to mining. Consequently, direct comparisons of total runoff and sediment yield cannot be made between undisturbed and reclaimed response at a given point in a watershed. Comparisons were made on the basis of unit rates of runoff (inches) and sediment yield (tons/acre) at the various modeling computation endpoints. Although the same disturbance boundary was used to define the extent of both pre- and postmine conditions, the topographic differences that resulted after mining and reclamation occurred in the N5 WA dictated that some areas would be included or excluded from the modeling. The total area modeled (combined area for N5-D and N5-E watersheds) for premine conditions is 64.7 acres (Exhibit 2) and for postmine conditions is 28.3 acres (Exhibit 1).

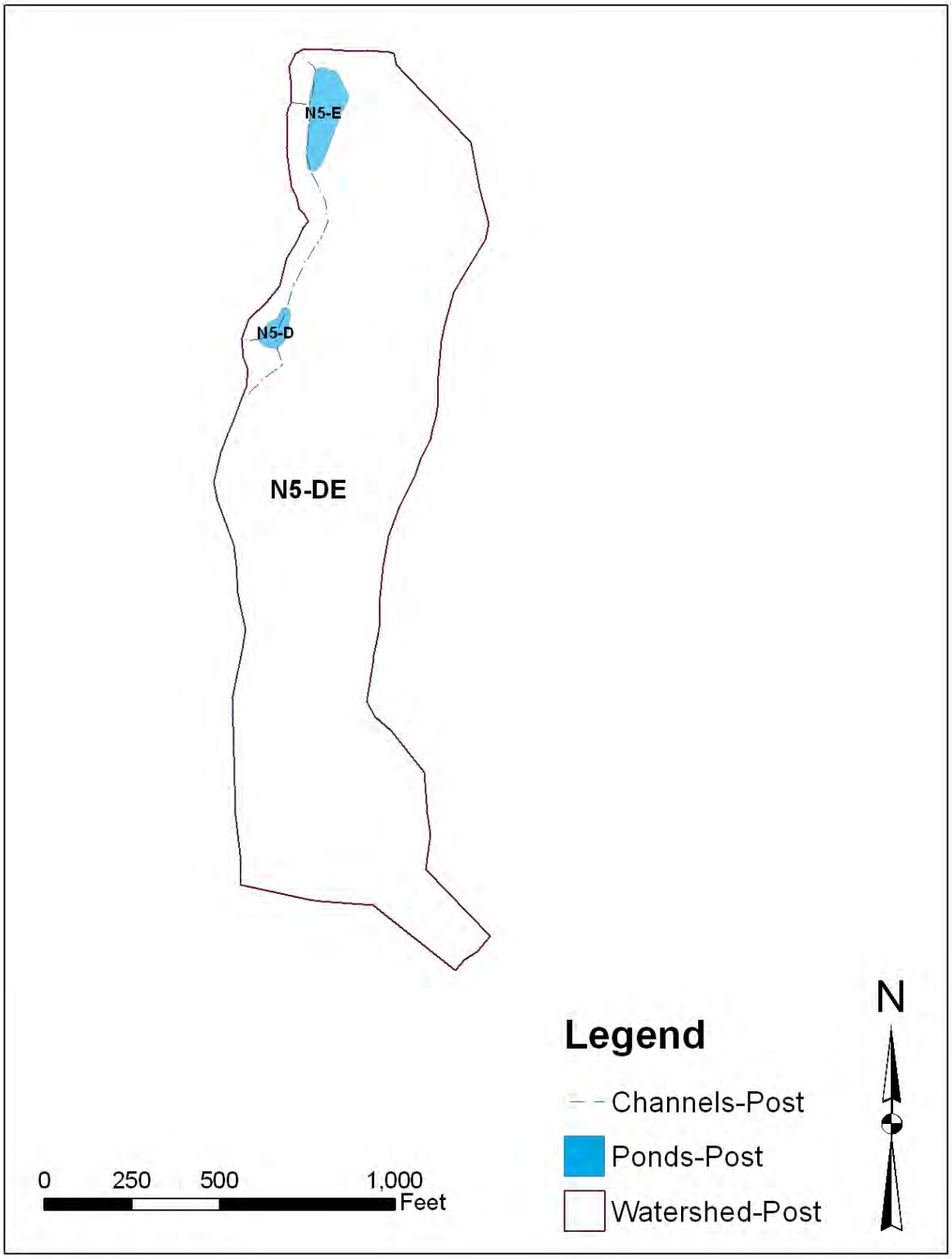


Figure 1.3. N5-D and N5-E postmine basins.

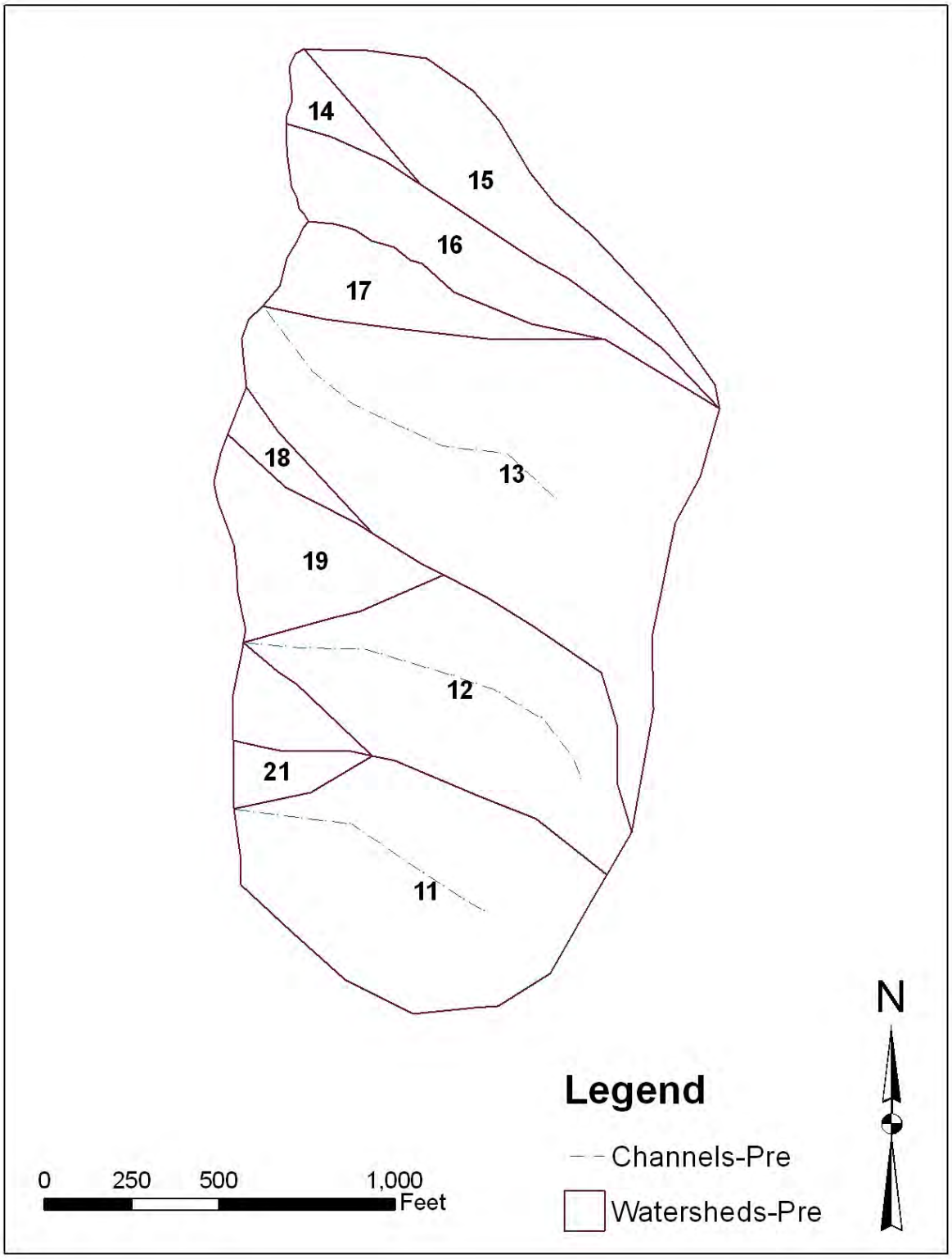


Figure 1.4. N5-D and N5-E premine basins.

1.4.1 Synthetic Rainfall

Synthetic storms of 2-, 5-, 10-, 25-, 50-, and 100-year return periods were used as input to the EASI model. Actual hyetographs were taken from the previous study (RCE 1993) and are based on both local data collection and the NOAA Atlas (Miller et al. 1973).

1.4.2 Computation of Average Runoff and Sediment Yield

The EASI model was used to evaluate runoff and sediment yield from a series of storm events having recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100 years. To define average annual conditions, the average annual runoff and sediment yield generated from storm events were computed using the commonly used equation of Lagasse et al. (1985).

1.5 Results

Figures 1.3 and 1.4 show the post- and premine basin delineations. Since the individual subareas differ in number, acreage and outlet locations, a direct comparison is not possible on a subarea basis. Therefore, the best way to compare the results is on an average basis for the WA. **Table 1.4** shows pre- and postmine drainage area, runoff, and sediment yield for the N5 WA. N5-D and N5-E ponds were constructed in a way that N5-D pond flows to N5-E pond when the surface water elevation reaches a certain level. Therefore, both ponds were connected in the postmine model and there is only an outlet for the whole domain. Sediment yield and runoff were not reported for individual ponds. For the postmine condition, the overall sediment yield is less than the premine condition and runoff is the same as the premine amount.

To consider the situation of pond removal for the postmine condition, the EASI model replaces a sediment pond with a channel, which lies near the location of the pond and discharges to the basin outlet. The channel is assumed to have a length equal to the pond's length and a slope similar to the outlet's natural slope. Runoff is defined as the total volume of water leaving the WA on an average annual basis and, therefore, does not include water stored in depression areas and ponds. For the premine condition, this is equal to the amount of water that drains off the hillslopes and subwatersheds because there are no ponds or significant depressions. For the postmine condition, this is equal to the amount of hillslope runoff less the amount stored in ponds. No ponds or significant depressions exist within the reclaimed N5 WA that was modeled. Similarly, the sediment yield is the amount of eroded material that leaves the WA on an average annual basis computed using the equation of Lagasse et al. (1985). The sediment yield is the production from the hillslope areas and erosion from the channels. The amount of erosion is the sediment yield from the hillslopes and subwatersheds only and does not include channel erosion, channel deposition or sediment trapped in ponds. Sediment yield can be greater or less than erosion, depending on the amount of channel erosion and the capacity of the channel network to convey sediment off the leasehold.

Table 1.4. Average Runoff and Sediment Yield Results.

Area	Condition	Drainage Area (ac)	Runoff (in)	Sediment Yield (t/ac/yr)
N5 WA	Premine	64.7	0.42	2.83
N5 WA	Postmine	28.3	0.42	1.47

1.6 Discussion

Table 1.5 gives an overview of the geometric properties of the pre- and postmine topographies for the N5 WA. Mean channel slope for the postmine condition is smaller than the premine condition; and drainage density for the postmine condition is much higher than the premine condition due to terracing and the relatively smaller drainage area. Average hillslope gradient for the postmine condition is much larger than the premine condition, because the premine modeling area (64.7 acres) is more than twice the postmine modeling area (28.3 acres) and includes a relatively flat ridge top area. The two major differences between pre- and postmine properties are drainage area and hillslope gradient. These two properties are inversely related at this location. This is because the upper portion of the premine basin, which had the lowest gradient, now drains to another concentration point rather than to N5-D or N5-E.

Table 1.5. Average Physical Properties of the N5 WA.

	Premine	Postmine
Total Area (ac)	64.7	28.3
Total Channel Length (ft)	2949	2664
Mean Channel Slope	0.0870	0.0504
Drainage Density (mi/mi^2)	5.5	11.4
Mean Hillslope Length (ft)	348	221
Mean Hillslope Gradient	0.0738	0.1215

2. COMPARISONS WITH MEASURED SEDIMENT TRANSPORT

As discussed in Section 1, PWCC has monitored flow and sediment on the main channels, principal tributaries and small watersheds within the leasehold. These data, along with the runoff plots, were used to calibrate the EASI model soil erodibility and infiltration input variables. **Figures 2.1** and **2.2** show sediment transport and sediment concentration versus discharge for measured unmined (background), measured reclaimed, WA N5's modeled unmined (premine) and modeled reclaimed (postmine) data. Although there is significant scatter shown in the data (as is expected with any sediment transport conditions), there are several conclusions that can be drawn from this data.

The open symbols in both figures depict measured data and whether the data were collected from reclaimed areas (the small watershed study) or from unmined or background surface water monitoring stations. The range of flows is generally greater for the background data but there is significant overlap between the two data sets between 0.1 and 100 cfs. This is because the reclaimed data are from small watersheds and the unmined data are from channels draining larger basins. These data show the same trend for sediment transport and sediment concentration over the entire range of flows and very close agreement in the area of discharge overlap. This, in itself, is strong evidence that (1) the sediment yields are channel transport capacity limited, (2) overlap of model predictions for both pre- and postmine conditions with measured data strongly indicate that EASI model predictions are representative and reasonable, and (3) sediment yields from reclaimed areas will not be additive to yields on the receiving streams.

The closed symbols depict data from WA N5's pre- and postmine EASI model runs. They represent data generated by EASI for both subwatersheds and channels for peak discharges resulting from 2-, 5-, 10-, 25-, 50-, and 100-year storms. Using the peak flows from extreme events results in discharges that generally exceed 10 cfs. The trend of the model-derived data is similar and the ranges of concentration and sediment transport are similar to the measured data and between pre- and postmine conditions.

The sediment discharge plot (Figure 2.1) shows a stronger trend because it is plotting discharge (sediment) against discharge (flow). This is expected because the sediment discharge does depend on flow discharge. The concentration plot (Figure 2.2) shows the two separate variables and, therefore, a less significant trend. PWCC believes that data measurement may have some influence on the scatter (outliers were removed), but the process variability is probably the major influence. The majority of the data, however, fall in a group centered on 100 cfs and 100,000 mg/l, both in the observed data and in the model results. These plots support the use of the EASI model, the results of the modeling, the conclusion that sediment yields from reclaimed areas are not additive to receiving stream sediment loads, and that sediment impacts to the prevailing hydrologic balance have been minimized.

From Figures 2.1 and 2.2 it is apparent that sediment loads and concentrations are dependent on the channel sediment transport capacity for both pre- and postmine conditions. Channel sources of sediment in this arid environment are virtually unlimited. Therefore, channel transport capacity and channel derived sediment limits and governs sediment yields from the small tributaries, large channels and the WA as a whole. The similarity of sediment discharge (or concentration) between pre- and postmine conditions appears to be inconsistent with the lower rates of sediment yield shown in Table 1.4.

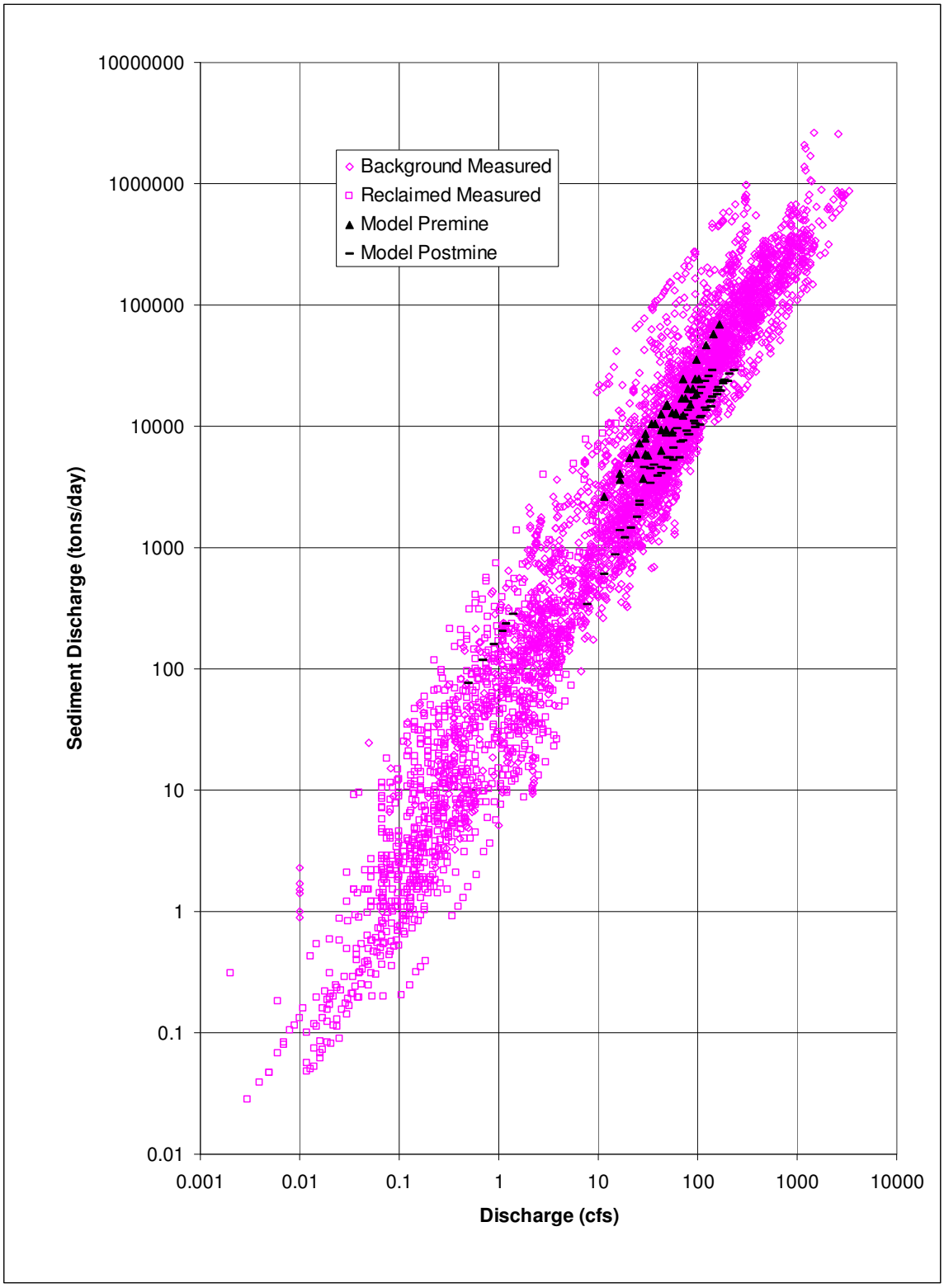


Figure 2.1. Observed and modeled sediment and water discharge.

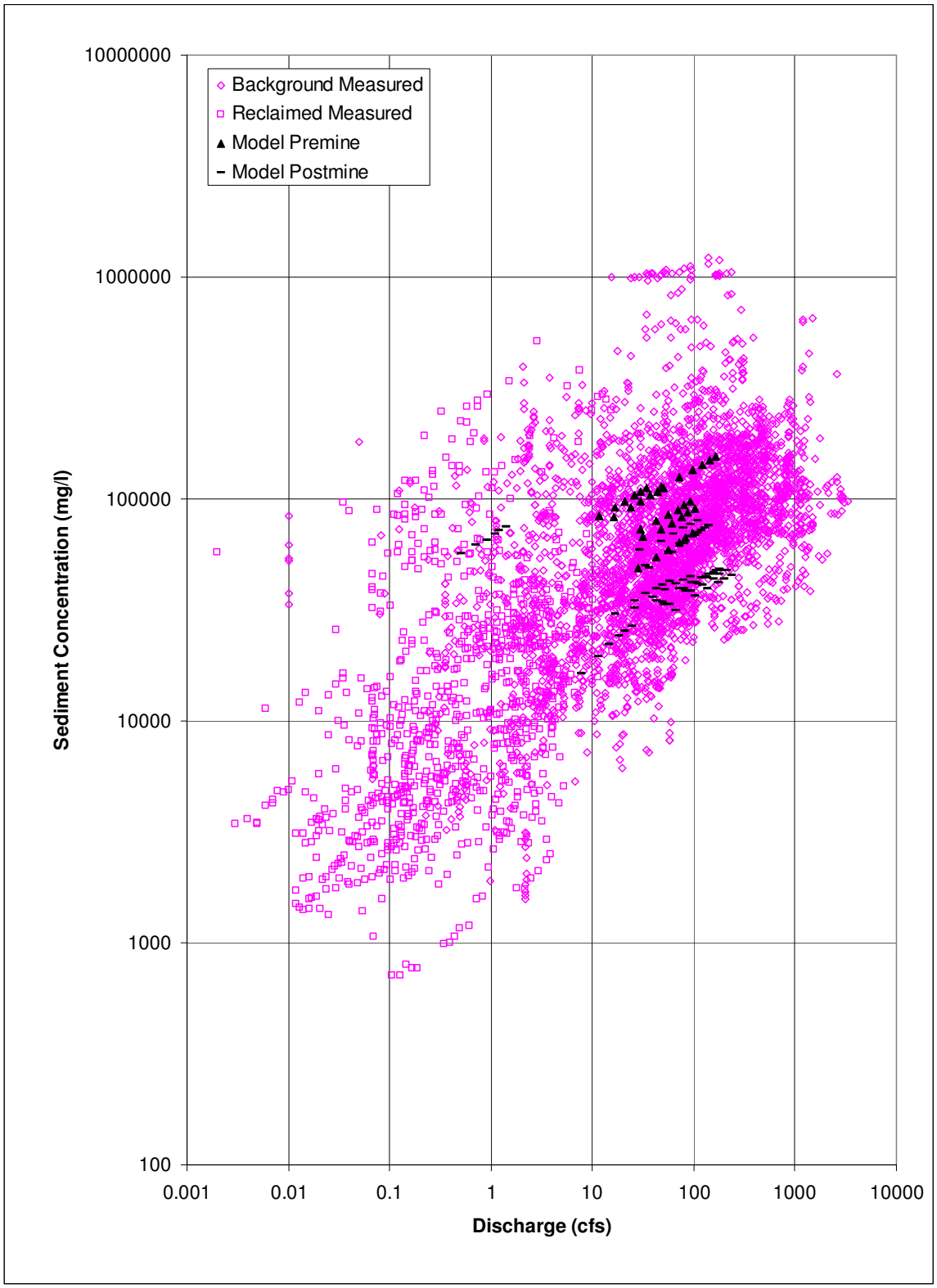


Figure 2.2. Observed versus modeled sediment concentration and discharge.

