Phase II Bond Release Application

N11 and J19 Coal Resource Areas, Kayenta Mine

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Section 4. Phase II Bond Release Supporting Information

Suspended Solids Outside of the Permit Area

Introduction

Beginning in the early 1980's, Peabody Western Coal Company (PWCC) collected numerous measurements of suspended solids (Total Suspended Solids – TSS) in runoff events at sites established on the main washes and at small watersheds located on both reclaimed and un-mined areas within the leasehold. TSS values collected in runoff from runoff plots and small flumes contributed to the development of a surface water model (EASI) used to predict runoff and sediment loads from both un-mined and reclaimed mined lands at the Kayenta Mine. The following sections summarize the development of the EASI model and reference recent EASI modeling reports for reclaimed parcels adjacent to or within the Phase II parcels subject to this Phase II application (N-11 and J-19). Comparisons of measured and predicted sediment discharges and TSS concentrations collected at main channel monitoring sites, small un-mined watersheds, and in small, reclaimed parcels located within the Black Mesa and Kayenta Mines are also summarized. Based on the following discussions, PWCC is confident that runoff from these parcels will not contribute additional suspended solids to stream flow outside the permit area.

EASI Model Development

PWCC initiated a Small Watershed Study (SWS) monitoring program on Black Mesa in 1985, and continued monitoring through 1992. Details regarding study objectives and monitoring associated with the study are provided in Attachment 4 in Chapter 16, Hydrologic Monitoring Program in the AZ-0001F Permit Application Package (PAP). Several small watersheds located within reclaimed and undisturbed areas were instrumented with supercritical flow flumes and continuous flow recorders for collecting runoff, sediment (TSS) and water quality data. Rainfall data were collected using Belfort automated tipping bucket rain gauges located at the centroids of each watershed and direct reading rain gauges set up at various locations within each watershed. Total overland runoff and sediment yield data for individual storm events were collected from hill slopes in each watershed using runoff plots. Small flumes were also installed downstream of the plots and were instrumented with continuous stage recorders and automated samplers to measure runoff rates and TSS concentrations during runoff events. In addition, runoff rates and TSS concentrations were collected at sites located in the main channels (e.g., Moenkopi Wash) over many years as part of historic monitoring commitments contained in the Hydrologic Monitoring Program during the 1980s into the mid-1990s. The data results were utilized to calibrate the physically based runoff and sediment yield model named EASI (Erosion And Sediment Impacts - Zevenbergen et al., 1990; WET, 1990). EASI has been used to support Termination of Jurisdiction (TOJ) applications for mined areas reclaimed under the initial program rules (30 CFR Part 715) and bond release applications for mined areas reclaimed under the permanent program rules (30 CFR Part 816). The modeling results were used to support the first TOJ application submitted for the Kayenta Complex in March 1994 for the N-1/N-2 and J-27 interim program reclaimed areas (PWCC, 1994). The 1994 TOJ application included the final report for the modeling project completed in August of 1993 (RCE, 1993).

The model was calibrated and verified using a two-step process and site-specific data collected as part of the Small Watershed Study. The EASI model was first calibrated and validated using total runoff volumes and sediment yields measured in the runoff plots along with rainfall data, followed by simulation of actual runoff hydrographs and corresponding sediment concentrations collected from the flumes considering measured storm durations and intensities. Soils and vegetative cover data measured in each plot and at select points in each watershed were also used in the model development process. Parameters that influence the model's predictions of runoff and sediment were calculated from observed data or estimated through model testing. Other theoretical parameters such as rainfall interception storage and Manning's "n" were estimated based on previous experience in the application of EASI at other surface mines in the Colorado Plateau region (WET, 1990).

EASI Model Sensitivity Analysis. The 1993 report provides a discussion of the influence of several key input parameters on its ability to duplicate measured hillslope and channel responses. Runoff and sediment yields (TSS) predicted by EASI are controlled by the short-duration, high-intensity rainfall events common to the area. The model tends to underpredict runoff and sediment yield response for small rainfall events (< 0.1 inches), especially on hillslopes where antecedent moisture, looseness of surface soils, wind and temperature can vary appreciably. For larger events, the small watershed study runoff plot and flume data were in good agreement with EASI model predictions based on the calibration and validation process utilized for optimizing model inputs.

The sensitivity of the EASI model to several input parameters was performed after completing the calibration and validation work. The analysis evaluated calibrated values for soil hydraulic conductivity, total ground cover, and both overland flow (hillslope) and channel flow detachment coefficients (erosion) by varying the input parameter values by percentages. Model response to these variations was evaluated on a unit runoff (inches) and sediment yield (tons/acre) basis at both hillslope and watershed scales. The analysis indicates runoff is not appreciably affected by cover at either a hillslope or watershed scale. For larger events, rainfall intensities are far higher than infiltration rates.

However, sediment yield from pre-mining and reclaimed hillslopes is highly sensitive to total ground cover and less sensitive to infiltration (hydraulic conductivity) and erosion (detachment coefficients). On a watershed scale, the differences between pre-mine and reclaimed sediment yield are less pronounced because channel sediment transport processes dominate at the watershed outlet.

Many of the required EASI model input parameters used for modeling runoff and sediment yield from watersheds at the Kayenta Mine were developed during the calibration and validation process because direct measurements were difficult to obtain and not readily available. However, percent ground cover values for modeling un-mined and reclaimed areas are based on field measurements of vegetative ground cover, litter and rock. These values are measured directly in the field and are required for demonstrating successful establishment of vegetation growth in the reclaimed parcels subject to this Phase II bond release application. Because predictions of sediment yields (including TSS concentrations) using EASI are sensitive to values of total ground cover, and are readily available, it follows that measurements of total ground cover in reclaimed areas may be used to indicate whether reclaimed areas are generating sediment yields, expressed as tons/acre on a unit basis or as individual TSS concentrations (mg/L), that may result in appreciable contributions of suspended solids to streamflow outside the permit area.

Table 4.1 presents average total ground cover used in previous EASI models to predict sediment yields in numerous reclaimed areas throughout the leasehold and provides a general description of the reclaimed areas modeled, drainage area, and average total ground cover used for modeling purposes. The values range from 38.2 percent to 65.6 percent. Of note, the EASI models that were developed for all reclaimed areas listed predicted average annual sediment yields less than or equal to pre-mining conditions. Importantly, the processes that dominate the sediment yield predictions involve sediment transport in channels, not erosion from hill slopes. Measurements of total ground cover during 2020 and 2021 in the reclaimed parcels subject to this application averaged 55.2 percent in N-11 and 60.4 percent in J-19 (see Table 3.2 in Section 3.0). Accordingly, absent application of the EASI model to these parcels, the average total ground cover values indicate average annual sediment yields from these areas will be less than or equal to conditions that were present prior to mining these parcels.