However, the sediment yield shown in Table 1.4 is the average annual amount of sediment leaving the N5 WA whereas the sediment discharge shown in Figure 2.1 is the peak rate of sediment in transport occurring in any channel represented by the data, whether the channel is located upstream or downstream of a pond. Therefore, it should be concluded that with or without a pond left in the postmine landscape that traps sediment or stores water, the mine reclamation is not contributing additional sediment to the receiving streams and sediment impacts to the prevailing hydrologic balance have been minimized.

Smith and Best (2000) analyzed the measured data (background and reclaimed) shown in Figure 2.1 to develop an approach that can be used to determine if channels in reclaimed areas have similar sediment transport characteristics as background channels. The method that they used was to develop Sen lines (Sen 1968) and confidence intervals around the data. The slope of the Sen line is a non-parametric statistic computed as the median slope of all possible slopes determined from pairing all the data points. The Sen line is drawn through the median coordinate of the data. Smith and Best first showed that the large channel flume data (background) and the small watershed background data could be combined. They concluded that since the data from one data set fall within the Sen line bounds of the other data set then the two data sets are merely extensions of each other and could be combined. Also, because the main channel and background small watershed site data could be combined, it indicated there is an unlimited supply of sediment and the channels are conveying sediment at (or near) capacity. The Sen line and bounds are shown with the background measured data in **Figure 2.3**.

They then plotted the reclaimed measured data (**Figure 2.4**) with the Sen line and bounds from the background data to show that the reclaimed data have the same characteristics even though the flow range of the measurements is lower. The data indicate that channel flows in this environment achieve the sediment transport capacity of the channel, whether in reclaimed or background conditions.

Using the same approach with the modeled data generated for the N5 WA, **Figures 2.5 and 2.6** show the pre- and postmine computed sediment transport rates with the Sen lines and bounds. One difference between the plots is that the measured data occur throughout the flow hydrograph whereas the modeled data are tabulated at the peak of the simulation flow hydrograph. The premine data plot (Figure 2.5) shows the data grouped densely around the Sen line and well within the bounds. The postmine data (Figure 2.6) plot slightly below the Sen line. On these graphs data plotting below the Sen line indicate that there is less sediment in transport for a given discharge.

Several conclusions can be drawn from these data plots: (1) EASI model well replicates erosion and sediment transport processes at the mine site for background and reclaimed conditions, (2) all data show similar trends and are within the same bounds, (3) data trends indicate that channels are transporting sediment at or near capacity, and (4) amounts of sediment leaving the WA for postmine conditions are similar to premine conditions and within the range expected for the background conditions. Therefore, the overall conclusion is that the postmine reclaimed condition in N5 WA is not contributing additional suspended solids to receiving streams, and related impacts to the hydrologic balance have been minimized.

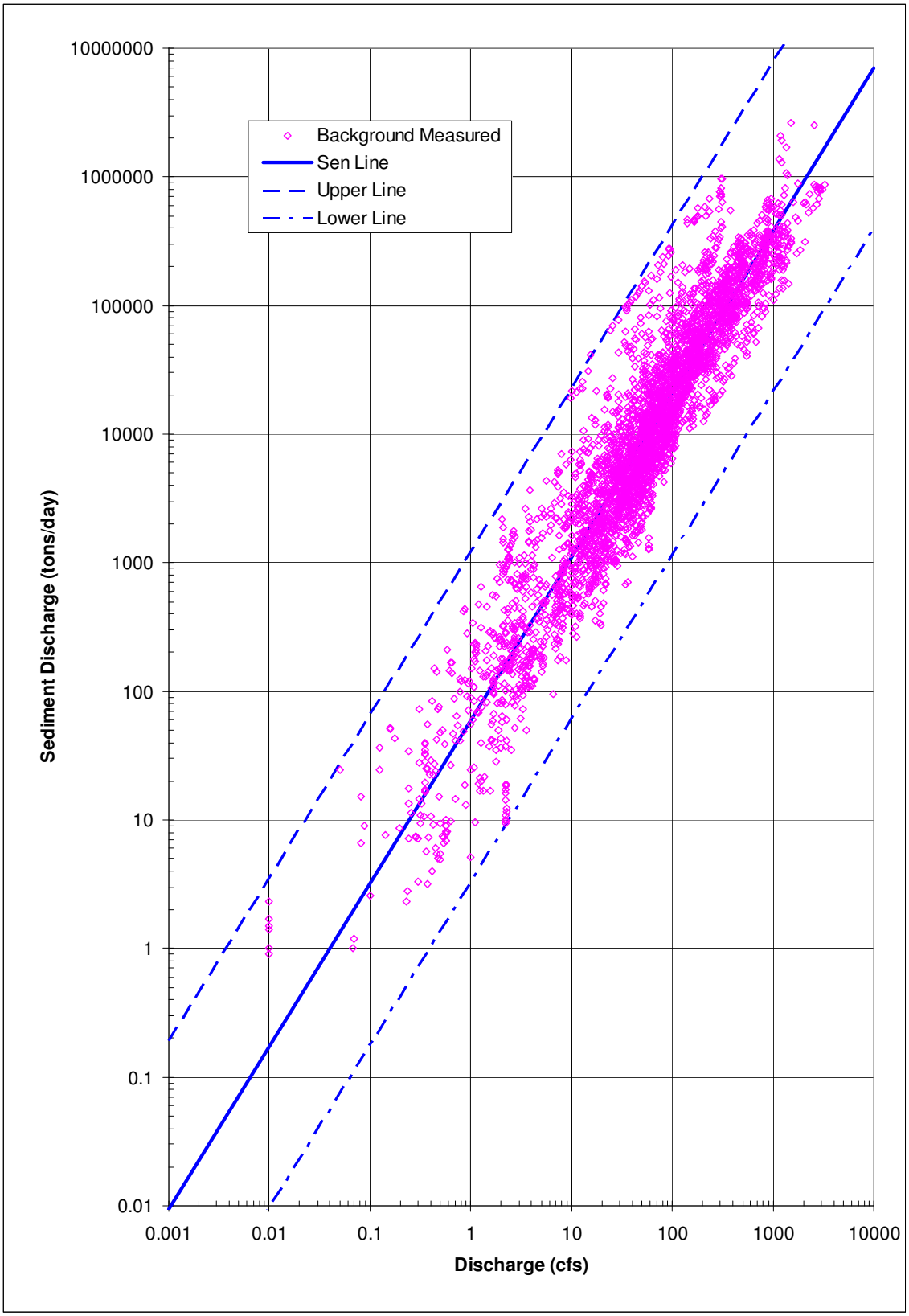


Figure 2.3. Background measured sediment and water discharge.

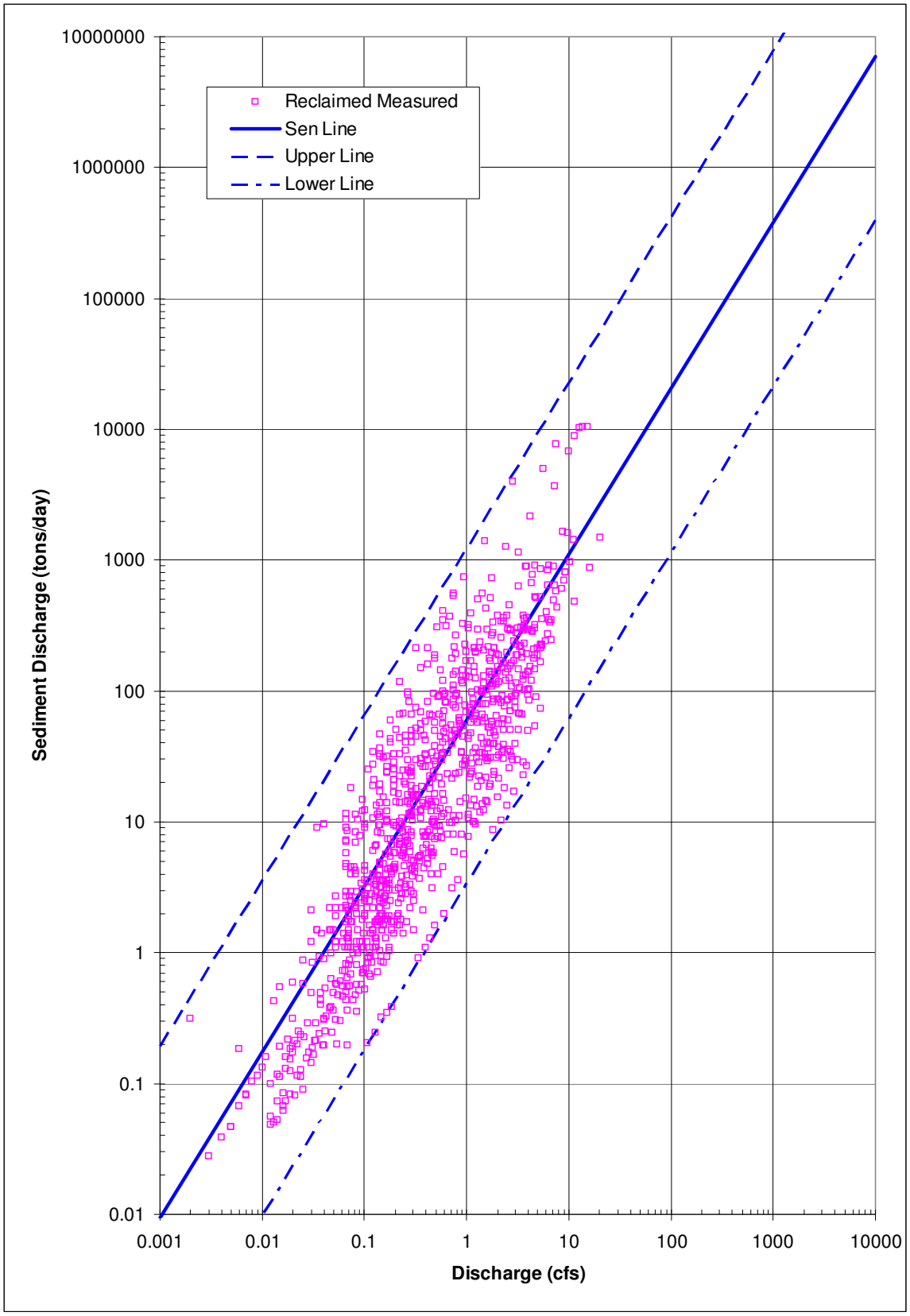


Figure 2.4. Reclaimed measured sediment and water discharge.

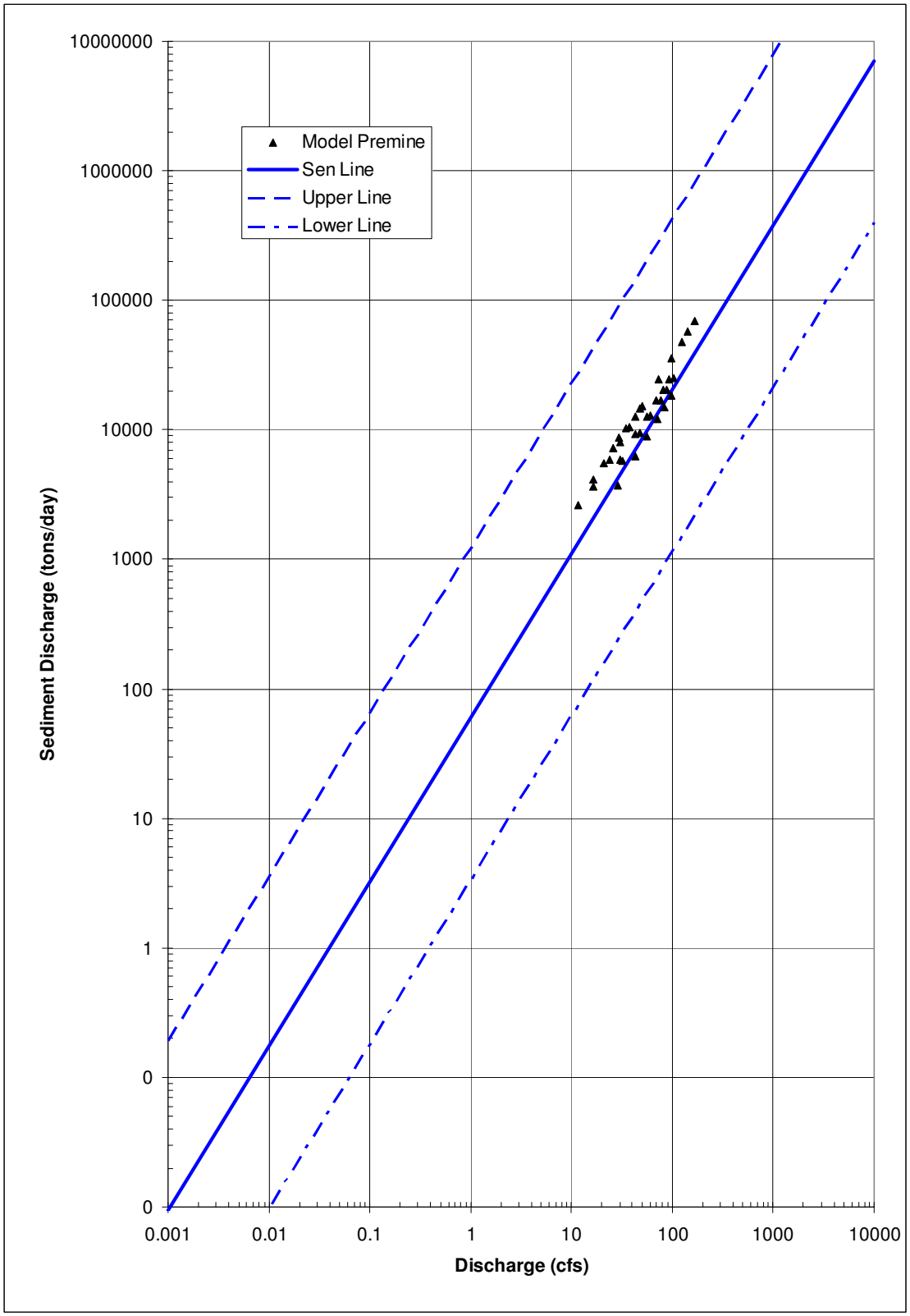


Figure 2.5. Modeled premine sediment and water discharge for the N5 WA.

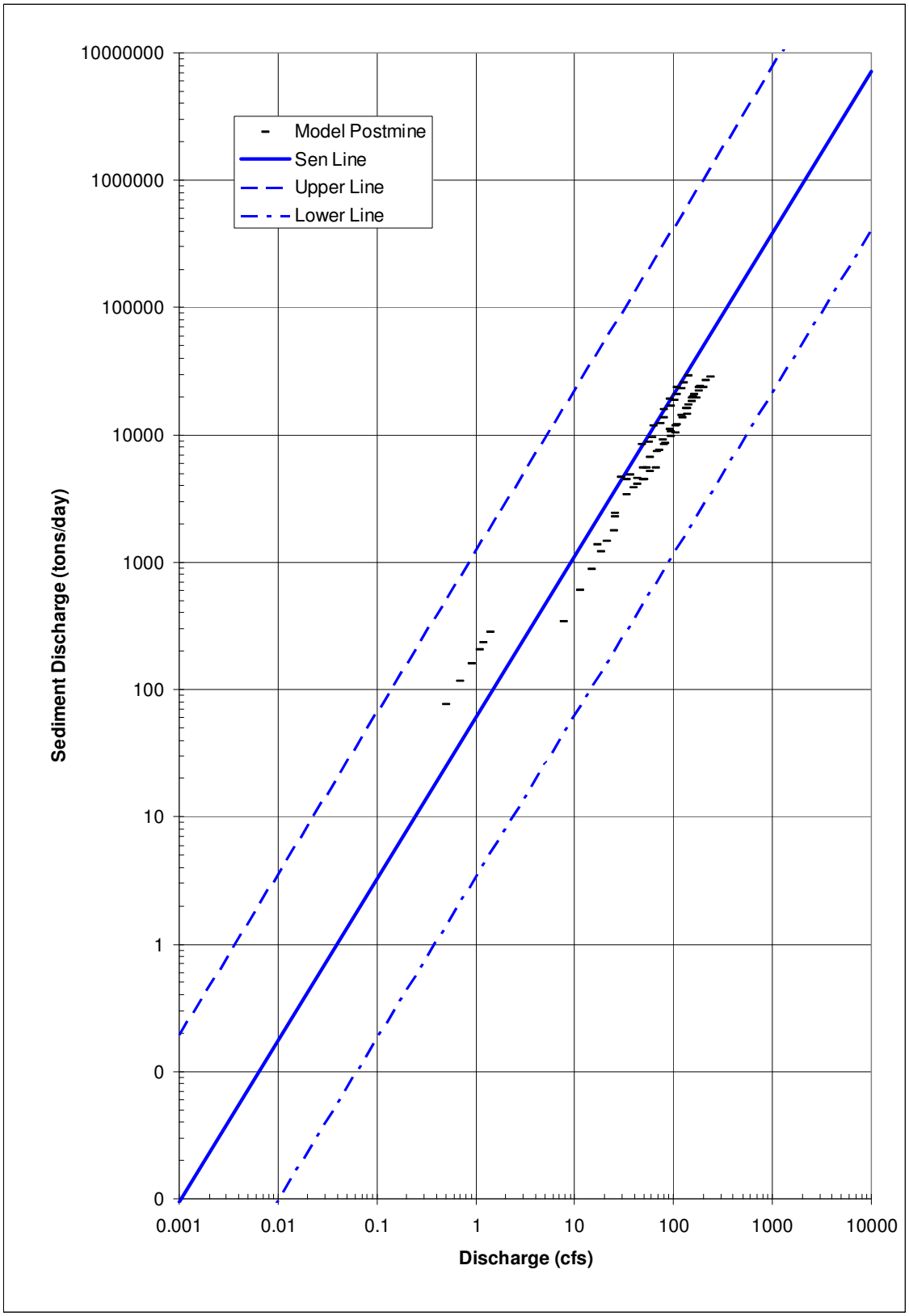


Figure 2.6. Modeled postmine sediment and water discharge for the N5 WA.

3. REFERENCES

Hjelmfelt, A.T., Kramer, L.A., and Spomer, R.G., 1986. Role of large events in average soil loss in Proceedings of the Fourth Federal Interagency Sedimentation Conference, March 24-27, 1986, Las Vegas, NV, p. 3-1 to 3-9.

Lagasse, P.F., Schall, J.D., and Peterson, M.R., 1985. Erosion Risk Analysis for a Southwestern Arroyo, Journal of Urban Planning and Management, American Society of Civil Engineers, v. III, no. I, November, 1985, Paper No. 20165.

Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973. "NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States," Volume VIII - Arizona, National Oceanic and Atmospheric Administration.

Renard, K.G. and Simaton, J.R., 1975. "Thunderstorm Precipitation Effects on the Rainfall-Erosion Index of the Universal Soil Loss Equation" in Volume 5 of Hydrology and Water Resources in Arizona and the Southwest, American Water Resources Assn., Arizona Section Arizona Academy of Science, Hydrology Section, Proceedings of April 11-12 meeting, Tempe AZ, v. 47-55.

Resource Consultants & Engineers, Inc. (RCE), 1993. "Surface Water Modeling of Reclaimed Parcels at the Black Mesa Complex," prepared for Peabody Western Coal Co.

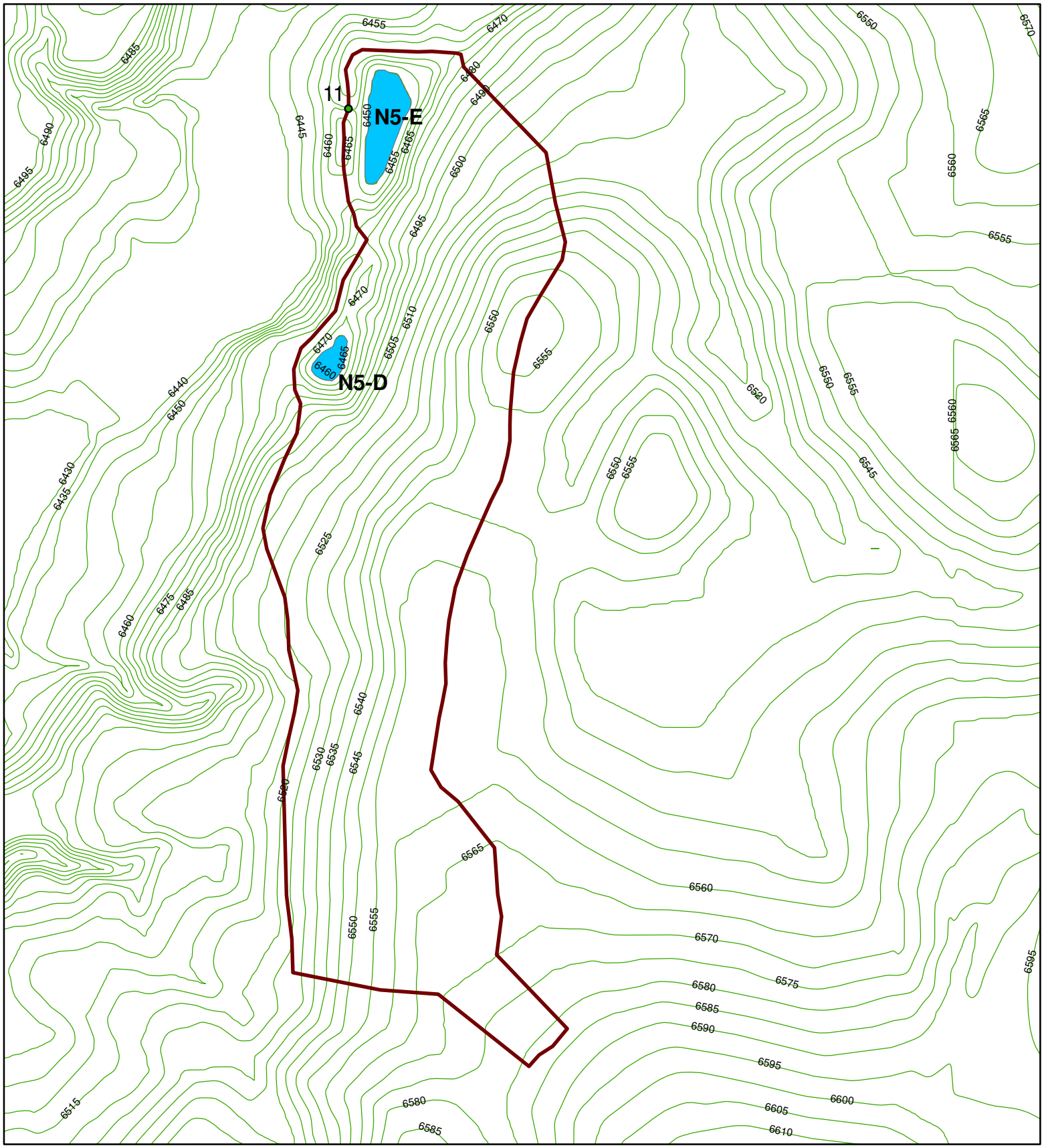
Sen, P.K., 1968. "Estimates of Regression Coefficient Based on Kendall's tau: Journal of American Statistical Association, v. 63, p. 1379-1389.

Smith, T. and Best, A., 2000. "Assessing Sedimentation and Protection of the Hydrologic Balance in Disturbed and Reclaimed Areas at the Black Mesa and Kayenta Mines, Arizona, Using Baseline Sediment Data Collected in Receiving Streams," presentation given at the Billings Mined Land Reclamation Symposium in 2001, Billings, MT.

Water Engineering & Technology, Inc. (WET), 1990. "Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control Technology at Surface Mines in the Semiarid West," prepared for Office of Surface Mining and the National Coal Association, Fort Collins, CO.

Zevenbergen, L.W., Peterson, M.R., and Watson, C.C., 1990. Computer simulation of watershed runoff and sedimentation processes, Proceedings of the Billings Symposium; Planning, Rehabilitation and Treatment of Disturbed Lands.

EXHIBIT 1
Postmine Topography



Legend

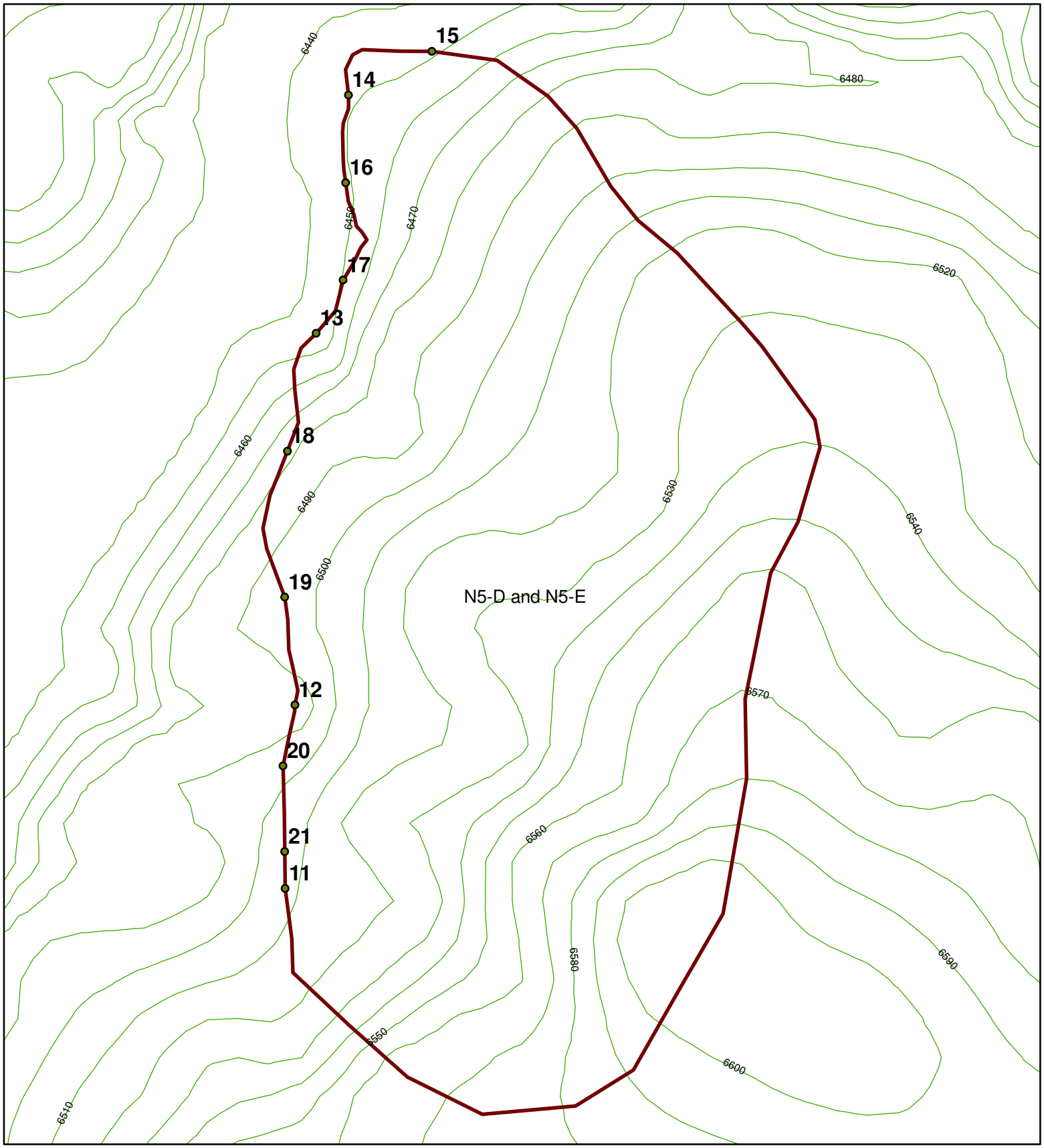
- End Point
- Ponds
- Modeling Area Post

N

0 150 300 600 900 Feet

Exhibit 1. Postmine Topography
(5 foot contour)

EXHIBIT 2
Premine Topography



N

Legend

- End Points
- Modeling Area

0 150 300 600 900 Feet

Exhibit 2. Premine Topography
(10 foot contour)

Appendix 9

Surface Water Modeling of the Reclaimed J7-A, J7-B1, J7-G, J7-H, J7-I, J7-J, J7-R1, and J7-R Watershed Area at Black Mesa Mine

SURFACE WATER MODELING OF THE RECLAIMED J7-A, J7-B1, J7-G, J7-H, J7-I, J7-J, J7-R1, AND J7-R WATERSHED AREA AT BLACK MESA MINE

Prepared for

Peabody Western Coal Company
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES

SURFACE WATER MODELING OF THE RECLAIMED J7-A, J7-B1, J7-G, J7-H, J7-I, J7-J, J7-R1, AND J7-R WATERSHED AREA AT BLACK MESA MINE

Prepared for

Peabody Western Coal Company
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

AYRES ASSOCIATES
P.O. Box 270460
Fort Collins, Colorado 80527
(970) 223-5556, FAX (970) 223-5578

Ayres Project No. 32-1304.02
PEAB-J7-02.DOC

February 2011

TABLE OF CONTENTS

1. Reclaimed Parcel Modeling 1.1

1.1 Introduction 1.1
1.2 Background 1.1
1.3 Data 1.2

1.3.1 Soils 1.2
1.3.2 Vegetation 1.2
1.3.3 Topography 1.2

1.4 Methodology 1.2

1.4.1 Synthetic Rainfall 1.8
1.4.2 Computation of Average Runoff and Sediment Yield 1.8

1.5 Results 1.8
1.6 Discussion 1.8

2. Comparisons With Measured Sediment Transport 2.1

2.1 Sediment Discharge and Concentration 2.1
2.2 Statistical Analysis 2.4
2.3 Conclusions 2.4

3. References 3.1

Exhibit 1 – Postmine Topography ..... --
Exhibit 2 – Premine Topography ..... --

LIST OF FIGURES

Figure 1.1. Reclaimed area soils trilinear graph. 1.3

Figure 1.2. Spatial distribution of vegetative cover types for WA J7 premine condition..... 1.4

Figure 1.3. WA J7 postmine basins. 1.6

Figure 1.4. WA J7 premine basins. 1.7

Figure 2.1. Observed and modeled sediment discharge and water discharge. 2.2

Figure 2.2. Observed versus modeled sediment concentration and discharge. 2.3

Figure 2.3. Background measured sediment and water discharge. 2.5

Figure 2.4. Reclaimed measured sediment and water discharge. 2.6

Figure 2.5. Modeled premine sediment and water discharge for the J7 WA. 2.7

Figure 2.6. Modeled postmine sediment and water discharge for the J7 WA. 2.8

LIST OF TABLES

Table 1.1. Soils Data. 1.3

Table 1.2. Cover Sampling Data. 1.5

Table 1.3. Cover Data for J7 Watersheds. 1.5

Table 1.4. Average Runoff and Sediment Yield Results. 1.9

Table 1.5. Average Physical Properties of the J7 WA. 1.9

1. RECLAIMED PARCEL MODELING

1.1 Introduction

The purpose of this project is to use a previously calibrated and validated runoff and erosion model EASI - Erosion And Sediment Impacts (Zevenbergen et al. 1990; WET 1990) for the Black Mesa and Kayenta Mines to predict mean annual runoff and sediment yields from the reclaimed J7-A, J7-B1, J7-G, J7-H, J7-I, J7-J, J7-R1, and J7-R watersheds. The objective of this project included computation of runoff and sediment yields under premine conditions for the same area. The response of the reclaimed parcels was evaluated relative to undisturbed (premine) conditions in the corresponding undisturbed watersheds. All soils and rainfall input to the model were taken from models calibrated in the previous study (RCE 1993). The input variables that were calibrated to the mine areas and used in this study include soil infiltration parameters, erodibility parameters, and the grain size distribution. Parameters that are specific to this study are vegetative canopy and ground cover percentages from data collected on site. The model serves as a tool for assessing the success of reclamation efforts to protect the hydrologic balance (30 CFR 715.17 and 30 CFR 816.41).

The model calibration was conducted in a previous study (RCE 1993) using data obtained from instrumented watersheds and small hillslope plots collected under natural rainfall conditions. For a detailed discussion of data collection and model calibration, please refer to the previous study (RCE 1993).

1.2 Background

The J7-A, J7-B1, J7-G, J7-H, J7-I, J7-J, J7-R1, and J7-R Watershed Area (J7 WA) that is the focus of this project was reclaimed between 1981 and 2006. The fundamental purpose of this study was to quantify the expected behavior and hydrologic response of the current conditions of reclaimed areas relative to the conditions that existed prior to the occurrence of mining activities.

Runoff and sediment yield response from the reclaimed lands should be managed by implementing Best Management Practices (BMP's) in conjunction with an OSM approved sediment control plan in order to not adversely impact the prevailing hydrologic balance and to limit additional contributions of suspended sediment to streamflow or runoff outside the mine permit areas. BMP's include regrading, replacing salvaged topsoil, ripping, contour tillage, revegetation, and other controls such as riprapped channel bottoms, check dams, rock down drains, and where practicable, contour terraces. The natural watersheds on the mesa contribute significant quantities of sediment to the channel system. It is expected that the postmine condition will also produce comparable amounts of sediment without adversely impacting the hydrologic balance.

The next sections describe the data and procedures used to evaluate the J7 WA. This area was modeled to determine the average annual hydrologic response following the completion of reclamation activities and maturation of the reclaimed area vegetation taking into account BMP's implemented as part of the reclamation process. Infiltration, runoff, and erosion processes from both hillslopes and channels within the J7 WA were modeled using EASI. Results were determined for concentration points at the outlets of the reclaimed watersheds, which correspond to the embankments associated with Ponds J7-A, J7-B1, J7-G, J7-H, J7-I, J7-J, J7-R1, and J7-R. The locations of these points are shown in **Exhibit 1**. Modeling was also conducted to determine hydrologic response under premine conditions based on the topography, soils, cover, and other conditions that typified the undisturbed watersheds draining to each concentration point. **Exhibit 2** shows the modeling endpoints for the premine J7 WA.

1.3 Data

1.3.1 Soils

Soils data used for the current study (J7 WA) were based on data developed from the calibration of models used in the previous study for Coal Resource Areas (CRAs) N1/N2 and J27 (RCE 1993). The composition of postmine soil in the current study is depicted along with the composition of postmine soils from the previous study in **Figure 1.1**. This figure shows that the soil composition of WA J7 is very similar to soils evaluated during model calibration. Therefore, the soil properties developed in the previous study are valid for this modeling project. These properties include calibrated parameters, such as infiltration and erodibility coefficients, and measured soil size distributions. **Table 1.1** lists the premine and postmine soils data used during EASI modeling of WA J7.

1.3.2 Vegetation

Vegetative cover data representative of both pre- and postmine conditions in WA J7 were supplied by PWCC. For the premine condition, land was characterized as being covered by sagebrush or pinon juniper. The spatial distribution of vegetative cover for the J7 WA premine condition appears in **Figure 1.2**. Average cover properties for WA J7 are shown in **Table 1.2**. For comparison, cover properties for CRAs N1/N2 and J27 of the previous study (RCE 1993) are also included. For the postmine condition, the reclaimed area was assigned the postmine cover type and any unmined area was assigned the same cover type as the premine condition. **Table 1.3** lists the pre- and postmine vegetative cover data used in the EASI model runs generated for the J7 WA. Note that if a unit contained significant portions of both sagebrush and pinon juniper cover types, it was classified as half pinon juniper and half sagebrush.

1.3.3 Topography

Pre- and postmine topographies were supplied by PWCC in the form of ArcGIS geodatabase. Basin delineations, hillslope delineations, subwatershed delineations, as well as areas, slopes, and lengths of all units of the study area were defined and calculated using ArcGIS software. **Figures 1.3 and 1.4** show the watershed delineation and numbers assigned to the basins used in the EASI model for the post- and premine conditions, respectively. Channel dimensions input to EASI were based on the topography supplied and limited field observations.

1.4 Methodology

Runoff and sediment yield in the semiarid western United States is largely governed by the occurrence of high-intensity, short-duration rainstorms of limited areal extent (Renard and Simanton 1975). Research has indicated that relatively few events may produce the greatest erosion (e.g., Hjelmfelt et al. 1986 reported that only 3 to 4% of rainfall events accounted for 50% of long-term sediment yields). Although there is a relatively limited physical basis for definition of an "average annual" runoff or sediment yield in a semiarid environment due to the extreme variability in response and importance of single infrequent events, such a term does provide a useful basis for long-term comparison between reclaimed and undisturbed conditions.

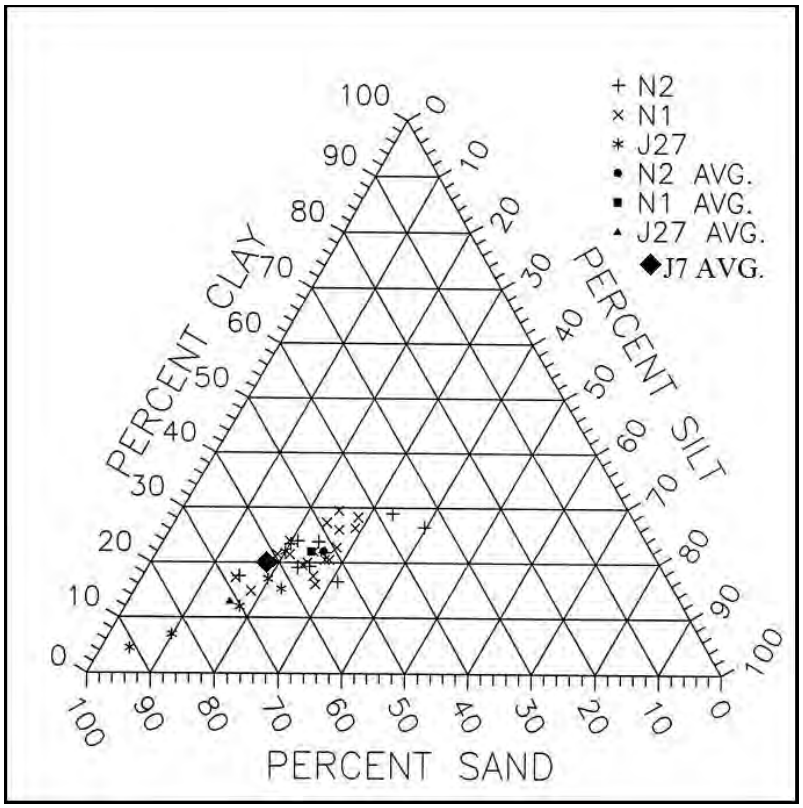


Figure 1.1. Reclaimed area soils trilinear graph.