Table 4.1. Total Ground Cover Values for Reclaimed Conditions used in Previous EASI Sediment Models

Reclaimed Area Modeled	Model Date (Month-Year)	Drainage Area (acres}	Total Ground Cover[1] (percent}
N1/N2	Aug-93	2732.5	41.2
J27	Aug-93	178.9	43.9
N7/N8	Jul-01	946.0	53.9
N14	Jul-08	1580.6	46.5
J21-D/J21-E	Aug-08	68.9	65.6
J16-E/J16-F	Aug-08	148.5	61.0
N6-C/N6-D/N6-F	Aug-08	280.9	38.2
J7-CD/J7-E/J7-F	Aug-08	99.8	48.5
J21-A	Apr-09	111.2	52.7
N6-G	Apr-09	37.9	55.6
J7-K/J7-M	Jun-09	37.3	55.2
N5-D/N5-E	Aug-09	28.3	48.9
J1/N6 and N6 East Central	Sep-09	1533.3	46.2
J21	Sep-10	2832.0	59.4
J7-A/J7-B1/J7-G/J7-H/ J7-I/J7-J/J7-R/J7-R1	Feb-11	440.0	55.2
J19	Sep-11	943.4	55.8
J3	Nov-12	95.5	39.9
J7	Nov-12	1194.7	48.7
Total Drainage Area Modeled =		13289.7	

[1] Total Ground Cover = Vegetation Ground Cover + Litter + Rock

Following the 1994 TOJ application submittal, sixteen additional EASI models were developed for reclaimed parcels located within the Kayenta and Black Mesa Mines, including reclaimed watersheds upstream of temporary sediment ponds that were permitted as outfalls in the Kayenta Complex NPDES Permit No. NN-0022179. As of 2016, a total of 13,289.7 acres of reclaimed areas had been modeled using EASI. The combined total of topsoiled and seeded areas at both mines at the end of 2016 was 15,584 acres, of which approximately 85 percent were modeled using EASI. The following sections discuss EASI models that have been developed proximate to the N-11 and J-19 reclaimed parcels subject to this application.

J1/N6 EASI Sediment Yield Model. Attachment 4.1 contains an EASI model report entitled "Surface Water Modeling of the Reclaimed Parcels at Black Mesa Complex J1/N6 and N6 East Central Coal Resource Areas" (Ayres, 2009) for reclaimed areas situated south of the N-11 reclaimed parcels. The results indicate average annual runoff (0.28 inches) generated from reclaimed hill slopes and low-order channels is less than pre-mining conditions (0.42 inches).

The difference is attributed to the creation of several internal draining impoundments in the eastern portion of the N-6 post-mining landscape. Reclamation methods including BMPs (e.g., vegetative cover) utilized in the N-11 reclaimed parcels were like those evaluated in the J1/N6 EASI model. In addition, physical properties of the reclaimed watersheds within the J1/N6 areas, including mean channel slope, drainage density and mean hillslope gradients were similar to pre-mining conditions.

J-19 EASI Sediment Yield Model. Attachment 4.2 contains the EASI model entitled "Surface Water Modeling of Reclaimed Parcels at the J19 Coal Resource Area, Kayenta Complex" (Ayres, 2011). The model results indicate post-mine (reclaimed parcels) average annual sediment yields are about 29 percent less than pre-mine levels. Hill slope and sub-watershed erosion rates, which are significant for sustaining the postmining land use, are 9 percent higher for the reclaimed landscape, yet are comparable to pre-mine levels and are less than 1.0 ton/acre/year. The reduction of sediment yield is due to comparable hill slope erosion combined with channel erosion control measures for the post-mine landscape.

Total Suspended Solids

Soils replaced within the N-11 and J-19 reclaimed parcels, naturally occurring soils in surrounding undisturbed areas within the leasehold overall and in the arid/semiarid Southwest typically lack cohesion. Un-mined stream channels within and adjacent to the Kayenta Mine and PWCC leasehold consist of steep sided, deeply incised arroyos with loosely consolidated channel banks and fine-grained sand bed channels. Figure 4.1 from Blatt, Middleton, and Murray (1972) shows these types of soils (unconsolidated clays, silts and fine-grained sands) are easiest to keep in suspension. The gray band shown in Figure 4.1 represents the flow velocity ranges necessary to keep particle types and sizes in suspension. Above the gray band are the velocities necessary to erode or entrain soil particles, whereas velocities below the gray band would be insufficient to transport the particles and deposition would occur. The bandwidths for the clay and silt particle sizes are quite wide because considerably higher velocities are necessary to erode consolidated and cohesive clays and silts. For the unconsolidated non-cohesive silts, clays and fine-grained sands found on the leasehold, velocities of less than 2 feet/second will erode and keep the particles in suspension. Typical flow velocities measured historically in the stream channels on the leasehold including Dinnebito Wash (sites CG34 and SW34) and the main channels along Yucca Flat Wash, Coal Mine Wash, and Moenkopi Wash where monitoring sites SW155, SW25, and SW26 are located, respectively, range from 8 to 12 feet/second.

In the semiarid Southwest, much of the precipitation is effective in terms of producing runoff. Most of the rainfall occurs in short duration, very high intensity storms that rapidly overcome soil infiltration and generate larger amounts of runoff. Total annual rainfall on the PWCC leasehold ranges from 6 to 12 inches. Figure 4.2, from Langbein and Schumm (1958), shows the relationship of annual sediment yield to effective annual precipitation and cover in the U.S. Note the highest annual sediment yields occur where there is a combination of approximately 12 inches of effective precipitation and desert/shrub type cover. Both factors are consistent for the leasehold and for the undisturbed areas adjacent to the N-11 and J-19 reclaimed parcels. Because of the soil and rainfall characteristics and the vegetative cover for this geomorphic region, stream flows on the leasehold more closely approximate debris flows than they do stream flows.

<u>Suspended Solids Outside of the Permit Area</u>

Section 2.0, Comparisons with Measured Sediment Transport in both EASI model reports provided in Attachments 4.1 (Ayres, 2009) and 4.2 (Ayres, 2011) contain a discussion of measured sediment discharge and total suspended sediment (TSS) concentrations along with EASI-model derived sediment discharge and TSS concentrations. Measured values were collected over many years at main channel stream monitoring sites and at Small Watershed Study (SWS) flumes. Each EASI model report compares predicted values for sediment discharge and TSS concentrations for reclaimed areas modeled with measured values based on data plots (see Figures 2.1 and 2.2 in each model report). Overlap of model predictions for both pre- and post-mine conditions with measured data strongly indicate EASI model predictions are representative and reasonable. In addition, the plots indicate sediment loads and concentrations are dependent on the channel sediment transport capacity for small un-mined and reclaimed channels as well as larger channels draining larger basins. Channel sources of sediment in the semi-arid environment of the leasehold are virtually unlimited. Accordingly, channel transport capacity and channel-derived sediment limits and governs sediment discharge and TSS concentrations from the small tributaries and large sand-bed channels (e.g., Moenkopi Wash).

Section 2.2 of each EASI model report (Attachments 4.1 and 4.2) also discusses statistical analysis of the sediment discharge and sediment concentration plots provided in Figures 2.1 and 2.2. The analysis involved applying non-parametric statistics to determine if channels in reclaimed areas have similar sediment transport characteristics as background (un-mined) channels. The analysis showed data collected at un-mined SWS flumes can be combined with the main channel monitoring site data, and that sediment is being conveyed at or near capacity. In addition, reclaimed channel sediment discharge and TSS concentrations show the same characteristics of the data collected at un-mined SWS flumes and main channel monitoring sites even though the flow ranges are lower. The data plots and statistical analysis indicate that channel flows within and adjacent to the leasehold achieve the sediment transport capacity of the channel regardless of whether they are located within reclaimed areas or in small and large basins that drain background watersheds not impacted by surface coal mining activities. Accordingly, runoff from any of the reclaimed parcels located within the N-11 and J-19 parcels subject to this Phase II bond release application are not contributing additional suspended solids (TSS) to streamflow outside the permit area.