Table 1.1. Soils Data.			
Condition	Premine	Postmine	Rock Chutes
Rainfall detachment	0.005	0.005	0
Overland flow detachment	0.44	0.44	0
Channel flow detachment	0.5	0.5	0
Initial soil moisture, %	70	70	70
Final soil moisture, %	90	90	90
Soil porosity, %	45	45	46
Temperature, *F	70	70	70
Hydraulic conductivity, in/hr	0.23	0.29	0.3
Capillary suction, in	3.7	2.6	2.6
	Particle Size Distribution (all conditions)		
	Size, mm	% Finer	
	0.001	0	
	0.004	18.0	
	0.016	27.4	
	0.062	36.6	
	0.125	56.2	
	0.250	64.3	
	0.500	72.4	
	1.000	80.5	
	2.000	88.6	
	4.000	92.4	
	16.000	100	

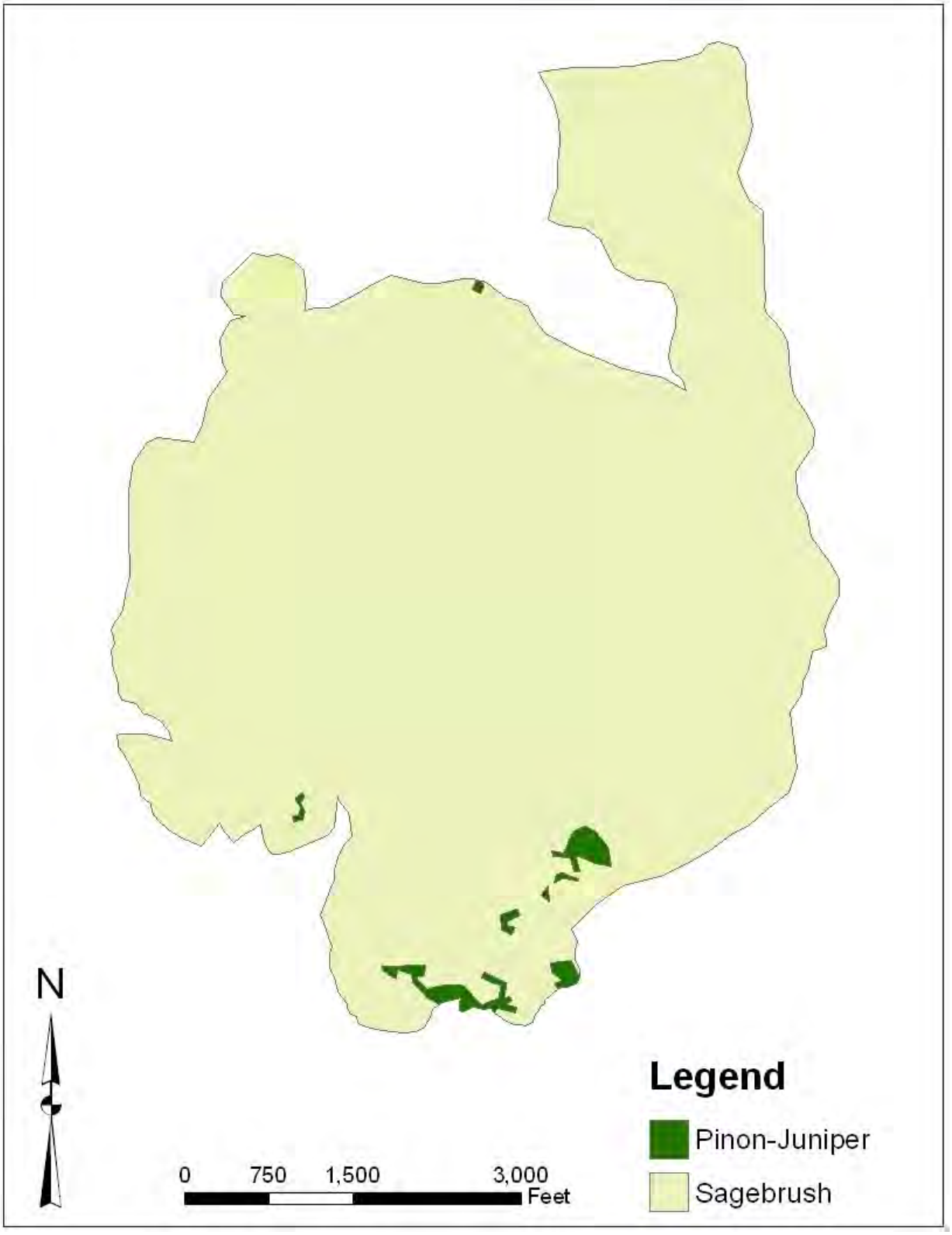


Figure 1.2. Spatial distribution of vegetative cover types for WA J7 premine condition.

Table 1.2. Cover Sampling Data.								
Area	Condition	Cover Type	Nonstratified Vegetation Cover (%)	Vegetation Canopy Cover (%)	Vegetation Ground Cover (%)	Litter* (%)	Rock (%)	Total Ground Cover (%)
N1/N2	Postmine	Postmine	25.6	1.4	24.2	13.6	4.2	42.0
J7 WA	Postmine	Postmine	21.3	0.3	21.1	31.5	2.6	55.2
N1/N2/J27	Premine	Pinon Juniper	32.7	31.1	3.0	44.0	19.7	66.7
J7 WA	Premine	Pinon Juniper	14.5	11.7	3.2	19.1	18.5	40.8
N1/N2	Premine	Sagebrush	25.1	16.0	10.3	25.3	18.1	53.7
J27	Premine	Sagebrush	30.6	9.7	22.0	24.0	1.6	47.6
J7 WA	Premine	Sagebrush	7.9	0.6	7.3	21.7	6.8	35.8
*Including standing dead litter								

Table 1.3. Cover Data for J7 Watersheds.				
Condition	Pinon Juniper	Sagebrush	Half Pinon Juniper-Half Sagebrush	Postmine
Canopy cover, %	11.7	0.6	6.1	0.3
Ground cover, %	40.8	35.8	38.3	55.2
Canopy storage, in	0.05	0.05	0.05	0.05
Ground storage, in	0.05	0.05	0.05	0.05
Depression storage, in	0.03	0.03	0.03	0.03
Impervious area, %	0	0	0	0
Manning n	0.07	0.07	0.07	0.05

To make comparisons between reclaimed lands and associated undisturbed lands at the Black Mesa Mining Complex on the basis of average annual sediment yield, a procedure was used that considers the importance of infrequent storm events in defining sediment yield in the semiarid west. First, however, the site-specific rainfall data available for the Black Mesa Mining Complex were used to evaluate the frequency and magnitude of the measured events relative to existing predictions for rainfall depth-duration (Miller et al. 1973). The analysis of the rainfall data was performed as part of a previous study of the N1/N2 and J27 CRAs (RCE 1993).

Comparisons between runoff and sediment yield from undisturbed and reclaimed areas in WA J7 were developed for specific modeling endpoints shown in Exhibits 1 and 2. Mining and reclamation activities did not exactly replicate the topography, drainage network, or drainage areas that existed prior to mining. Consequently, direct comparisons of total runoff and sediment yield cannot be made between undisturbed and reclaimed response at a given point in a watershed. Comparisons were made on the basis of unit rates of runoff (inches) and sediment yield (tons/acre) at the various modeling computation endpoints. Although the same disturbance boundary was used to define the extent of both pre- and postmine conditions, the topographic differences that resulted after mining and reclamation occurred in the J7 WA dictated that some areas would be included or excluded from the modeling. The total area modeled (combined area for J7-A, J7-B1, J7-G, J7-I, J7-J, J7-R1, and J7-R watersheds) for premine conditions is 790.3 acres (Exhibit 2) and for postmine conditions is 440.0 acres (Exhibit 1).

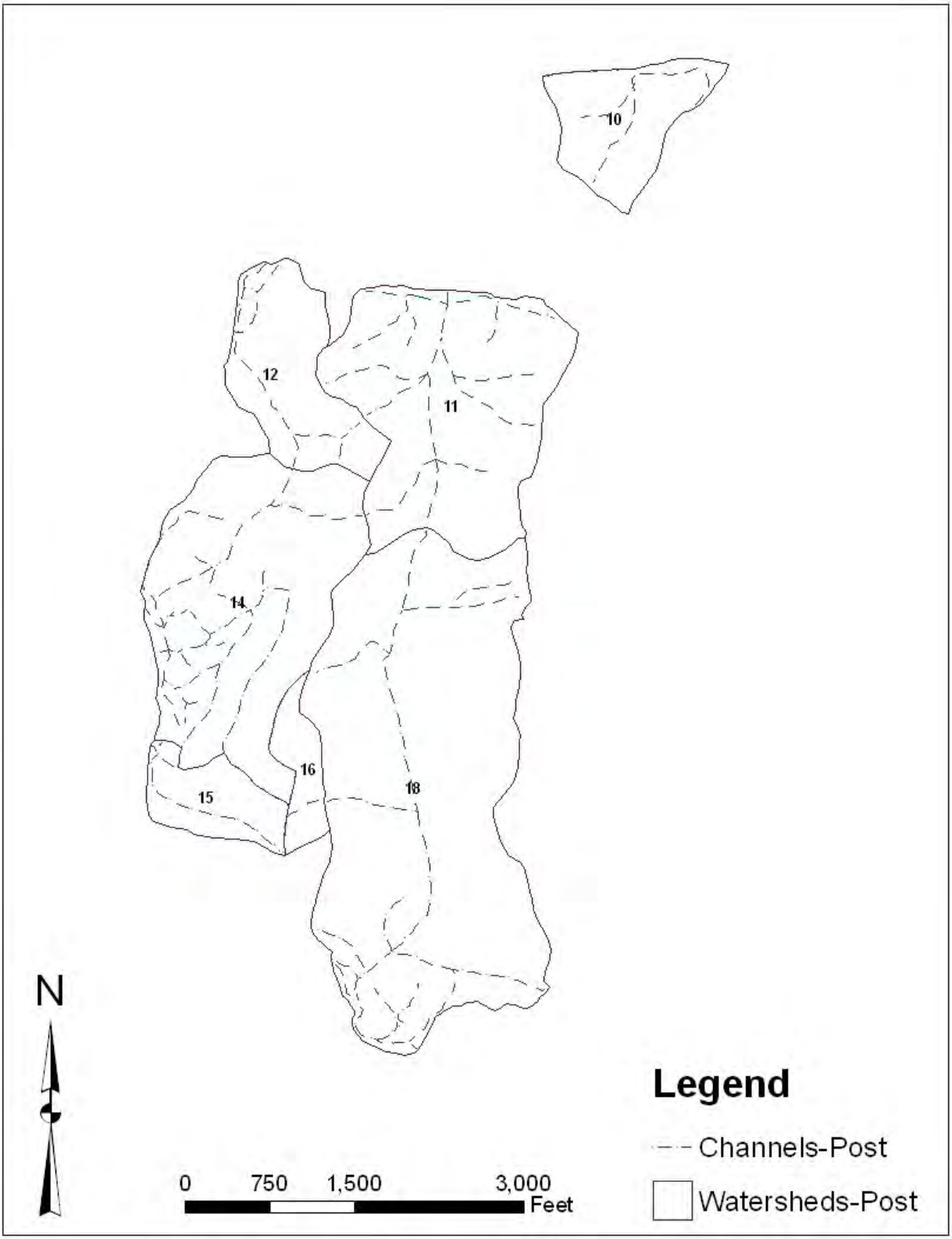


Figure 1.3. WA J7 postmine basins.

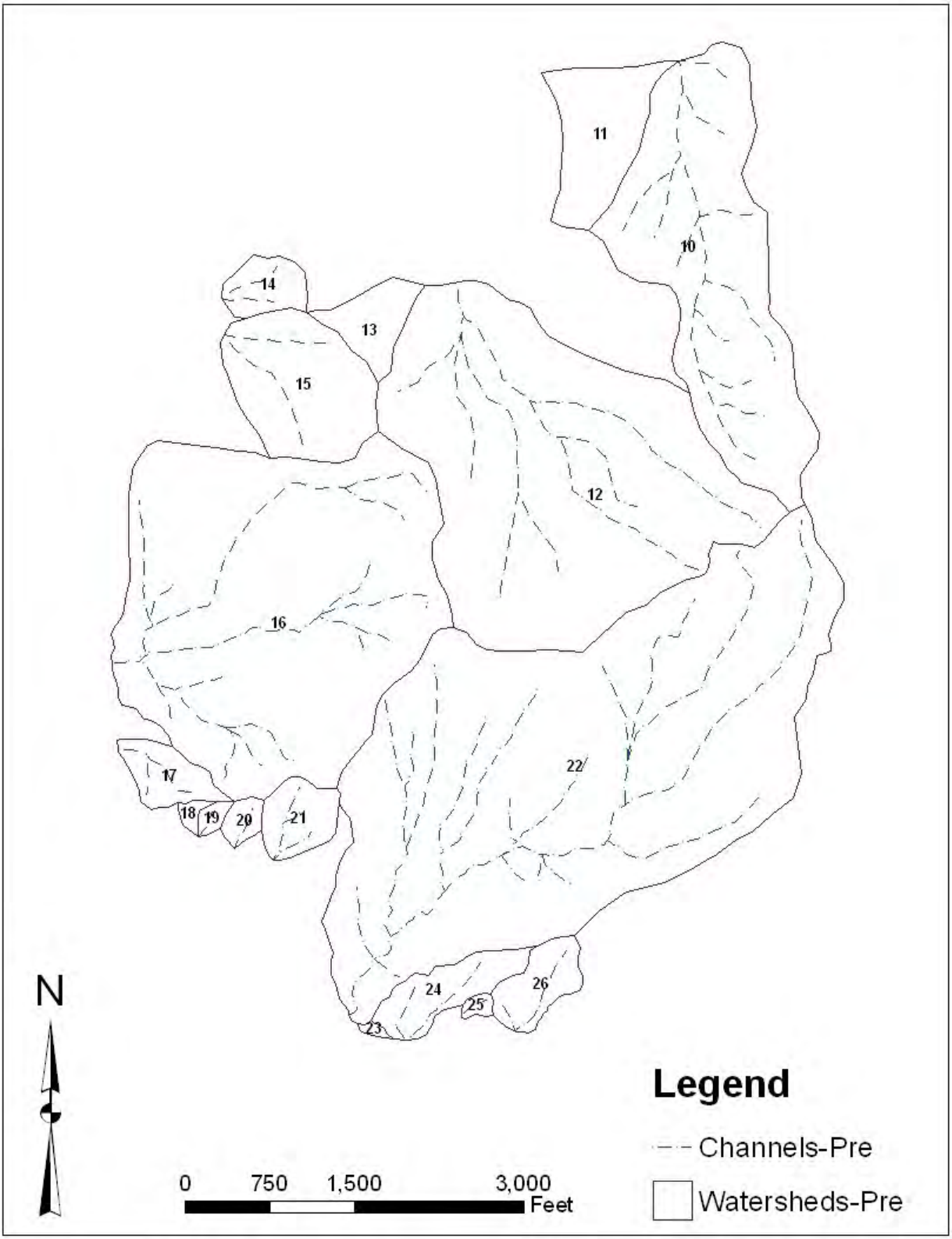


Figure 1.4. WA J7 premine basins.

1.4.1 Synthetic Rainfall

Synthetic storms of 2-, 5-, 10-, 25-, 50-, and 100-year return periods were used as input to the EASI model. Actual hyetographs were taken from the previous study (RCE 1993) and are based on both local data collection and the NOAA Atlas (Miller et al. 1973).

1.4.2 Computation of Average Runoff and Sediment Yield

The EASI model was used to evaluate runoff and sediment yield from a series of storm events having recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100 years. To define average annual conditions, the average annual runoff and sediment yield generated from storm events were computed using the commonly used equation of Lagasse et al. (1985).

1.5 Results

Figures 1.3 and 1.4 show the post- and premine basin delineations. Since the individual subareas differ in number, acreage and outlet locations, a direct comparison is not possible on a subarea basis. Therefore, the best way to compare the results is on an average annual basis for the WA. **Table 1.4** shows pre- and postmine drainage area, runoff, and sediment yield for the J7 WA. Runoff is defined as the total volume of water leaving the WA on an average annual basis and, therefore, does not include water stored in depression areas and ponds. For the premine condition, this is equal to the amount of water that drains off the hillslopes and subwatersheds because there were no ponds or significant depressions. For the postmine condition, this is equal to the amount of hillslope runoff less the amount stored in ponds. Similarly, the sediment yield is the amount of eroded material that leaves the WA on an average annual basis computed using the equation of Lagasse et al. (1985). The sediment yield is the production from the hillslope areas and erosion from the channels. The amount of erosion is the sediment yield from the hillslopes and subwatersheds only and does not include channel erosion, channel deposition or sediment trapped in ponds. Sediment yield can be greater or less than erosion, depending on the amount of channel erosion and the capacity of the channel network to convey sediment off the leasehold.

1.6 Discussion

For the postmine condition, sediment yield is less than the premine condition, while runoff is the same as the premine amount for the J7 WA. Sediment yield are lower for reclaimed (postmine) conditions due to more effective hydrologic cover and channel erosion control measures. **Table 1.5** gives an overview of the geometric properties of the pre- and postmine topographies for the J7 WA. Postmine hillslopes are generally about 20% shorter and steeper than premine hillslopes, postmine channels are about 25% less steep as premine channels, and the drainage density of the postmine condition is about 25% more than that of the premine condition.

Table 1.4. Average Runoff and Sediment Yield Results.				
Area	Condition	Drainage Area (ac)	Runoff (in)	Sediment Yield (t/ac/yr)
J7-A	Premine	113.2	0.42	3.77
J7-A	Postmine	28.2	0.42	2.03
J7-B1	Premine	170.7	0.42	5.37
J7-B1	Postmine	86.6	0.42	2.06
J7-G	Premine	39.8	0.42	1.98
J7-G	Postmine	35.6	0.42	1.97
J7-H	Premine	49.3	0.42	4.67
J7-H	Postmine	25.9	0.42	2.53
J7-I	Premine	168.1	0.42	6.57
J7-I	Postmine	91.9	0.42	2.95
J7-J	Premine	22.2	0.42	2.64
J7-J	Postmine	27.8	0.42	2.52
J7-R1	Premine	253.7	0.42	6.17
J7-R1	Postmine	161.8	0.42	2.95
J7-R	Premine	276.5	0.42	6.11
J7-R	Postmine	170.0	0.42	2.86

Table 1.5. Average Physical Properties of the J7 WA.		
	Premine	Postmine
Total Area (ac)	790.3	440.0
Total Channel Length (ft)	71,594	50,154
Mean Channel Slope	0.0555	0.0424
Drainage Density (mi/mi^2)	11.0	13.8
Mean Hillslope Length (ft)	218	171
Mean Hillslope Gradient	0.0660	0.0829

2. COMPARISONS WITH MEASURED SEDIMENT TRANSPORT

2.1 Sediment Discharge and Concentration

As discussed in Section 1, PWCC has monitored flow and sediment on the main channels, principal tributaries and small watersheds within the leasehold. These data, along with the runoff plots, were used to calibrate the EASI model soil erodibility and infiltration input variables. **Figures 2.1** and **2.2** show sediment transport and sediment concentration versus discharge for measured unmined (background), measured reclaimed, modeled unmined (WA J7 premine) and modeled reclaimed (WA J7 postmine) data. Although there is significant scatter shown in the data (as is expected with sediment transport), there are several conclusions that can be drawn from this data.

The open symbols in both figures depict measured data and whether the data were collected from reclaimed areas (the small watershed study) or from unmined or background surface water monitoring stations. The range of flows is generally greater for the background data but there is significant overlap between the two data sets between 0.1 cfs and 100 cfs. This is because the reclaimed data are from small watersheds and the unmined data are from channels draining larger basins. These data show the same trend for sediment transport and sediment concentration over the entire range of flows and very close agreement in the area of discharge overlap. This, in itself, is strong evidence that (1) the sediment yields are channel transport capacity limited, (2) overlap of model predictions for both pre- and postmine conditions with measured data strongly indicate that EASI model predictions are representative and reasonable, and (3) sediment yields from reclaimed areas will not be additive to yields on the receiving streams.

The closed symbols depict data from WA J7's pre- and postmine EASI model runs. They represent data generated by EASI for both subwatersheds and channels for peak discharges resulting from 2-, 5-, 10-, 25-, 50- and 100-year storms. Using the peak flows from extreme events results in discharges that generally exceed 10 cfs. The trend of the model-derived data is similar and the ranges of concentration and sediment transport are similar to the measured data and between pre- and postmine conditions.

The sediment discharge plot (**Figure 2.1**) shows a stronger trend because it is plotting discharge (sediment) against discharge (flow). This is expected because the sediment discharge does depend on flow discharge. The concentration plot (**Figure 2.2**) shows the two separate variables and, therefore, a less significant trend. PWCC believes that data measurement may have some influence on the scatter (outliers were removed), but the process variability is probably the major influence. The majority of the data, however, fall in a group centered on 100 cfs and 100,000 mg/l, both in the observed data and in the model results. These plots support the use of the EASI model, the results of the modeling, the conclusion that sediment yields from reclaimed areas are not additive to receiving stream sediment loads, and that sediment impacts to the prevailing hydrologic balance have been minimized.

From **Figures 2.1 and 2.2** it is apparent that sediment loads and concentrations are dependent on the channel sediment transport capacity for both pre- and postmine conditions. Channel sources of sediment in this arid environment are virtually unlimited. Therefore, channel transport capacity and channel derived sediment limits and governs sediment yields from the small tributaries, large channels and the WA as a whole. The similarity of sediment discharge (or concentration) between pre- and postmine conditions is inconsistent with the lower rates of sediment yield shown in **Table 1.4**.

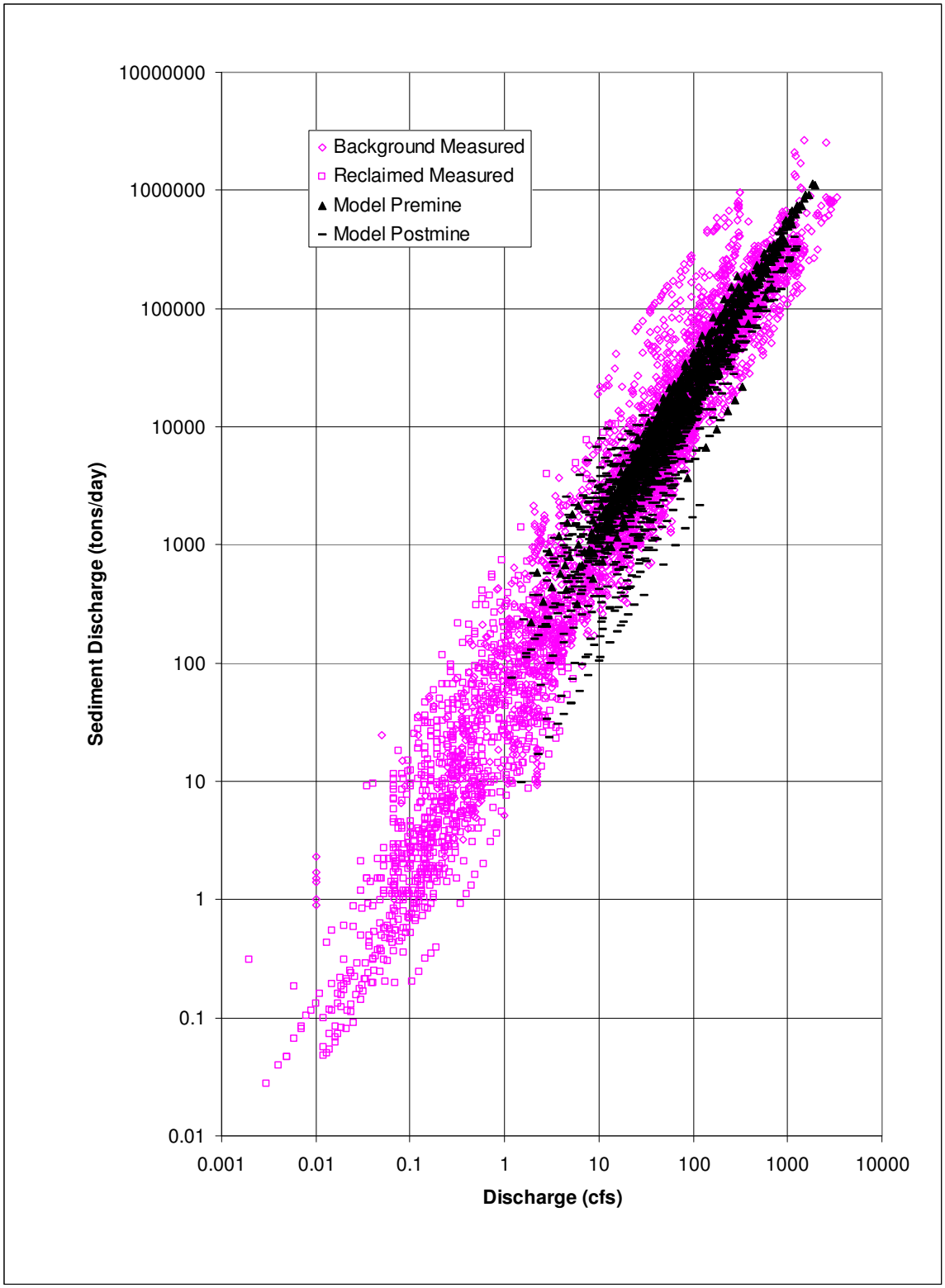


Figure 2.1. Observed and modeled sediment discharge and water discharge.

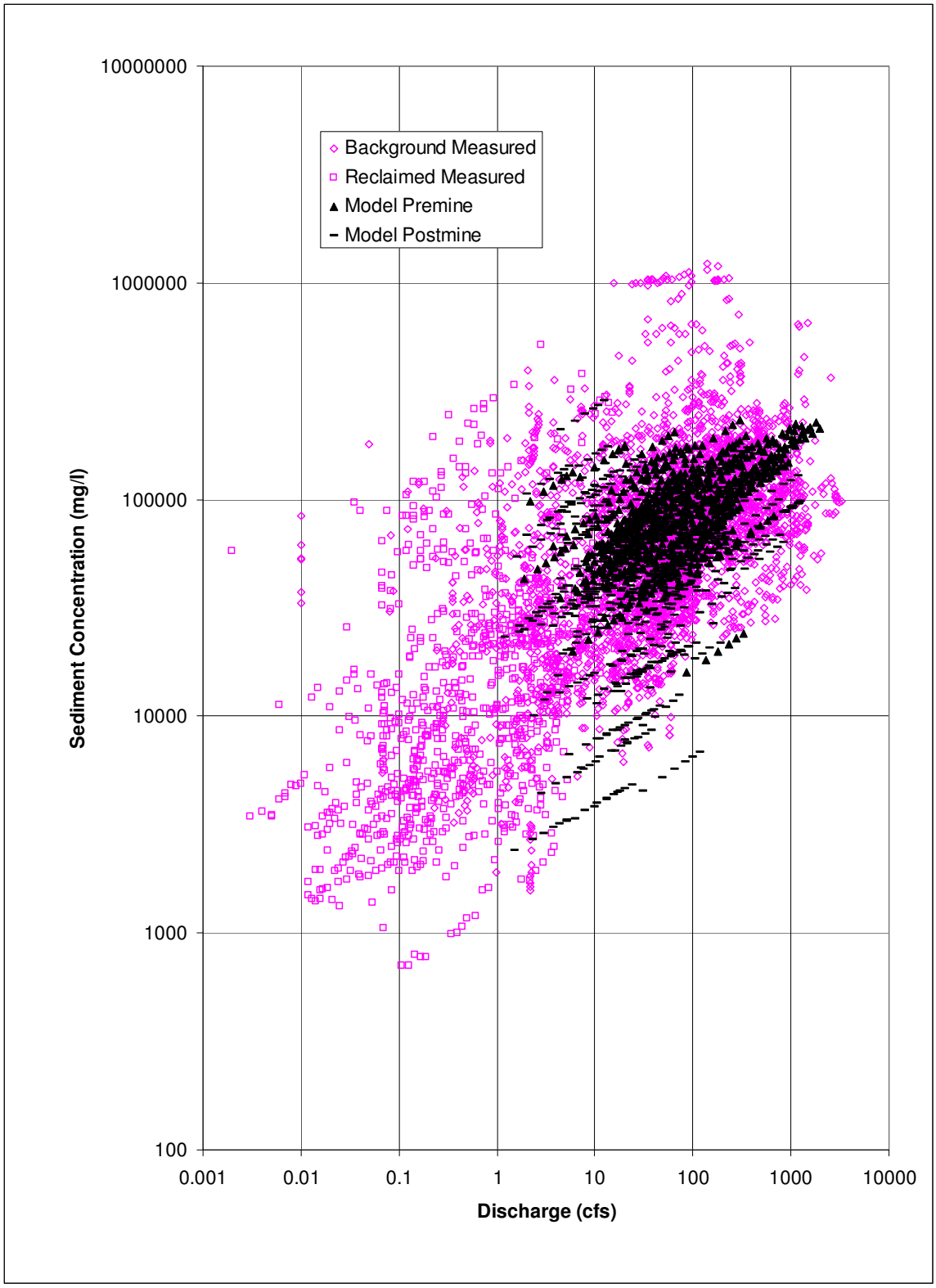


Figure 2.2. Observed versus modeled sediment concentration and discharge.

However, the sediment yield shown in **Table 1.4** is the amount of sediment leaving the J7 WA whereas the sediment discharge shown in **Figure 2.1** is the peak rate of sediment in transport occurring in any channel on the WA, whether the channel is located upstream or downstream of a pond. Therefore, with or without the ponds trapping sediment or storing water, the mine reclamation is not contributing additional sediment to the receiving streams, and sediment impacts to the prevailing hydrologic balance have been minimized.

2.2 Statistical Analysis

Smith and Best (2000) analyzed the measured data (background and reclaimed) shown in **Figure 2.1** to develop an approach that can be used to determine if channels in reclaimed areas have similar sediment transport characteristics as background channels. The method that they used was to develop Sen lines (Sen 1968) and confidence intervals around the data. The slope of the Sen line is a non-parametric statistic computed as the median slope of all possible slopes determined from pairing all the data points. The Sen line is drawn through the median coordinate of the data. Smith and Best first showed that the large channel flume data (background) and the small watershed background data could be combined. They concluded that since the data from one data set fall within the Sen line bounds of the other data set then the two data sets are merely extensions of each other and could be combined. Also, because the main channel and background small watershed site data could be combined, it indicated there is an unlimited supply of sediment and the channels are conveying sediment at (or near) capacity. The Sen line and bounds are shown with the background measured data in **Figure 2.3**.

Smith and Best then plotted the reclaimed measured data (**Figure 2.4**) with the Sen line and bounds from the background data to show that the reclaimed data have the same characteristics even though the flow range of the measurements is lower. The data indicate that channel flows in this environment achieve the sediment transport capacity of the channel, whether in reclaimed or background conditions.

Using the same approach with the modeled data generated for the J7 WA, **Figures 2.5 and 2.6** show the pre- and postmine computed sediment transport rates with the Sen lines and bounds. One difference between the plots is that the measured data occur throughout the flow hydrograph whereas the modeled data are tabulated at the peak of the simulation flow hydrograph. The premine data plot (**Figure 2.5**) shows the data grouped around the Sen line and well within the bounds. The postmine data (**Figure 2.6**) also plot closely around the Sen line and well within bounds.

2.3 Conclusions

Several conclusions can be drawn from these data plots: (1) the EASI model well replicates erosion and sediment transport processes at the mine site for background and reclaimed conditions, (2) all data show similar trends and are within the same bounds, (3) data trends indicate that channels are transporting sediment at or near capacity, and (4) amounts of sediment leaving the WA for postmine conditions are similar to premine conditions and within the range expected for the background conditions. Therefore, the overall conclusion is that the postmine reclaimed condition in the J7 WA is not contributing additional suspended solids to receiving streams, and related impacts to the hydrologic balance have been minimized.

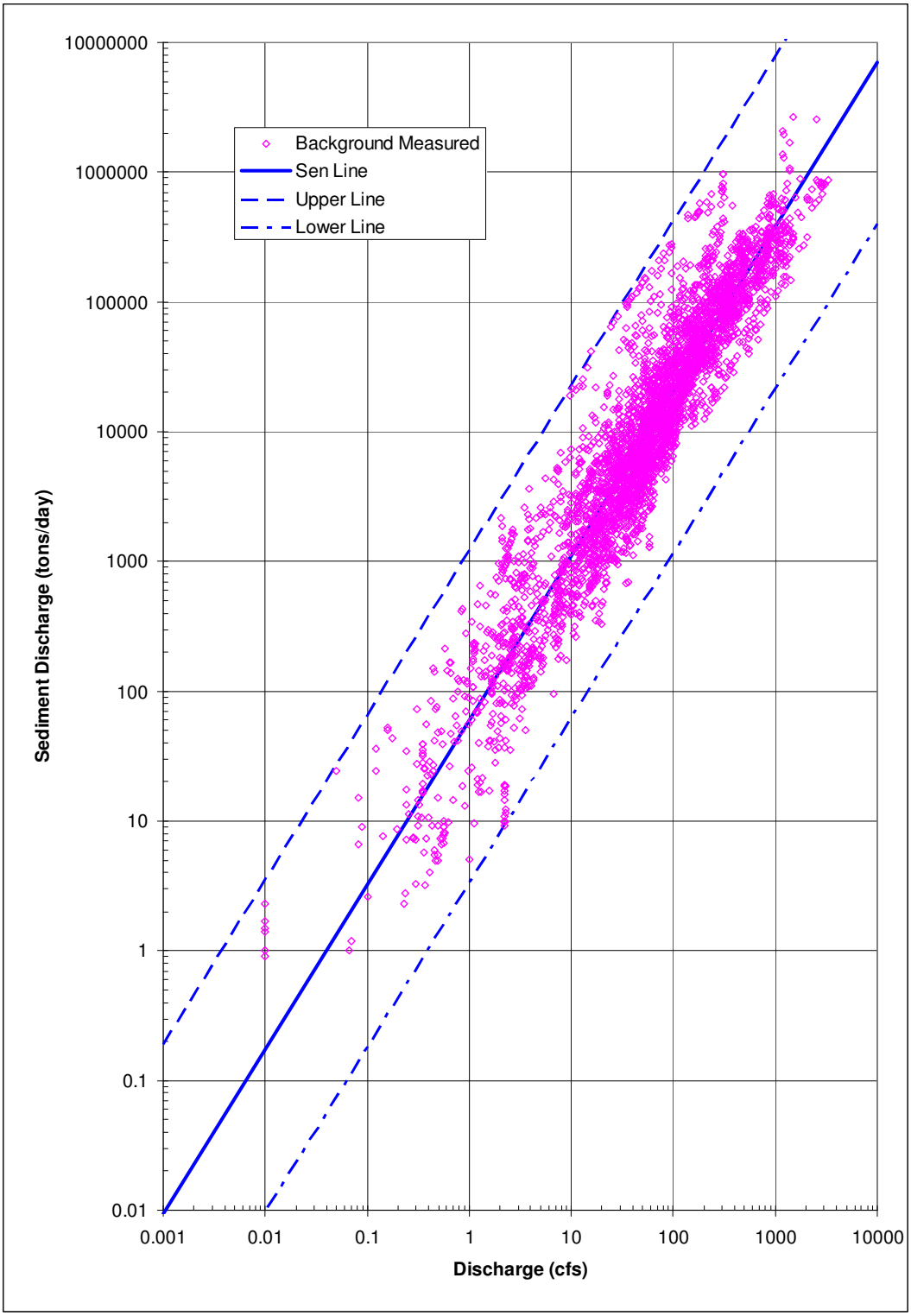


Figure 2.3. Background measured sediment and water discharge.

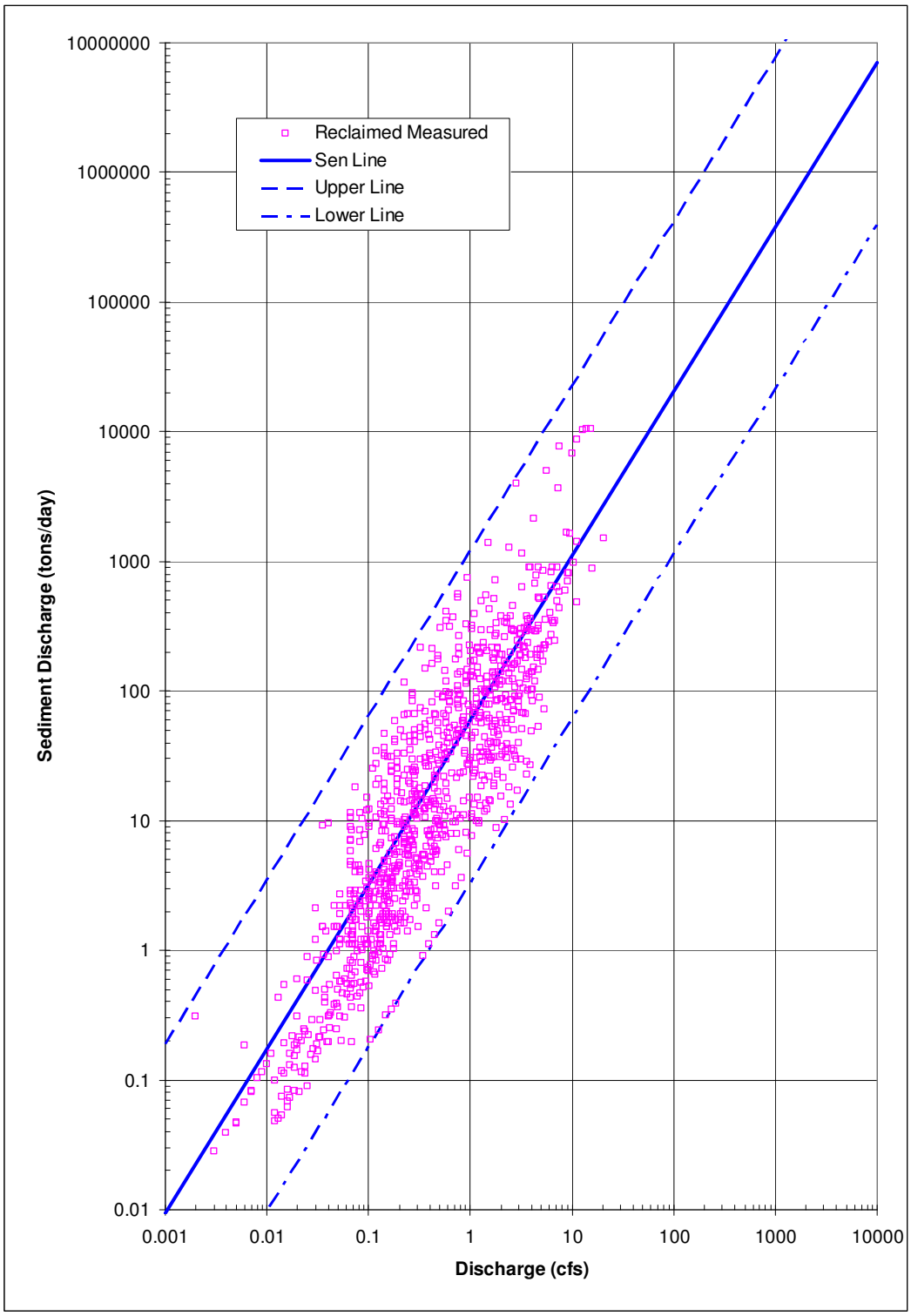


Figure 2.4. Reclaimed measured sediment and water discharge.

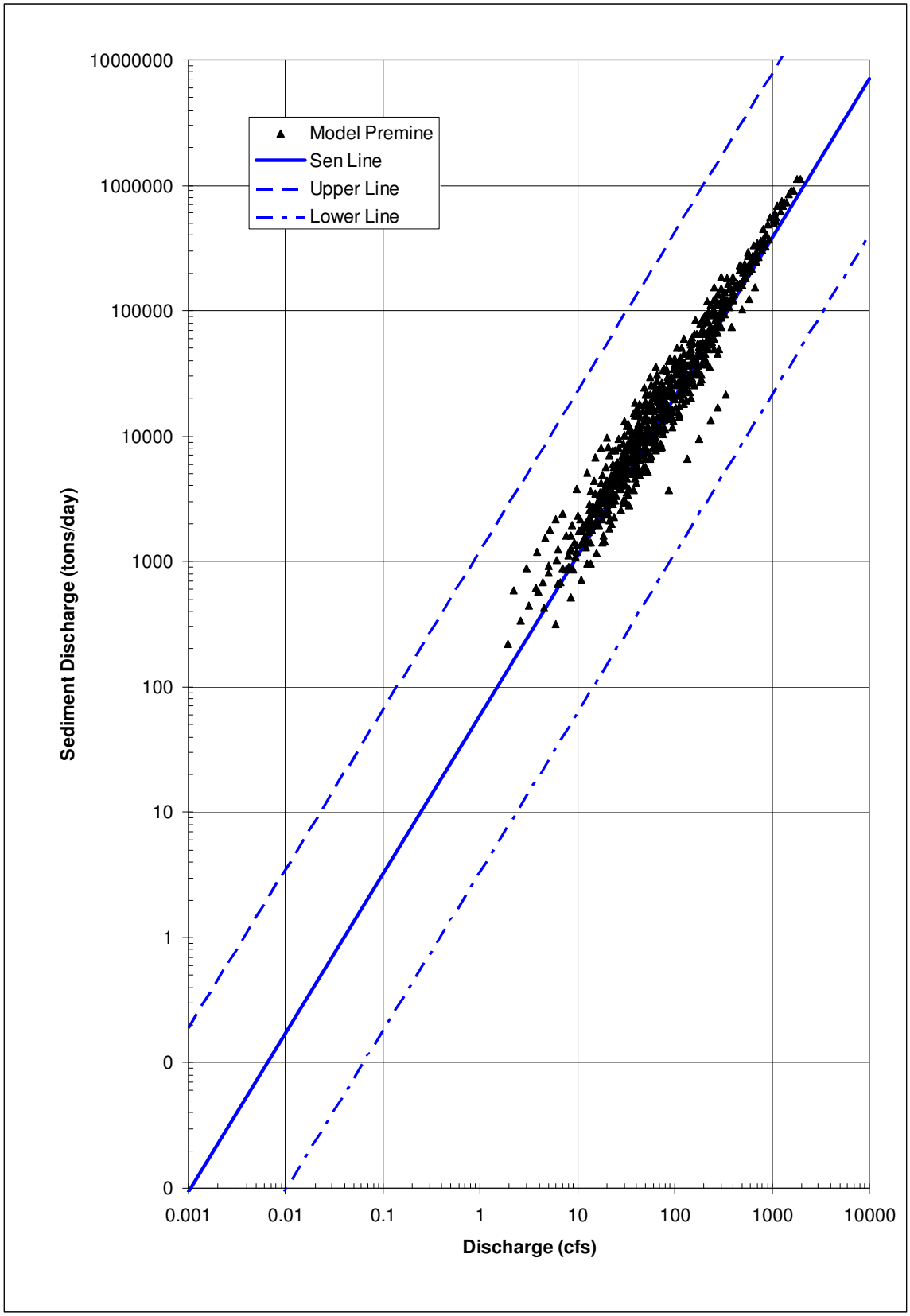


Figure 2.5. Modeled premine sediment and water discharge for the J7 WA.