Alluvial Valley Floors

Chapter 17, Protection of the Hydrologic Balance in the AZ-0001F PAP provides a summary of early investigations of the existence of alluvial valley floors (AVFs) within or adjacent to the leasehold. The findings clearly indicate there are no AVFs within or adjacent to the leasehold.

Surface and Subsurface Water Pollution

The regulations set forth under 30 CFR Parts 780 and 816 require operators to minimize impacts to the prevailing hydrologic balance. PWCC conducted mining and reclamation activities at the N-11 and J-19 reclaimed parcels subject to this Phase II bond release application in accordance with plans and procedures approved by the Office of Surface Mining Reclamation and Enforcement (OSMRE) as provided in the PAP for Surface Mining Permit AZ-0001F, many of which were developed in order to ensure impacts to the hydrologic balance in the vicinity were minimized. The changes to ground water (subsurface) are largely based on long term monitoring of ground water in monitoring wells completed in the Wepo Formation and adjacent alluvial deposits along Moenkopi Wash and Coal Mine Wash. Changes to surface water (surface) are based on long term monitoring of runoff at stream sites located on Moenkopi Wash and Coal Mine Wash. Changes in water chemistry discussed above cover decades of monitoring in many cases and are within magnitudes and ranges representative of naturally occurring or background values. In summary, no pollution of surface or subsurface sources of water has been found within or adjacent to the subject reclaimed N-11 and J-19 parcels shown on Map 1.1.

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Ayres Associates, 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.

Ayres Associates, 2011. "Surface Water Modeling of Reclaimed Parcels at the J19 Coal Resource Area, Kayenta Complex", Prepared for Peabody Western Coal Company.

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Peabody Western Coal Company (PWCC), 1994. "Application for Release of Reclamation Liability N-1/N-2 and J-27 Interim Program Indian Lands", submitted to the Office of Surface Mining Reclamation and Enforcement Albuquerque Field Office on March 31, 1994.

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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.

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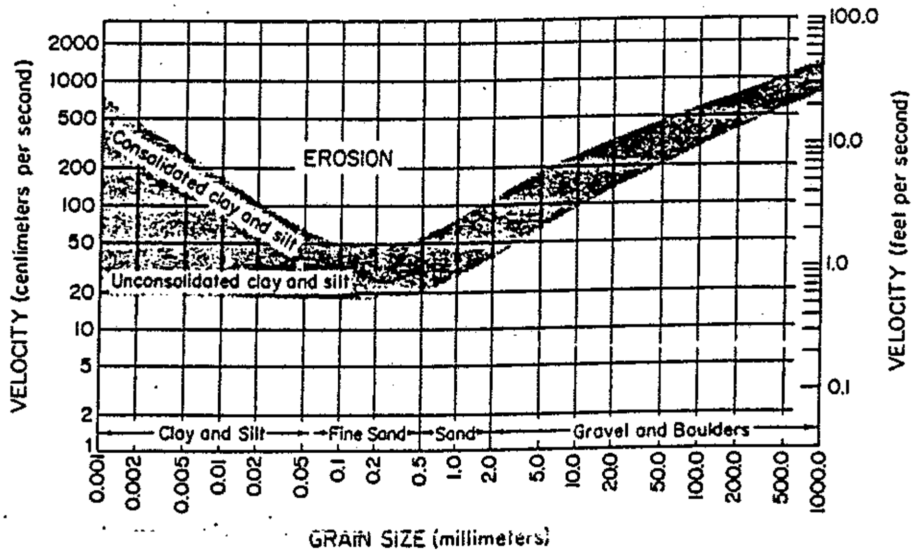
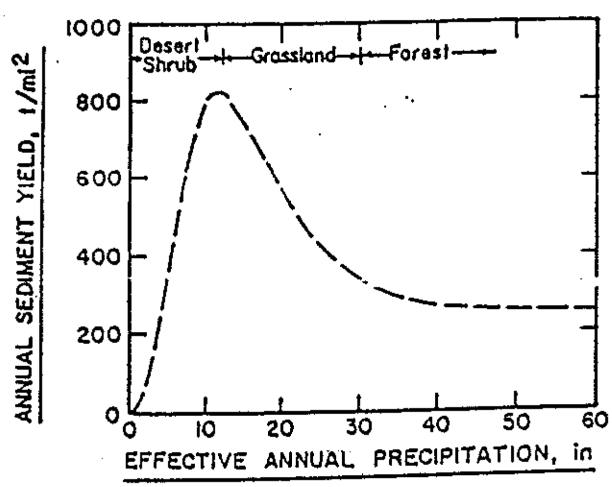
Figure 4.1



Hjulstrom's diagram, showing critical velocity for movement of quartz grains on a plane bed at a water depth of one meter, as modified by Sundborg (1956). The shaded area indicates the scatter of experimental data. There are very few reliable data in the clay and silt region.

(from Blatt, Middleton and Murray, 1972)

Figure 4.2



Variation of sediment yield with climate in the United States (from Langbein and Schumm, 1958).

SURFACE WATER MODELING OF THE RECLAIMED PARCELS AT BLACK MESA COMPLEX J1/N6 AND N6 East Central COAL RESOURCE AREAS

Prepared for

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SURFACE WATER MODELING OF THE RECLAIMED PARCELS AT BLACK MESA COMPLEX J1/N6 AND N6 EAST CENTRAL COAL RESOURCE AREAS

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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 (combined as Black Mesa Complex in December 2008) to predict mean annual runoff and sediment yields from the reclaimed parcel J1/N6 and N6 East Central. Since the model for the J1/N6 Coal Resource Area (CRA) was completed in 2001, the objectives of this project are to review the completed J1/N6 model, develop a model for the neighboring N6 East Central CRA, and incorporate the newly developed N6 East Central model into the existing J1/N6 model. 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 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 serves a tool for assessing the success of reclamation efforts to protect 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 J1/N6 and N6 East Central CRA that is the focus of this project was reclaimed between 1981 and 2007. This reclaimed area is now eligible for termination of jurisdiction from the Office of Surface Mining Regulation and Enforcement (OSMRE). 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, 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 CRA J1/N6 and N6 East Central. 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 CRA were modeled using EASI. Results were determined for concentration points at the outlets of the reclaimed watersheds. 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 J1/N6 and N6 East Central premining watersheds.

1.3 Data

1.3.1 Soils

Soils data used for the current study (CRA J1/N6 and N6 East Central) 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 CRA J1/N6 and N6 East Central 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 CRA J1/N6 and N6 East Central.

1.3.2 Vegetation

Vegetative cover data representative of both pre- and postmine conditions in CRA J1/N6 and N6 East Central 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 J1/N6 and N6 East Central CRA premine condition appears in **Figure 1.2**. Average cover properties for CRAs N1/N2 and J27 of the previous study and CRA J1/N6 and N6 East Central 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 J1/N6 and N6 East Central CRA. 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 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.

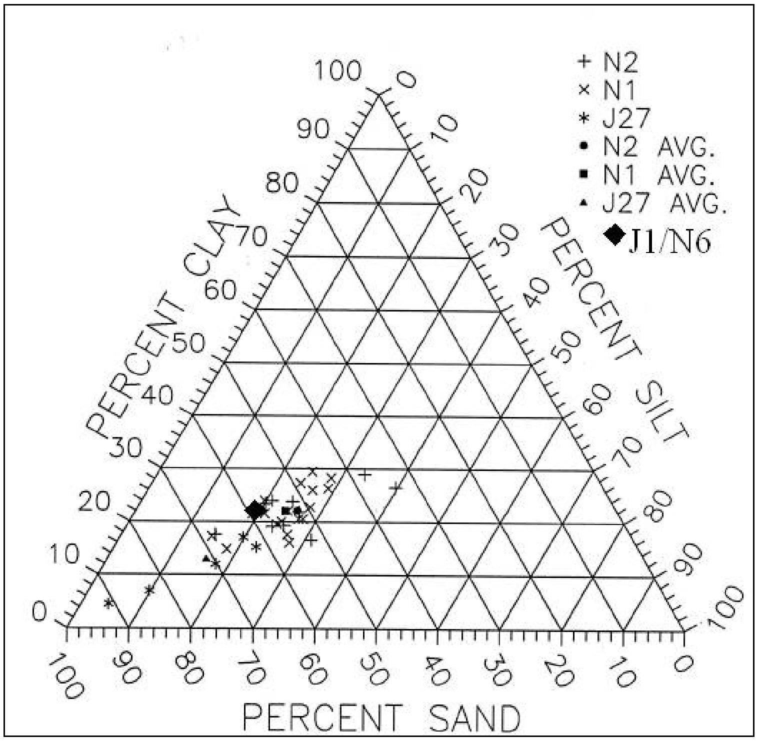

Figure 1.1. Reclaimed area soils trilinear graph.

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	

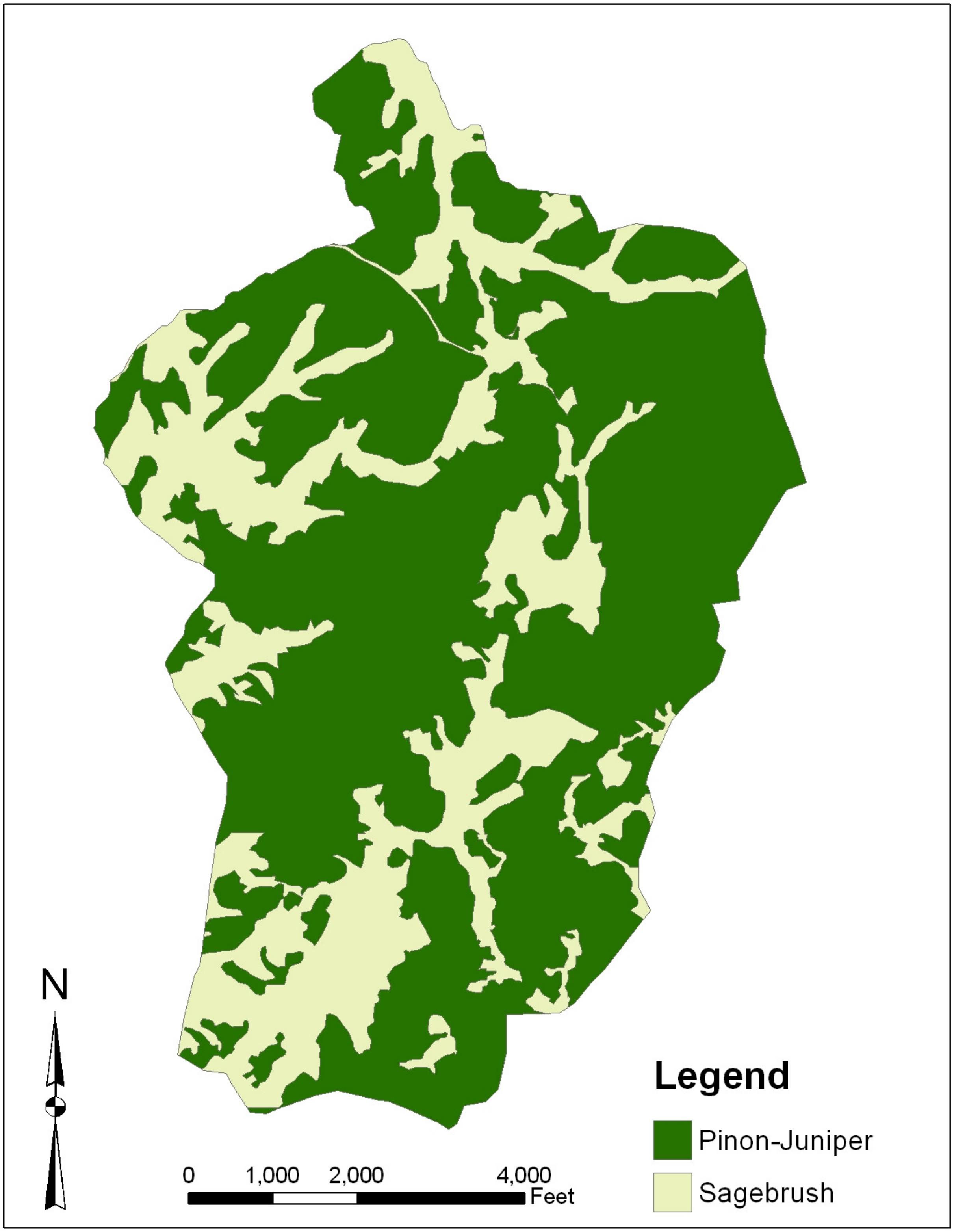

Figure 1.2. Vegetative cover for CRA J1/N6 and N6 East Central premine condition.

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
J1/N6	Postmine	Postmine	20.6	0.3	20.4	21.6	4.2	46.2
N1/N2/J27	Premine	Pinon Juniper	32.7	31.1	3.0	44.0	19.7	66.7
J1/N6	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
J1/N6	Premine	Sagebrush	12.4	1.3	11.2	24.7	2.5	38.3
*Including standing dead litter								

Table 1.3. Cover Data for J1/N6 and N6 East Central Watersheds.				
Condition	Pinon Juniper	Sagebrush	Half Pinon Juniper-Half Sagebrush	Postmine
Canopy cover, %	14.6	1.3	8.0	0.3
Ground cover, %	38.8	38.3	38.5	46.2
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 CRA J1/N6 and N6 East Central 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 J1/N6 and N6 East Central CRA dictated that some areas would be included or excluded from the modeling. The total area modeled for premine conditions is 1499.7 acres (Exhibit 2) and for postmine conditions is 1533.3 acres (Exhibit 1).