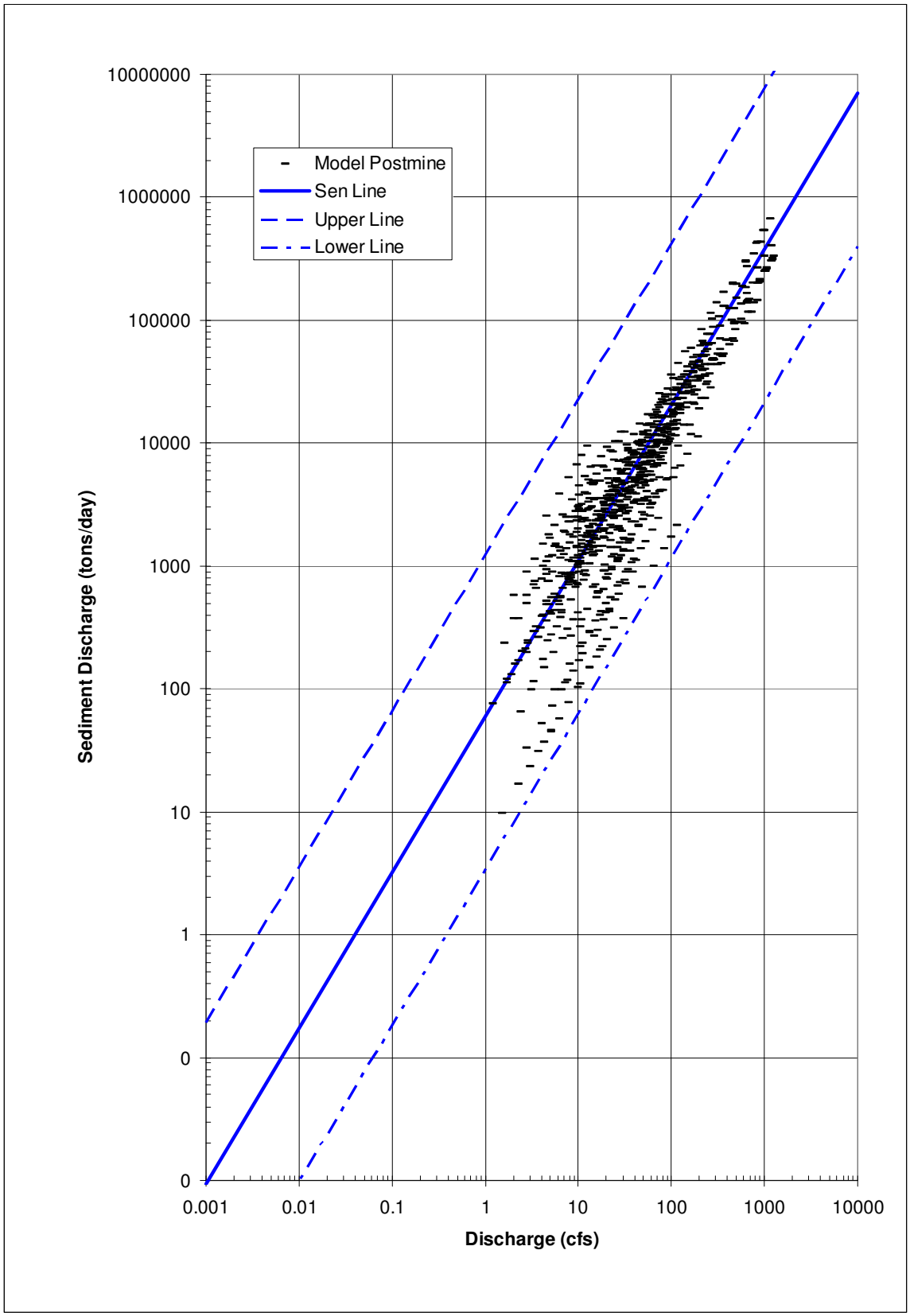


Figure 2.6. Modeled postmine sediment and water discharge for the J7 WA.

3. REFERENCES

Hjelmfelt, A.T., Kramer, L.A., and Spomer, R.G., 1986. "Role of large events in average soil loss," in Proceedings of the Fourth Federal Interagency Sedimentation Conference, March 24-27, 1986, Las Vegas, Nevada, p. 3-1 to 3-9.

Lagasse, P.F., Schall, J.D., and Peterson, M.R., 1985. "Erosion Risk Analysis for a Southwestern Arroyo," Journal of Urban Planning and Management, American Society of Civil Engineers, v. III, no. I, November, 1985, Paper No. 20165.

Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973. "NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States," Volume VIII - Arizona, National Oceanic and Atmospheric Administration.

Renard, K.G. and Simanton, J.R., 1975. "Thunderstorm Precipitation Effects on the Rainfall-Erosion Index of the Universal Soil Loss Equation," in Volume 5 of Hydrology and Water Resources in Arizona and the Southwest, American Water Resources Assn., Arizona Section Arizona Academy of Science, Hydrology Section, Proceedings of April 11-12 meeting, Tempe Arizona, v. 47-55.

Resource Consultants & Engineers, Inc. (RCE), 1993. "Surface Water Modeling of Reclaimed Parcels at the Black Mesa Complex," prepared for Peabody Western Coal Co.

Sen, P.K., 1968. "Estimates of Regression Coefficient Based on Kendall's Tau," Journal of American Statistical Association, v. 63, p. 1379-1389.

Smith, T. and Best, A., 2000. "Assessing Sedimentation and Protection of the Hydrologic Balance in Disturbed and Reclaimed Areas at the Black Mesa and Kayenta Mines, Arizona, Using Baseline Sediment Data Collected in Receiving Streams," presentation given at the Billings Mined Land Reclamation Symposium in 2001, Billings, MT.

Water Engineering & Technology, Inc. (WET), 1990. "Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control Technology at Surface Mines in the Semiarid West," prepared for Office of Surface Mining and the National Coal Association, Fort Collins, CO.

Zevenbergen, L.W., Peterson, M.R., and Watson, C.C., 1990. "Computer simulation of watershed runoff and sedimentation processes," Proceedings of the Billings Symposium; Planning, Rehabilitation and Treatment of Disturbed Lands.

EXHIBIT 1
Postmine Topography

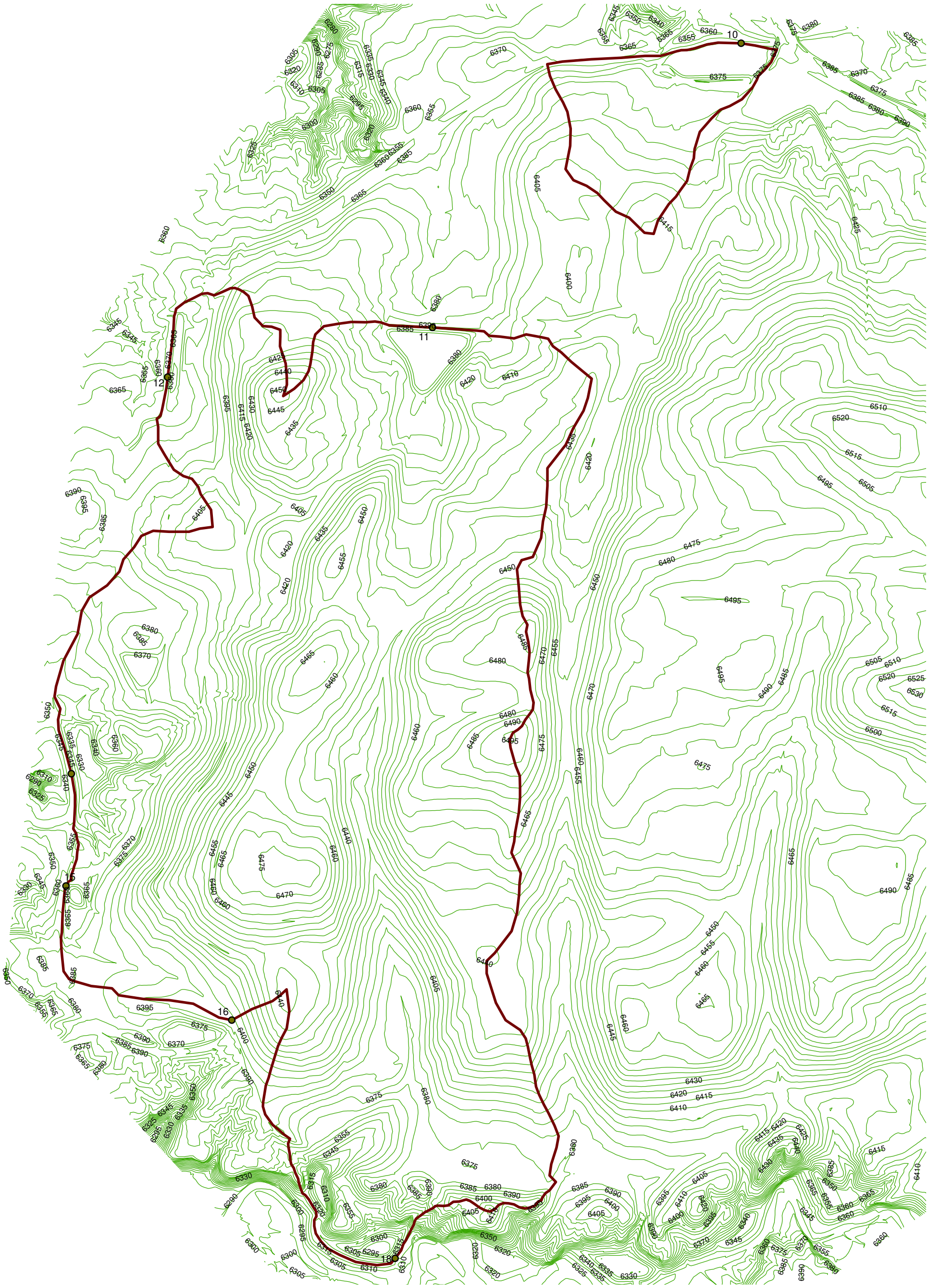


Exhibit 1. Postmine Topography
(5 foot contour)

EXHIBIT 2
Premine Topography

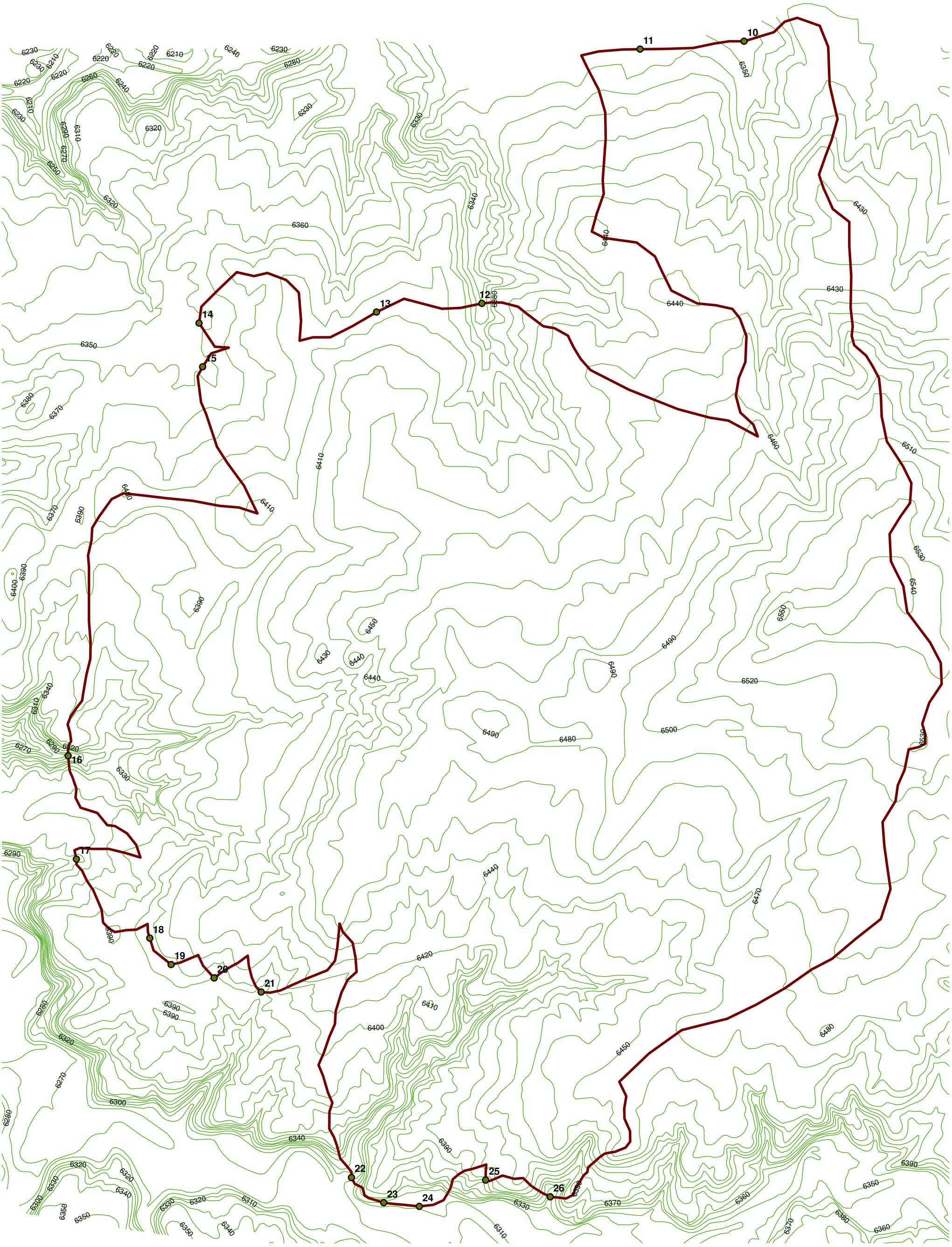
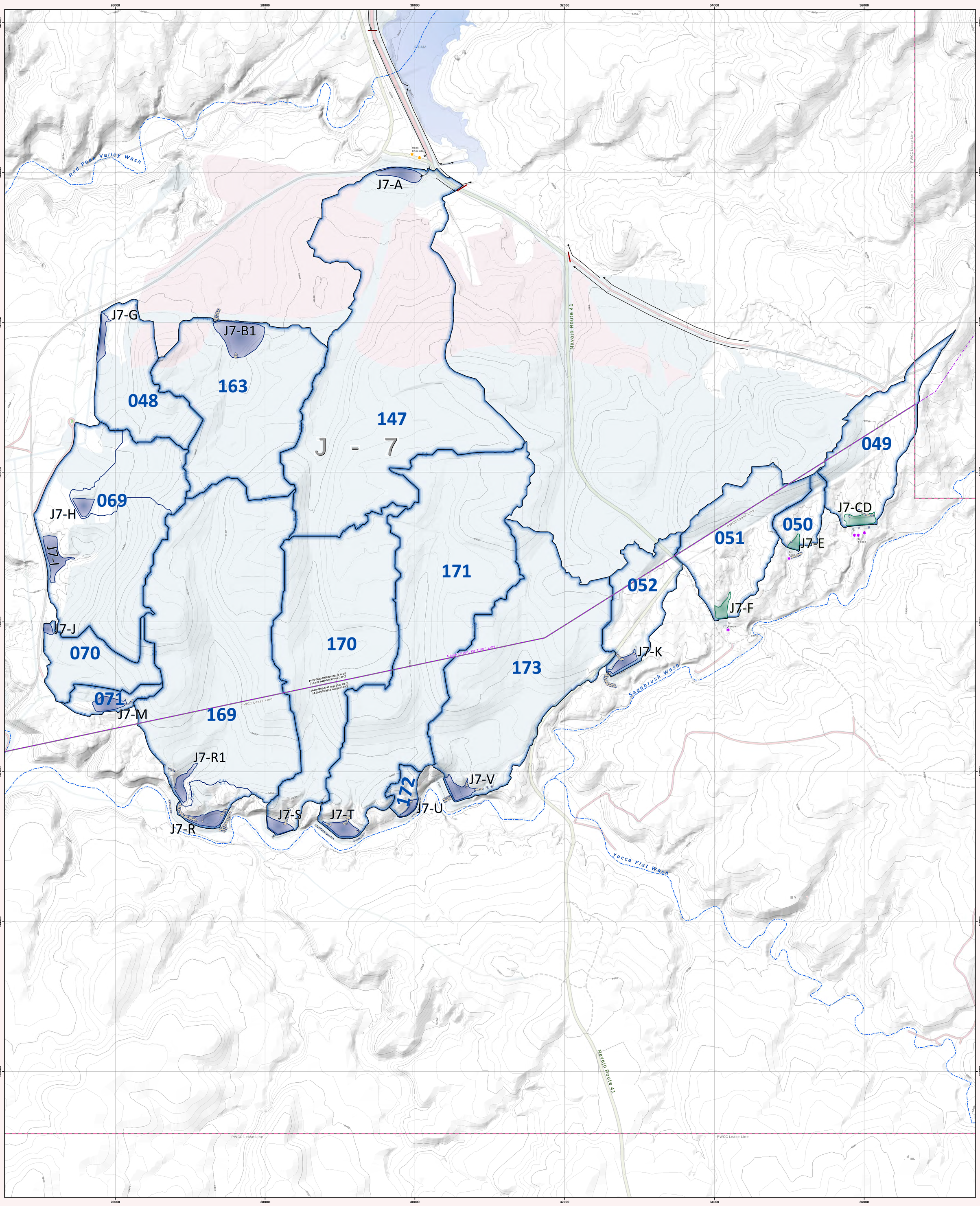


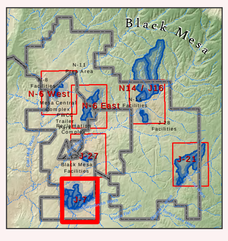
Exhibit 2. Premine Topography
(10 foot contour)



Sediment Control Plan

J-7 Area

July 2, 2012 Revision



Watersheds and Ponds
- Outfall Watershed
- Pond Watershed
- Existing Pond
- Reclaimed Pond

Water Conveyance
- Road Ditch
- Culvert
- Existing Terrace
- Diversion
- Rock Rip Rap Drain
- Major Drainage

BTCA Structures
- Berm/Sump
- Riprap Rock
- Rock Checkdam
- Silt Fence
- Straw Bales

Transport
- Haul Road
- Ramp
- Other Mine Roads
- US/State Highway
- Navajo Route 41
- Local Route
- Single Track
- Overland Conveyor Line
- Black Mesa / Lake Powell Railway

Disturbed Land Status
- Initial Program
- TOJ
- Permanent Program
- Phase I Release
- Phase II Release
- Pre-Law
- Active Pit

Administrative
- Lease Line
- Navajo-Hopi Partition Line
- 1E Permit
- Interim
- J-19 Coal Resource Area

PEABODY WESTERN GIS

Peabody Western Coal Company
Kayenta Complex
PO Box 650
Kayenta, Arizona 86033

Produced by John Cochran
Manager Environmental Hydrology

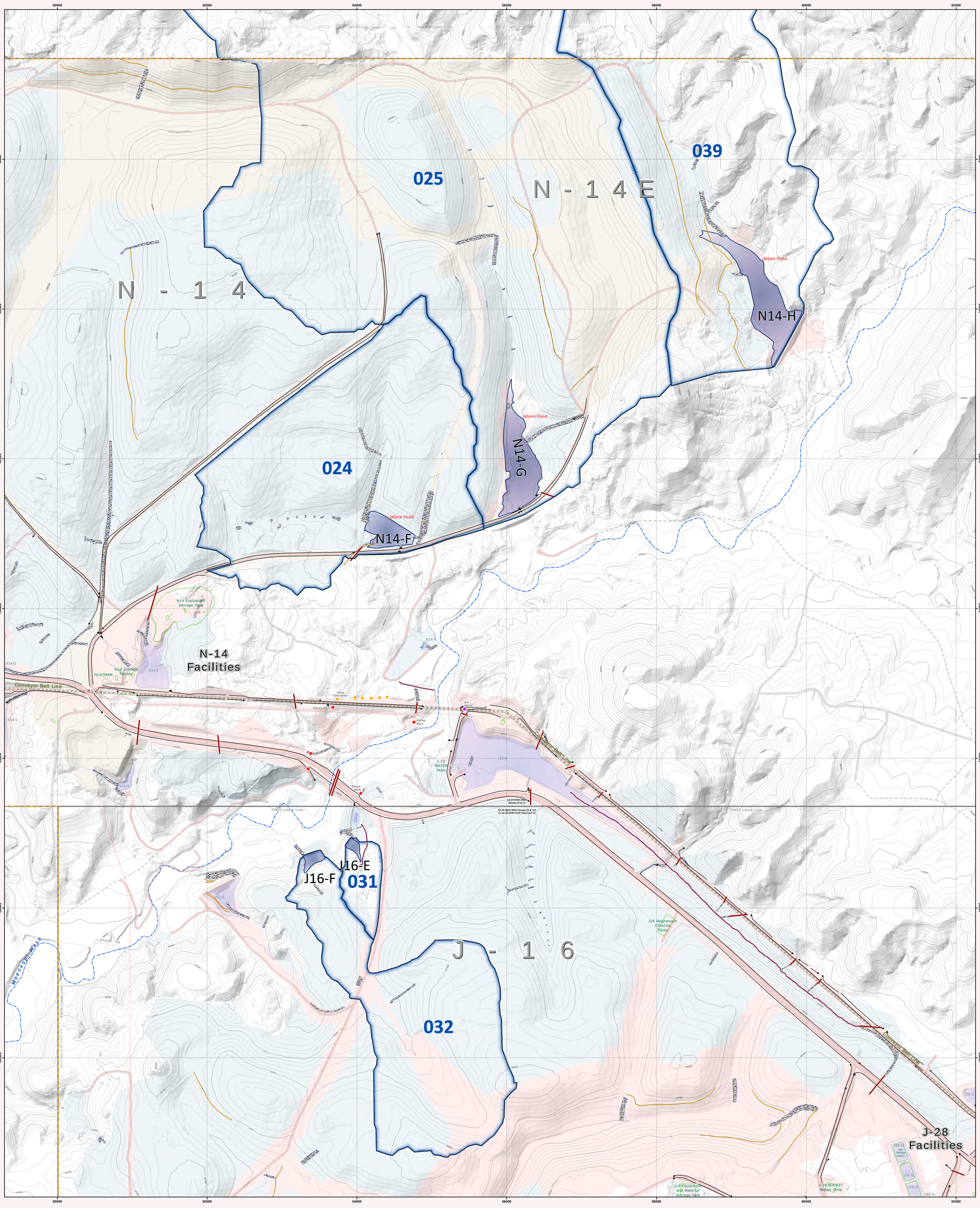
Map design by Deepsouthwest Enterprises

1 Inch = 400 Feet

10-foot contour interval
Index contours at 50 feet

Peabody ENERGY

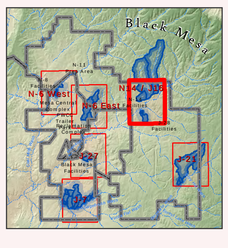
File: T:\Projects\Environmental\Sediment Control Plan\Maps\Sediment Control Plan 400.mxd