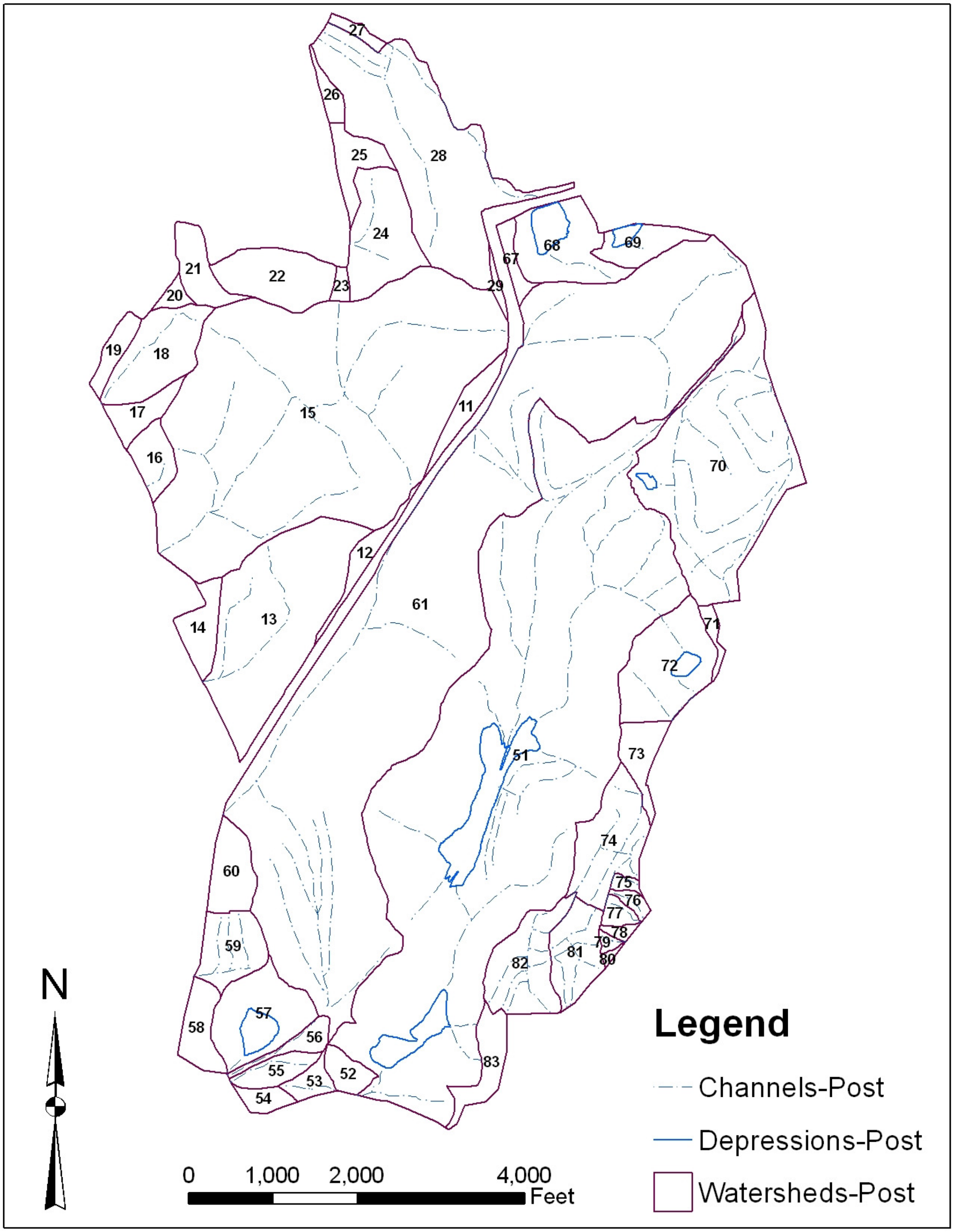

Figure 1.3. J1/N6 and N6 East Central postmine basins.

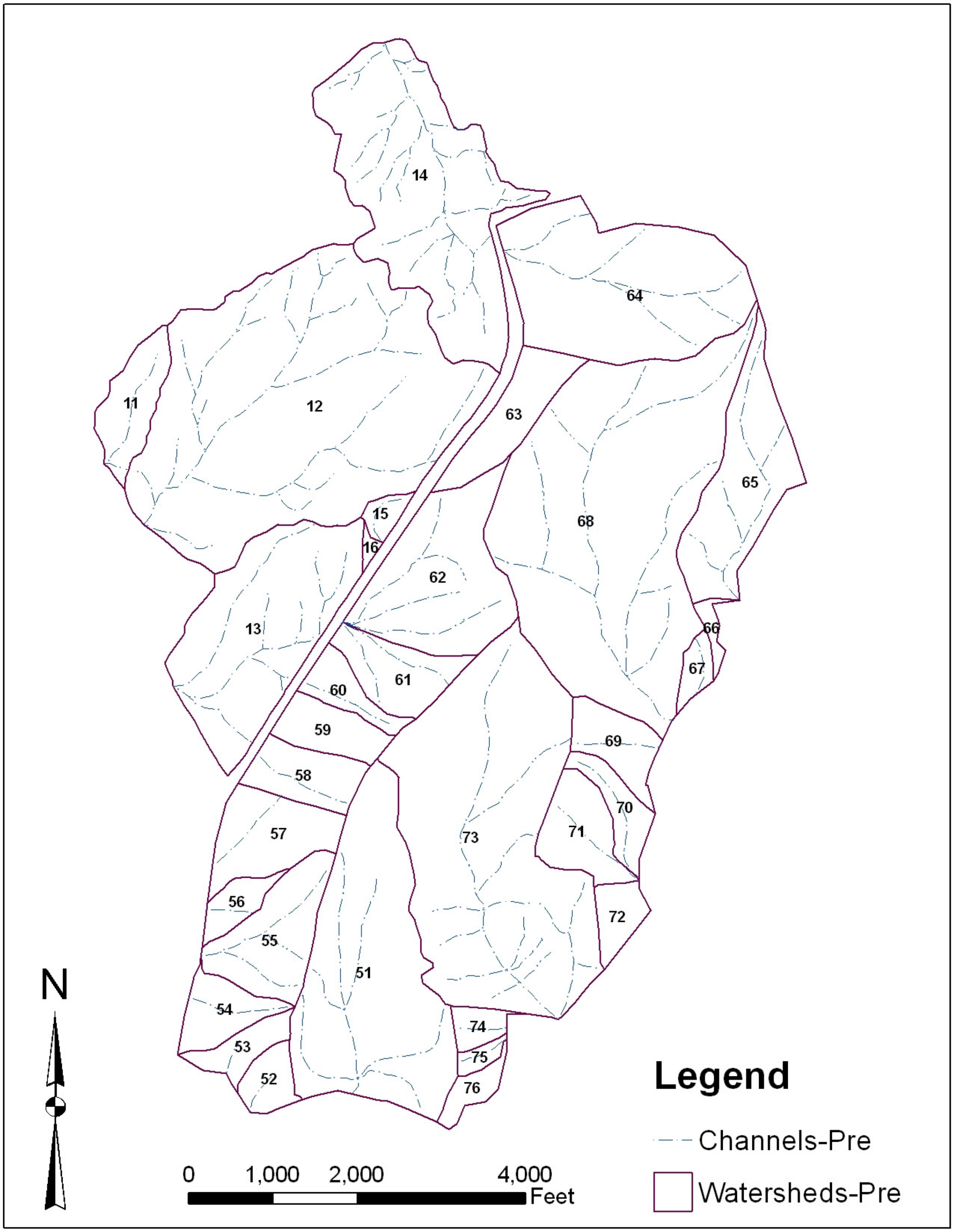

Figure 1.4. J1/N6 and N6 East Central premine basins.

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 CRA. **Table 1.4** shows pre- and postmine drainage area, runoff, and sediment yield for the J1/N6 and N6 East Central CRA. Runoff is defined as the total volume of water leaving the CRA 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. Similarly, the sediment yield is the amount of eroded material that leaves the CRA 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.

For the postmine condition, sediment yield is substantially less than the premine condition. Sediment yield is approximately one-third of the premine amount. Runoff is the same as the premine amount for the N6 East Central CRA, while runoff for postmine is much smaller than the premine amount for the J1/N6 CRA. The amount of hillslope runoff is virtually the same between pre- and postmine conditions and the difference between the runoff leaving the CRA is due to ponds and depressions storing water in the postmine condition. Hillslope and subwatershed erosion rates are lower for reclaimed (postmine) conditions due to more effective hydrologic cover and channel erosion control measures.

1.6 Discussion

Table 1.5 gives an overview of the geometric properties of the pre- and postmine topographies for the J1/N6 and N6 East Central CRA. The geometric properties for the postmine condition are similar to the premine condition.

Table 1.4. Average Runoff and Sediment Yield Results.					
Area	Condition	Drainage Area (ac)	Runoff (in)	Sediment Yield (t/ac/yr)	Erosion (t/ac/yr)
J1/N6	Premine	1024.8	0.42	3.79	1.74
J1/N6	Postmine	1039.7	0.22	1.32	1.22
N6 East Central	Premine	474.9	0.42	3.68	0.80
N6 East Central	Postmine	493.6	0.42	1.61	0.65
Combined	Premine	1499.7	0.42	3.76	1.44
Combined	Postmine	1533.3	0.28	1.41	1.03

Table 1.5. Average Physical Properties of the J1/N6 and N6 East Central CRA.		
	Premine	Postmine
Total Area (ac)	1499.7	1533.3
Total Channel Length (ft)	112,844	116,293
Mean Channel Slope	0.0563	0.0576
Drainage Density (mi/mi^2)	9.1	9.2
Mean Hillslope Length (ft)	269	320
Mean Hillslope Gradient	0.1171	0.1149

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, J1/N6 and N6 East Central'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 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 J1/N6 and N6 East Central'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 CRA 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.

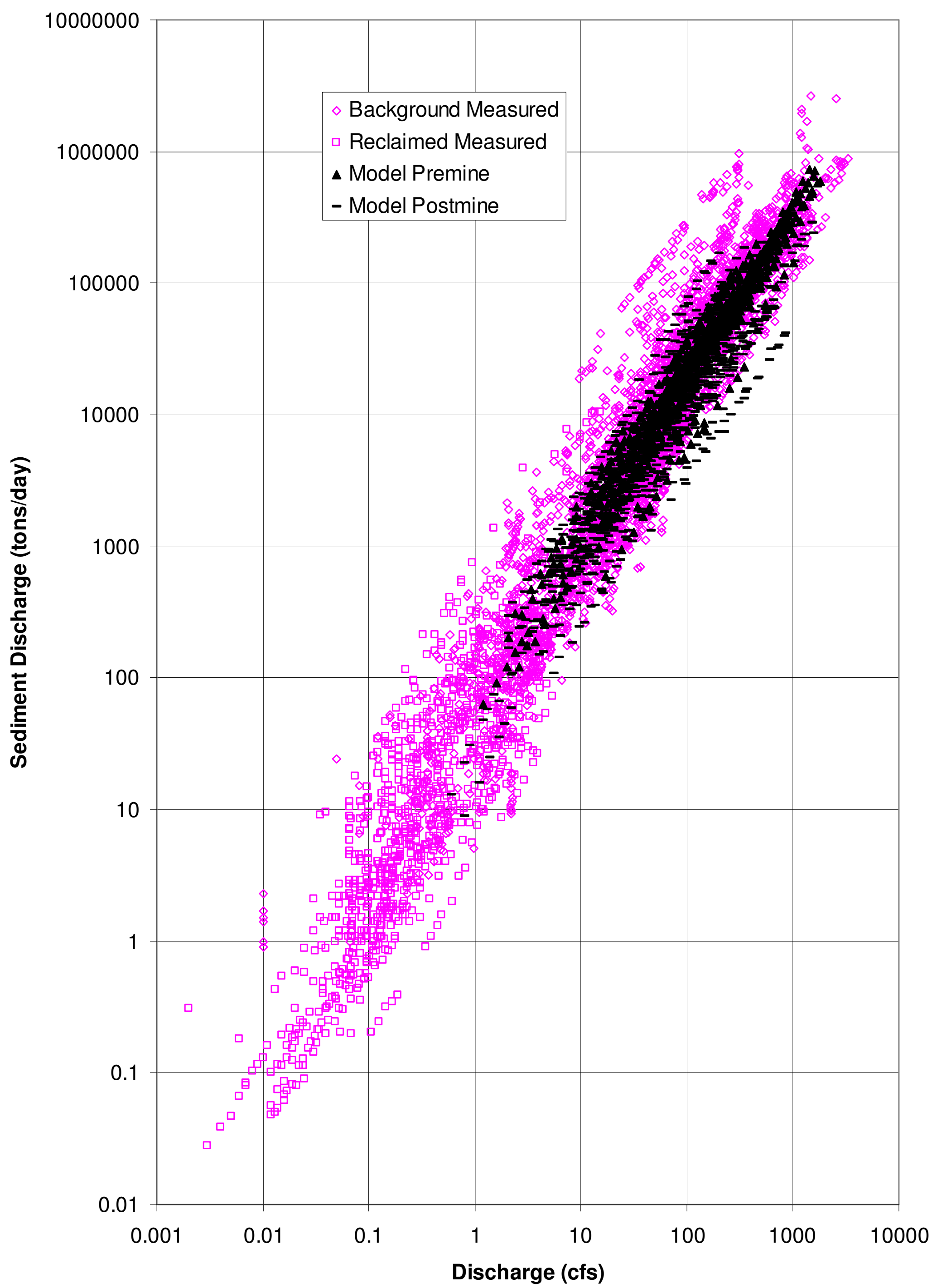

Figure 2.1. Observed and modeled sediment discharge and water discharge.