Sediment Control Plan

N14 / J16 Area

July 2, 2012
Revision



Watersheds and Ponds
- Outfall Watershed
- Pond Watershed
- Existing Pond
- Reclaimed Pond

Water Conveyance
- Road Ditch
- Culvert
- Existing Terrace
- Diversion
- Rock Rip Rap Drain
- Major Drainage

BTCA Structures
- Berm/Sump
- Riprap Rock
- Rock Checkdam
- Silt Fence
- Straw Bales

Transport
- Haul Road
- Ramp
- Other Mine Roads
- US/State Highway
- Navajo Route 41
- Local Route
- Single Track
- Overland Conveyor Line
- Black Mesa / Lake Powell Railway

Disturbed Land Status
- Initial Program
- TOJ
- Permanent Program
- Phase I Release
- Phase II Release
- Pre-Law
- Active Pit

Administrative
- Lease Line
- Navajo-Hopi Partition Line
- 1E Permit
- Interim
- J-19 Coal Resource Area

PEABODY WESTERN GIS

Peabody Western Coal Company
Kayenta Complex
PO Box 650
Kayenta, Arizona 86033

Produced by John Cochran
Manager Environmental Hydrology

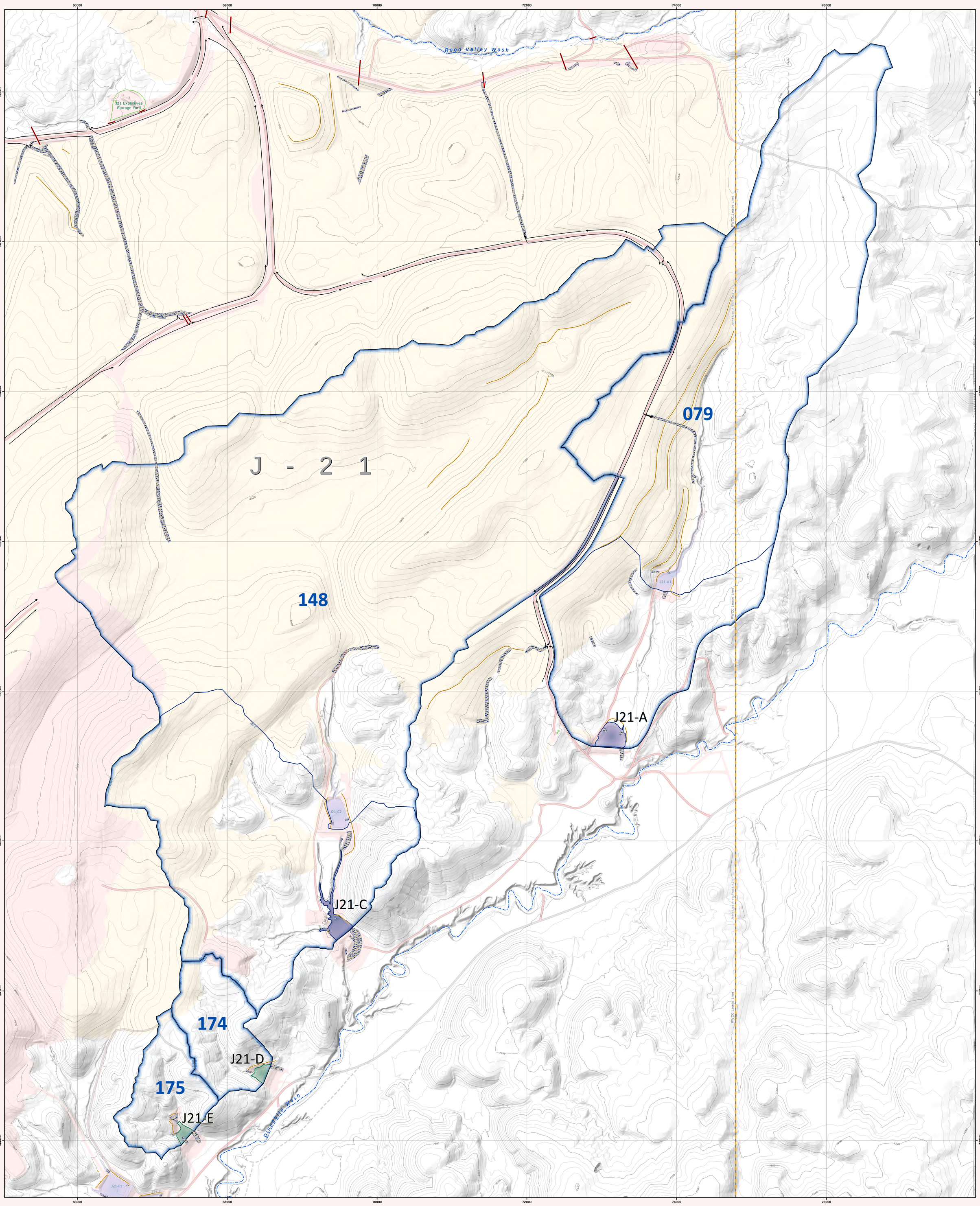
Map design by Deepsouthwest Enterprises

1 Inch = 400 Feet

10-foot contour interval
Index contours at 50 feet

Peabody ENERGY

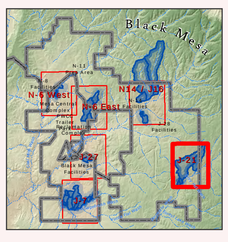
File: T:\Projects\Environmental\Sediment Control Plan\Maps\Sediment Control Plan 400.mxd



Sediment Control Plan

J-21 Area

July 2, 2012 Revision



Watersheds and Ponds
- Outfall Watershed
- Pond Watershed
- Existing Pond
- Reclaimed Pond

Water Conveyance
- Road Ditch
- Culvert
- Existing Terrace
- Diversion
- Rock Rip Rap Drain
- Major Drainage

BTCA Structures
- Berm/Sump
- Riprap Rock
- Rock Checkdam
- Silt Fence
- Straw Bales

Transport
- Haul Road
- Ramp
- Other Mine Roads
- US/State Highway
- Navajo Route 41
- Local Route
- Single Track
- Overland Conveyor Line
- Black Mesa / Lake Powell Railway

Disturbed Land Status
- Initial Program
- TOJ
- Permanent Program
- Phase I Release
- Phase II Release
- Pre-Law
- Active Pit

Administrative
- Lease Line
- Navajo-Hopi Partition Line
- 1E Permit
- Interim
- J-19 Coal Resource Area

PEABODY WESTERN GIS

Peabody Western Coal Company
Kayenta Complex
PO Box 650
Kayenta, Arizona 86033

Produced by John Cochran
Manager Environmental Hydrology

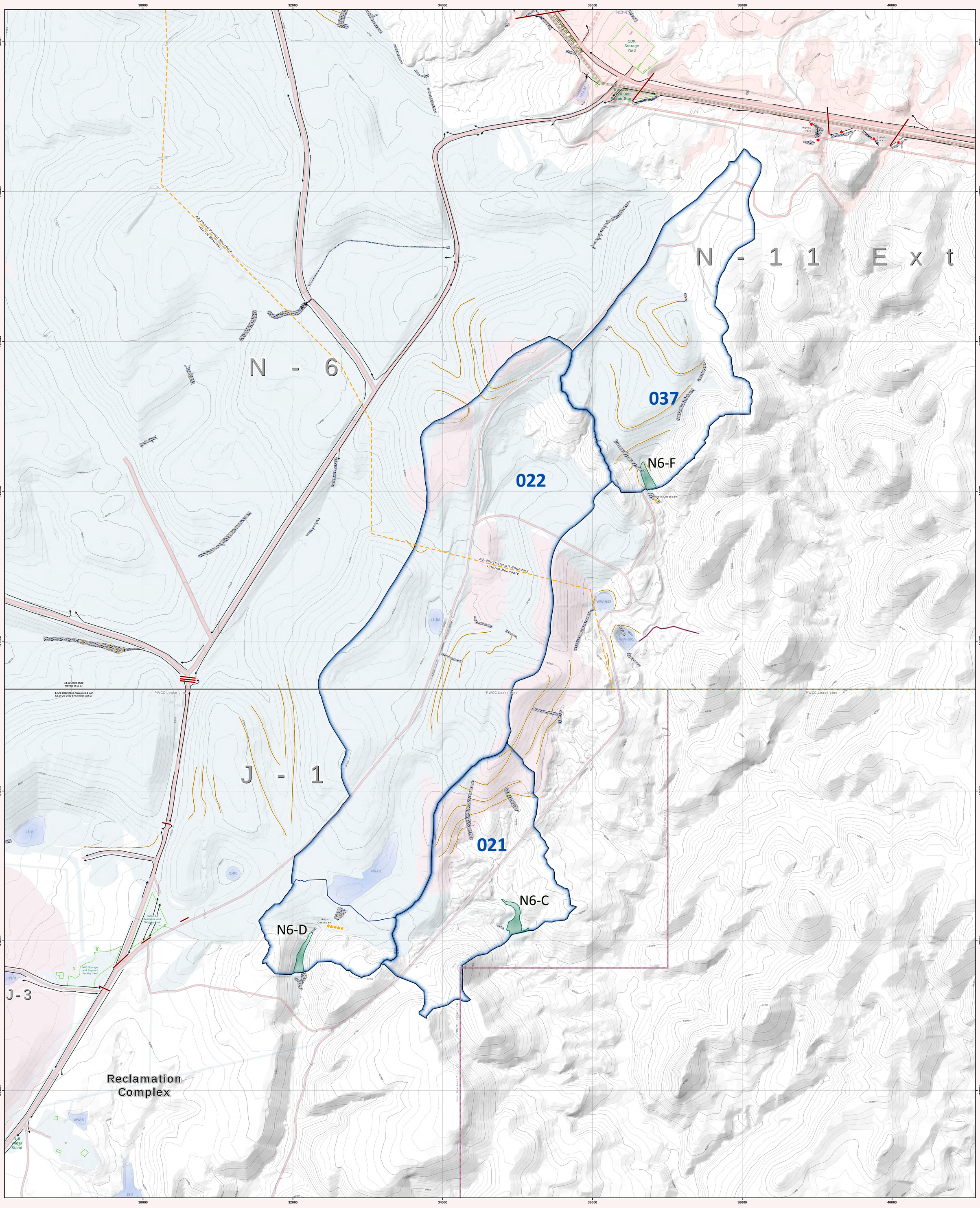
Map design by Deepsouthwest Enterprises

1 Inch = 400 Feet

10-foot contour interval
Index contours at 50 feet

Peabody ENERGY

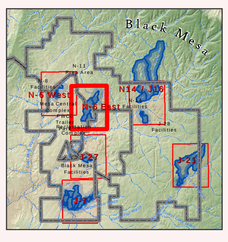
File: T:\Projects\Environmental\Sediment Control Plan\Maps\Sediment Control Plan 400.mxd



Sediment Control Plan

N-6 East Area

July 2, 2012
Revision



Watersheds and Ponds
- Outfall Watershed
- Pond Watershed
- Existing Pond
- Reclaimed Pond

Water Conveyance
- Road Ditch
- Culvert
- Existing Terrace
- Diversion
- Rock Rip Rap Drain
- Major Drainage

BTCA Structures
- Berm/Sump
- Riprap Rock
- Rock Checkdam
- Silt Fence
- Straw Bales

Transport
- Haul Road
- Ramp
- Other Mine Roads
- US/State Highway
- Navajo Route 41
- Local Route
- Single Track
- Overland Conveyor Line
- Black Mesa / Lake Powell Railway

Disturbed Land Status
- Initial Program
- TOJ
- Permanent Program
- Phase I Release
- Phase II Release
- Pre-Law
- Active Pit

Administrative
- Lease Line
- Navajo-Hopi Partition Line
- 1E Permit
- Interim
- J-19 Coal Resource Area

PEABODY WESTERN GIS

Peabody Western Coal Company
Kayenta Complex
PO Box 650
Kayenta, Arizona 86033

Produced by John Cochran
Manager Environmental Hydrology

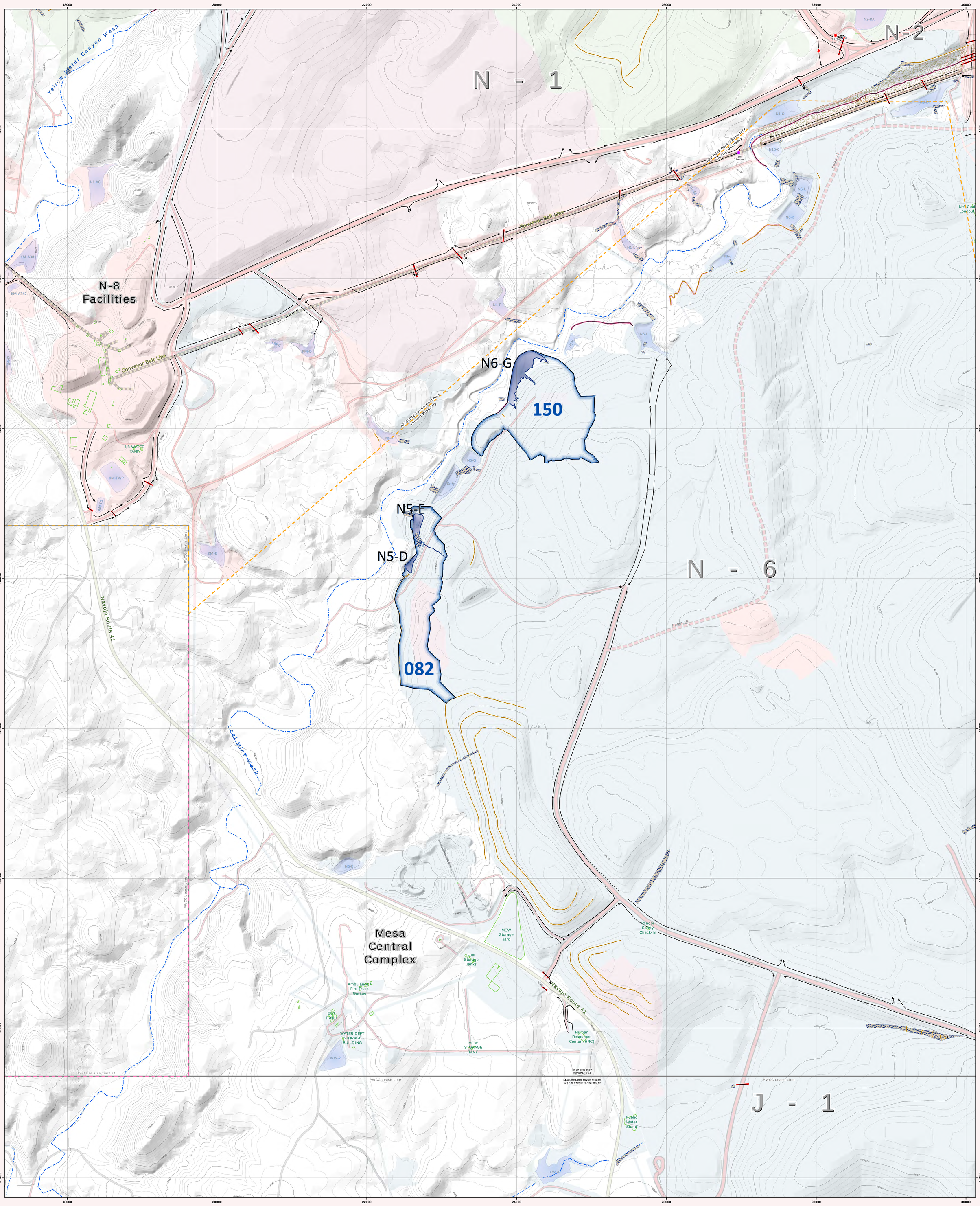
Map design by Deepsouthwest Enterprises

1 Inch = 400 Feet

10-foot contour interval
Index contours at 50 feet

Peabody ENERGY

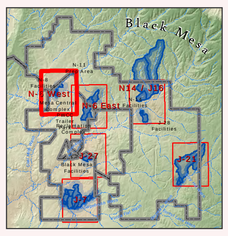
File: T:\Projects\Environmental\Sediment Control Plan\Maps\Sediment Control Plan 400.mxd



Sediment Control Plan

N-6 West Area

July 2, 2012
Revision



Watersheds and Ponds
- Outfall Watershed
- Pond Watershed
- Existing Pond
- Reclaimed Pond

Water Conveyance
- Road Ditch
- Culvert
- Existing Terrace
- Diversion
- Rock Rip Rap Drain
- Major Drainage

BTCA Structures
- Berm/Sump
- Riprap Rock
- Rock Checkdam
- Silt Fence
- Straw Bales

Transport
- Haul Road
- Ramp
- Other Mine Roads
- US/State Highway
- Navajo Route 41
- Local Route
- Single Track
- Overland Conveyor Line
- Black Mesa / Lake Powell Railway

Disturbed Land Status
- Initial Program
- TOJ
- Permanent Program
- Phase I Release
- Phase II Release
- Pre-Law
- Active Pit

Administrative
- Lease Line
- Navajo-Hopi Partition Line
- 1E Permit
- Interim
- J-19 Coal Resource Area

PEABODY WESTERN GIS

Peabody Western Coal Company
Kayenta Complex
PO Box 650
Kayenta, Arizona 86033

Produced by John Cochran
Manager Environmental Hydrology

Map design by Deepsouthwest Enterprises

1 Inch = 400 Feet

10-foot contour interval
Index contours at 50 feet

Peabody ENERGY

File: T:\Projects\Environmental\Sediment Control Plan\Maps\Sediment Control Plan 400.mxd

J27-RC

178

J - 2 7

Black Mesa Facilities

Navajo Route 41

Red peak Valley Wash

PWCC Lease Line

Joint Use Area Tract 2

Joint Use Area Tract 1

Conveyor Belt Line

MW-A

MW-B

BM-SS

BM-TW

BM-T

BM-A1

WW-3

J7-DAM

J27-RA

J27-RB

J27-R

Black Mesa

N-14 East

N-6 West

J-27

Facilities

Sediment Control Plan

J-27 Area

July 2, 2012 Revision

Watersheds and Ponds

- Outfall Watershed
- Pond Watershed
- Existing Pond
- Reclaimed Pond

Water Conveyance

- Road Ditch
- Culvert
- Existing Terrace
- Diversion
- Rock Rip Rap Drain
- Major Drainage

BTCA Structures

- Berm/Sump
- Riprap Rock
- Rock Checkdam
- Silt Fence
- Straw Bales

Transport

- Haul Road
- Ramp
- Other Mine Roads
- US/State Highway
- Navajo Route 41
- Local Route
- Single Track
- Overland Conveyor Line
- Black Mesa / Lake Powell Railway

Disturbed Land Status

- Initial Program
- TOJ
- Permanent Program
- Phase I Release
- Phase II Release
- Pre-Law
- Active Pit

Administrative

- Lease Line
- Navajo-Hopi Partition Line
- 1E Permit
- Interim
- J-19 Coal Resource Area

PEABODY WESTERN GIS

Peabody Western Coal Company
Kayenta Complex
PO Box 650
Kayenta, Arizona 86033

Produced by John Cochran
Manager Environmental Hydrology

Map design by Deepsouthwest Enterprises

1 Inch = 400 Feet

10-foot contour interval
Index contours at 50 feet

Peabody ENERGY

File: T:\Projects\Environmental\Sediment Control Plan\Maps\Sediment Control Plan 400.mxd