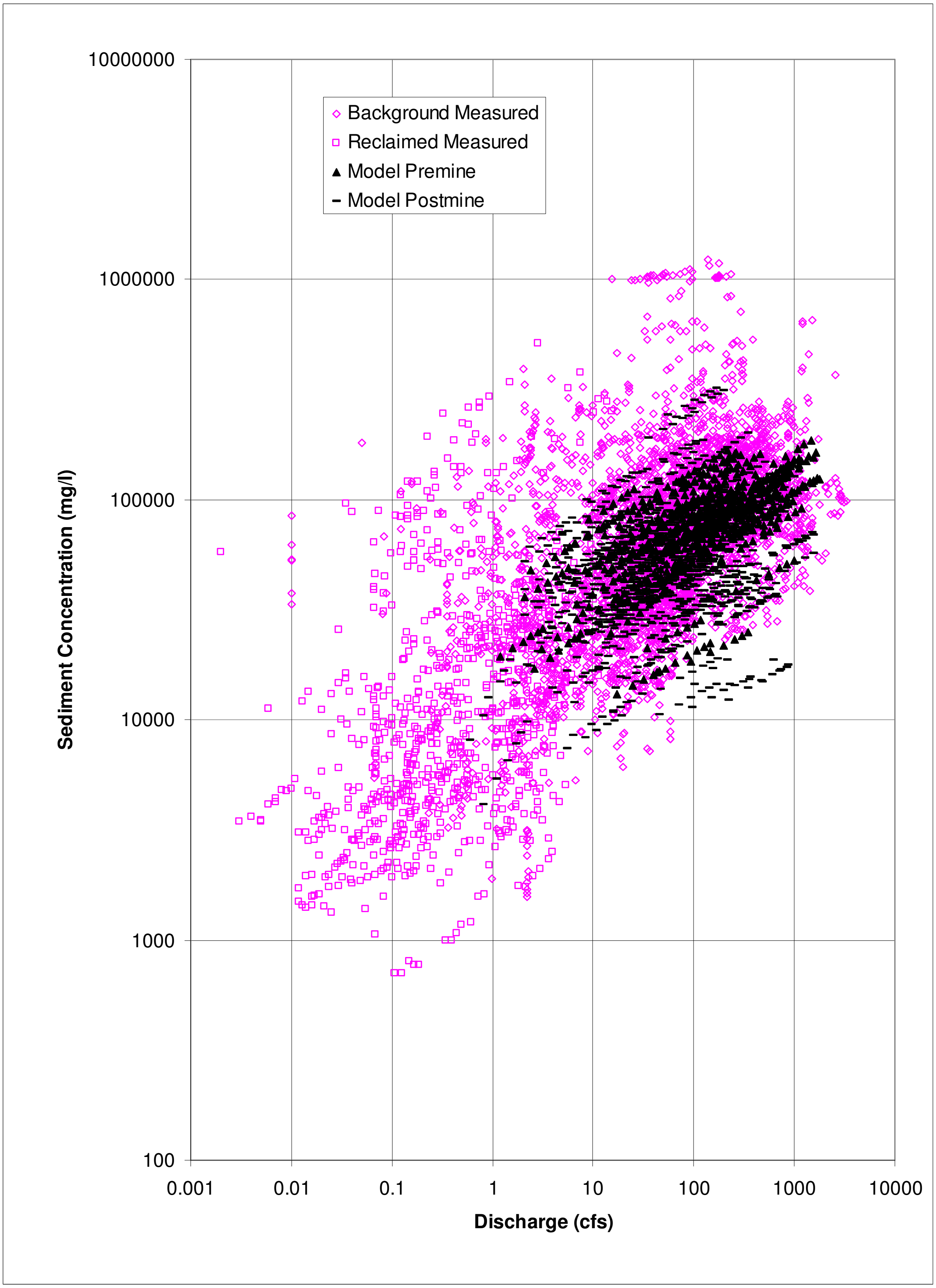

Figure 2.2. Observed versus modeled sediment concentration and discharge.

However, the sediment yield shown in Table 1.4 is the amount of sediment leaving the CRA whereas the sediment discharge shown in Figure 2.1 is the peak rate of sediment in transport occurring in any channel on the CRA, 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.

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 CRA, **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) also plot closely around the Sen line and well within bounds. 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 CRA 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 J1/N6 and N6 East Central CRA is not contributing additional suspended solids to receiving streams, and related impacts to the hydrologic balance have been minimized.

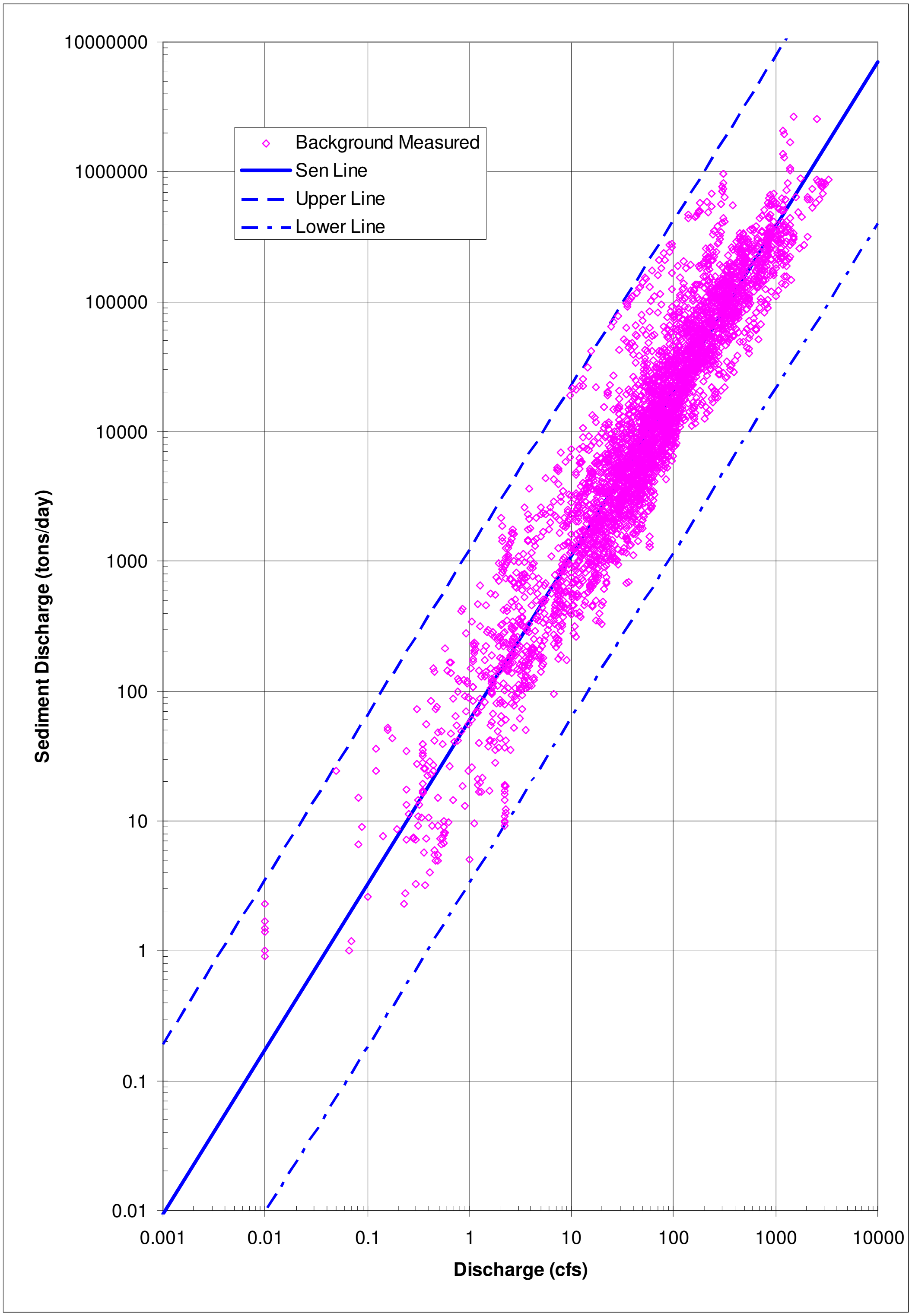

Figure 2.3. Background measured sediment and water discharge.