ATTACHMENT E

J-16 WHITE GRASS HILLS DRAINAGE PLAN

INCLUDING TERRACES & DOWNDRAINS

PERMIT REVISION

FEB 2010
APPROVED

J16 WHITEGRASS HILLS
SLOPE DESIGN
WATERSHED I

JUN 2003
APPROVED

Gary Altsisi

Peabody Western Coal
P.O. Box 650
Kayenta, AZ 86033

General Information

Storm Information:

Storm Type:	NRCS Type II
Design Storm:	100 yr - 6 hr
Rainfall Depth:	2.400 inches

Structure Summary:

	Immediate Contributing Area (ac)	Total Contributing Area (ac)	Peak Discharge (cfs)	Total Runoff Volume (ac-ft)
#1	2.790	2.790	4.11	0.20

APPROVED
JUN 2003

Subwatershed Hydrology Detail:

Stru #	SWS #	SWS Area (ac)	Time of Conc (hrs)	Musk K (hrs)	Musk X	Curve Number	UHS	Peak Discharge (cfs)	Runoff Volume (ac-ft)
#1	1	2.790	0.044	0.000	0.000	81.000	F	4.11	0.203
	Σ	**2.790**						**4.11**	**0.203**

Subwatershed Time of Concentration Details:

Stru #	SWS #	Land Flow Condition	Slope (%)	Vert. Dist. (ft)	Horiz. Dist. (ft)	Velocity (fps)	Time (hrs)
#1	1	8. Large gullies, diversions, and low flowing streams	5.11	55.00	1,076.00	6.780	0.044
#1	**1**	**Time of Concentration:**					**0.044**

J16 WHITEGRASS HILLS SLOPE DESIGN WATERSHED II

APPROVED
JUN 2003

Gary Altsisi

Peabody Western Coal
P.O. Box 650
Kayenta, AZ 86033

General Information

Storm Information:

Storm Type:	NRCS Type II
Design Storm:	100 yr - 6 hr
Rainfall Depth:	2.400 inches

Structure Summary:

	Immediate Contributing Area (ac)	Total Contributing Area (ac)	Peak Discharge (cfs)	Total Runoff Volume (ac-ft)
#1	2.410	2.410	3.55	0.18

APPROVED
JUN 2003

Subwatershed Hydrology Detail:

Stru #	SWS #	SWS Area (ac)	Time of Conc (hrs)	Musk K (hrs)	Musk X	Curve Number	UHS	Peak Discharge (cfs)	Runoff Volume (ac-ft)
#1	1	2.410	0.029	0.000	0.000	81.000	F	3.55	0.175
	Σ	**2.410**						**3.55**	**0.175**

Subwatershed Time of Concentration Details:

Stru #	SWS #	Land Flow Condition	Slope (%)	Vert. Dist. (ft)	Horiz. Dist. (ft)	Velocity (fps)	Time (hrs)
#1	1	8. Large gullies, diversions, and low flowing streams	7.35	63.00	857.00	8.130	0.029
#1	**1**	**Time of Concentration:**					**0.029**

J16 WHITEGRASS HILLS
SLOPE DESIGN
WATERSHED III

APPROVED
JUN 2003

Gary Altsisi

Peabody Western Coal
P.O. Box 650
Kayenta, AZ 86033

General Information

Storm Information:

Storm Type:	NRCS Type II
Design Storm:	100 yr - 6 hr
Rainfall Depth:	2.400 inches

Structure Summary:

	Immediate Contributing Area (ac)	Total Contributing Area (ac)	Peak Discharge (cfs)	Total Runoff Volume (ac-ft)
#1	2.740	2.740	4.04	0.20

APPROVED
JUN 2003

Subwatershed Hydrology Detail:

Stru #	SWS #	SWS Area (ac)	Time of Conc (hrs)	Musk K (hrs)	Musk X	Curve Number	UHS	Peak Discharge (cfs)	Runoff Volume (ac-ft)
#1	1	2.740	0.021	0.000	0.000	81.000	F	4.04	0.199
	Σ	**2.740**						**4.04**	**0.199**

Subwatershed Time of Concentration Details:

Stru #	SWS #	Land Flow Condition	Slope (%)	Vert. Dist. (ft)	Horiz. Dist. (ft)	Velocity (fps)	Time (hrs)
#1	1	8. Large gullies, diversions, and low flowing streams	10.38	76.30	735.00	9.660	0.021
#1	**1**	**Time of Concentration:**					**0.021**

J16 WHITEGRASS HILLS
SLOPE DESIGN
WATERSHED I-IV

JUN 2003
APPROVED

Gary Altsisi

Peabody Western Coal
P.O. Box 650
Kayenta, AZ 86033

General Information

Storm Information:

Storm Type:	NRCS Type II
Design Storm:	100 yr - 6 hr
Rainfall Depth:	2.400 inches

Structure Summary:

	Immediate Contributing Area (ac)	Total Contributing Area (ac)	Peak Discharge (cfs)	Total Runoff Volume (ac-ft)
#1	10.940	10.940	16.12	0.79

JUN 2003
APPROVED

Subwatershed Hydrology Detail:

Stru #	SWS #	SWS Area (ac)	Time of Conc (hrs)	Musk K (hrs)	Musk X	Curve Number	UHS	Peak Discharge (cfs)	Runoff Volume (ac-ft)
#1	1	10.940	0.030	0.000	0.000	81.000	F	16.12	0.795
	Σ	**10.940**						**16.12**	**0.795**

Subwatershed Time of Concentration Details:

Stru #	SWS #	Land Flow Condition	Slope (%)	Vert. Dist. (ft)	Horiz. Dist. (ft)	Velocity (fps)	Time (hrs)
#1	1	8. Large gullies, diversions, and low flowing streams	17.52	239.30	1,366.00	12.550	0.030
#1	**1**	**Time of Concentration:**					**0.030**

J16 WHITEGRASS HILLS
SLOPE DESIGN
WATERSHED V

APPROVED
JUN 2003

Gary Altsisi

Peabody Western Coal
P.O. Box 650
Kayenta, AZ 86033

General Information

Storm Information:

Storm Type:	NRCS Type II
Design Storm:	100 yr - 6 hr
Rainfall Depth:	2.400 inches

Structure Summary:

	Immediate Contributing Area (ac)	Total Contributing Area (ac)	Peak Discharge (cfs)	Total Runoff Volume (ac-ft)
#1	0.910	0.910	1.34	0.07

JUN 2003
APPROVED

Subwatershed Hydrology Detail:

Stru #	SWS #	SWS Area (ac)	Time of Conc (hrs)	Musk K (hrs)	Musk X	Curve Number	UHS	Peak Discharge (cfs)	Runoff Volume (ac-ft)
#1	1	0.910	0.014	0.000	0.000	81.000	F	1.34	0.066
	Σ	**0.910**						**1.34**	**0.066**

Subwatershed Time of Concentration Details:

Stru #	SWS #	Land Flow Condition	Slope (%)	Vert. Dist. (ft)	Horiz. Dist. (ft)	Velocity (fps)	Time (hrs)
#1	1	8. Large gullies, diversions, and low flowing streams	10.18	50.00	491.00	9.570	0.014
#1	**1**	**Time of Concentration:**					**0.014**

J16 WHITEGRASS HILLS
SLOPE DESIGN
WATERSHED VI

JUN 2003
APPROVED

Gary Altsisi

Peabody Western Coal
P.O. Box 650
Kayenta, AZ 86033

General Information

Storm Information:

Storm Type:	NRCS Type II
Design Storm:	100 yr - 6 hr
Rainfall Depth:	2.400 inches

Structure Summary:

	Immediate Contributing Area (ac)	Total Contributing Area (ac)	Peak Discharge (cfs)	Total Runoff Volume (ac-ft)
#1	0.450	0.450	0.66	0.03

JUN 2003
APPROVED

Subwatershed Hydrology Detail:

Stru #	SWS #	SWS Area (ac)	Time of Conc (hrs)	Musk K (hrs)	Musk X	Curve Number	UHS	Peak Discharge (cfs)	Runoff Volume (ac-ft)
#1	1	0.450	0.007	0.000	0.000	81.000	F	0.66	0.033
	Σ	**0.450**						**0.66**	**0.033**

Subwatershed Time of Concentration Details:

Stru #	SWS #	Land Flow Condition	Slope (%)	Vert. Dist. (ft)	Horiz. Dist. (ft)	Velocity (fps)	Time (hrs)
#1	1	8. Large gullies, diversions, and low flowing streams	14.17	42.50	300.00	11.290	0.007
#1	**1**	**Time of Concentration:**					**0.007**

J16 WHITEGRASS HILLS
SLOPE DESIGN
WATERSHED V-VI

Gary Altsisi

Peabody Western Coal
P.O. Box 650
Kayenta, AZ 86033

General Information

Storm Information:

Storm Type:	NRCS Type II
Design Storm:	100 yr - 6 hr
Rainfall Depth:	2.400 inches

Structure Summary:

	Immediate Contributing Area (ac)	Total Contributing Area (ac)	Peak Discharge (cfs)	Total Runoff Volume (ac-ft)
#1	1.360	1.360	2.00	0.10

JUN 2003
APPROVED

Subwatershed Hydrology Detail:

Stru #	SWS #	SWS Area (ac)	Time of Conc (hrs)	Musk K (hrs)	Musk X	Curve Number	UHS	Peak Discharge (cfs)	Runoff Volume (ac-ft)
#1	1	1.360	0.014	0.000	0.000	81.000	F	2.00	0.099
	Σ	**1.360**						**2.00**	**0.099**

Subwatershed Time of Concentration Details:

Stru #	SWS #	Land Flow Condition	Slope (%)	Vert. Dist. (ft)	Horiz. Dist. (ft)	Velocity (fps)	Time (hrs)
#1	1	8. Large gullies, diversions, and low flowing streams	15.42	92.50	600.00	11.770	0.014
#1	**1**	**Time of Concentration:**					**0.014**

OUTFLOW CHANNEL DESIGN - WATERSHED I-IV

Material: Riprap

Triangular Channel

Left Sideslope Ratio	Right Sideslope Ratio	Slope (%)	Freeboard Depth (ft)	Freeboard % of Depth	Freeboard Mult. x (VxD)
3.0:1	3.0:1	33.3	1.00		

PADER Method - Steep Slope Design

	w/o Freeboard	w/ Freeboard
Design Discharge:	16.12 cfs	
Depth:	0.80 ft	1.80 ft
Top Width:	4.78 ft	10.78 ft
Velocity:	8.48 fps	
X-Section Area:	1.90 sq ft	
Hydraulic Radius:	0.378	
Froude Number:	2.37	
Manning's n:	0.0530	
Dmin:	3.00 in	
D50:	6.00 in	
Dmax:	9.00 in	

APPROVED
JUN 2003

OUTFLOW CHANNEL DESIGN - WATERSHED V-VI

Material: Coarse gravel noncolloidal

Triangular Channel

Left Sideslope Ratio	Right Sideslope Ratio	Slope (%)	Manning's n	Freeboard Depth (ft)	Freeboard % of Depth	Freeboard Mult. x (VxD)	Limiting Velocity (fps)
3.0:1	3.0:1	33.3	0.0250	1.00			9.0

	w/o Freeboard	w/ Freeboard
Design Discharge:	2.00 cfs	
Depth:	0.28 ft	1.28 ft
Top Width:	1.65 ft	7.65 ft
Velocity:	8.86 fps	
X-Section Area:	0.23 sq ft	
Hydraulic Radius:	0.131	
Froude Number:	4.21	

APPROVED
JUN 2003

TYPICAL V-DITCH TERRACE DESIGN - using max. flow

Material: Stiff clay very colloidal

Triangular Channel

Left Sideslope Ratio	Right Sideslope Ratio	Slope (%)	Manning's n	Freeboard Depth (ft)	Freeboard % of Depth	Freeboard Mult. x (VxD)	Limiting Velocity (fps)
2.0:1	2.0:1	1.5	0.0250	1.00			3.8

	w/o Freeboard	w/ Freeboard
Design Discharge:	4.11 cfs	
Depth:	0.76 ft	1.76 ft
Top Width:	3.04 ft	7.04 ft
Velocity:	3.56 fps	
X-Section Area:	1.16 sq ft	
Hydraulic Radius:	0.340	
Froude Number:	1.02	

APPROVED
JUN 2003

Whitegrass Hills Slope Stabilization
Revegetation Plan

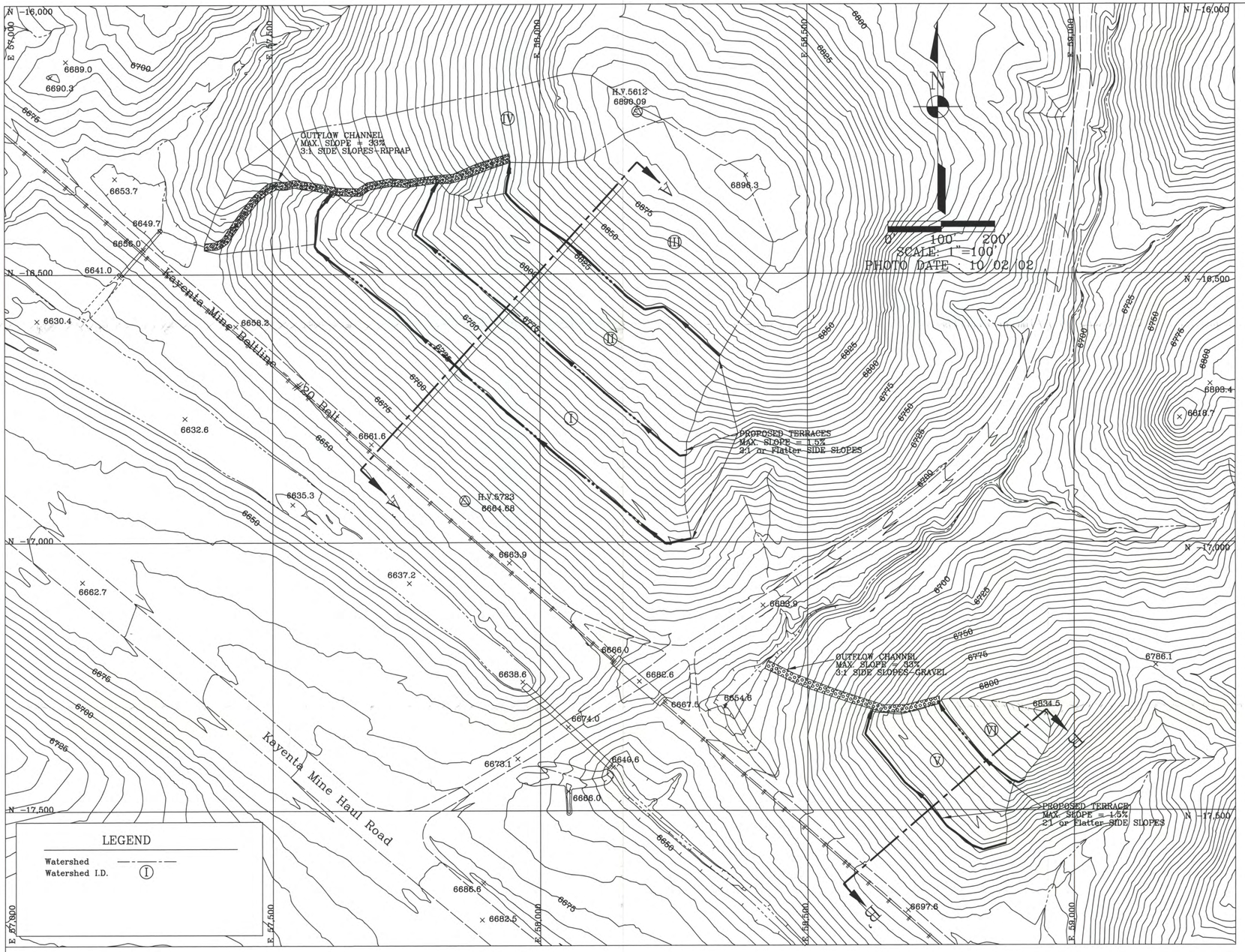
The slopes will be contour furrow disked or ripped on the contour with a chisel plow or a small dozer equipped with triple shank rippers. If necessary, after a site-by-site evaluation, soil may be redistributed to ensure successful vegetation establishment and stabilization. In some areas, rocky or coarse textured plant growth media may be placed on slopes as a stabilization measure. These areas will be hand broadcast seeded if equipment access is restricted. Following terrace construction, tillage and seedbed preparation, the soiled areas will be drill seeded on the contour with the mix listed below. Broadcast seeded areas will receive an application of double the drilled rate.

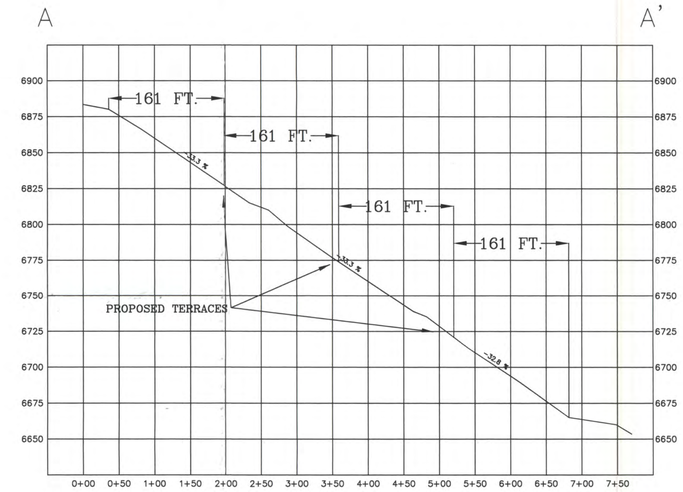
Species		PLS lbs	Seeds/ft^2
Tall wheatgrass	(Agropyron elongatum)	3.0	5.4
Thickspike wheatgrass	(Agropyron dasystachyum)	4.0	14.0
Western wheatgrass	(Agropyron smithii)	4.0	10.0
Pubescent wheatgrass	(Agropyron trichophorum)	3.0	6.6
Fourwing saltbush	(Atriplex canescens)	3.0	3.6
Total (drilled rate)		17.0	39.6

The mix contains 3 sod forming wheatgrass species and tall wheatgrass, a tall and coarse grass with very low palatability to discourage livestock grazing. Fourwing saltbush is included at a high rate to provide additional structural cover, soil binding benefits, and provide some restriction to livestock access. The reseeded areas will be mulched with grass hay at 2 tons per acre and crimped. Any areas where high rock or coarse fragment materials were placed will not be mulched.

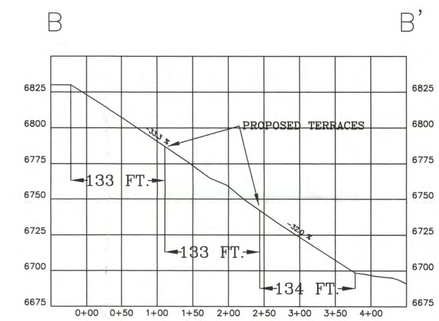
JUN 2003 APPROVED

JUN 2003 APPROVED

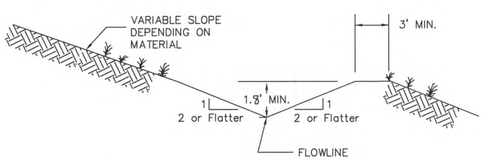




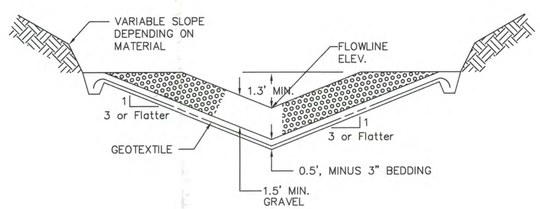
SCALE:
HORIZ. : 1"=100'
VERT. : 1"=50'



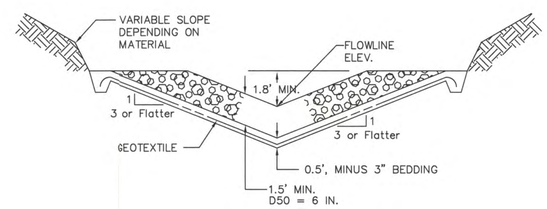
SCALE:
HORIZ. : 1"=100'
VERT. : 1"=50'



V-DITCH GRADIENT TERRACE (TYPICAL)
NOT DRAWN TO SCALE



SECTION OF OUTFLOW CHANNEL – GRAVEL
NOT DRAWN TO SCALE



SECTION OF OUTFLOW CHANNEL – RIPRAP
NOT DRAWN TO SCALE

CERTIFICATION

GARY ALTSISI
ENGINEER
PEABODY WESTERN COAL COMPANY

ARIZONA P.E. 37842
DATE: FEB 17 2003

APPROVED JUN 2003

PEABODY WESTERN

KAYENTA MINE

Exhibit 1
Whitegrass Hills Drainage Design
J16 Area - #20 Belt

DRAWN BY: G. Altsisi	DATE 02/13/03		
SURVEYED BY:		SIZE / JOB NO.:	DWG FILENAME: J16Beltline_0802.dwg / REV
DESIGN BY: G. Altsisi	02/13/03	Scale : 1" = 100'	SHEET 1 OF 1