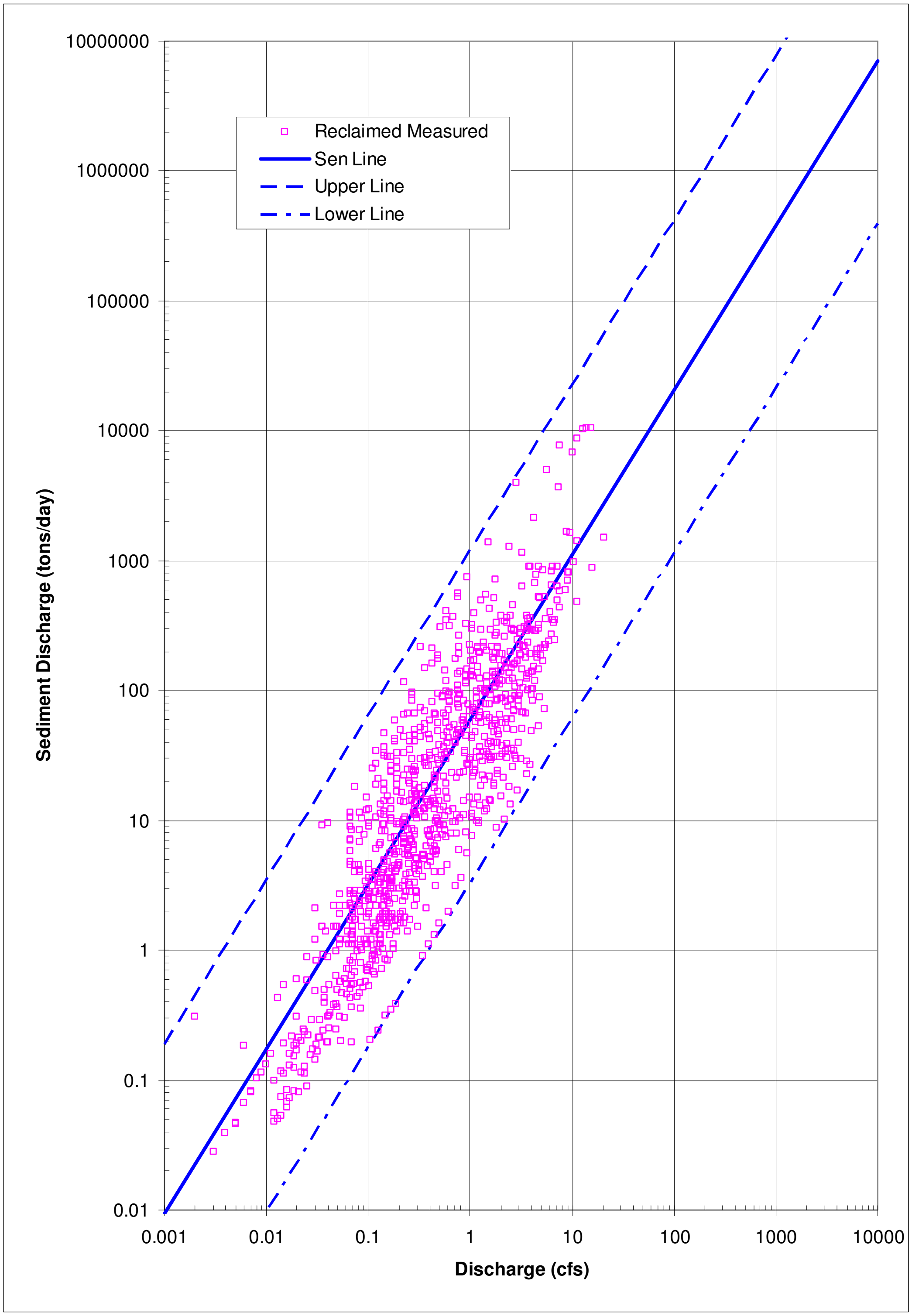

Figure 2.4. Reclaimed measured sediment and water discharge.

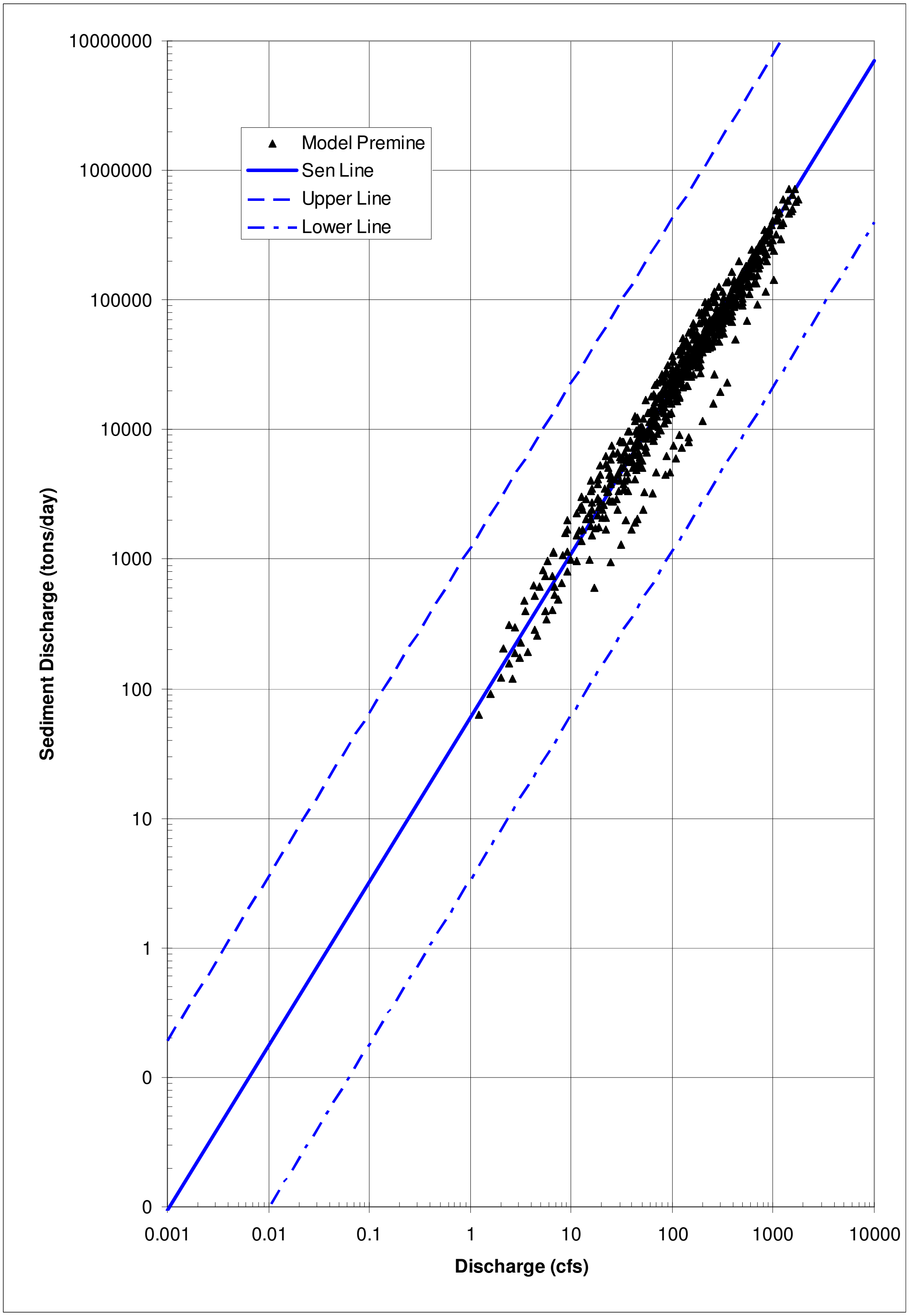

Figure 2.5. Modeled premine sediment and water discharge for J1/N6 and N6 East Central.

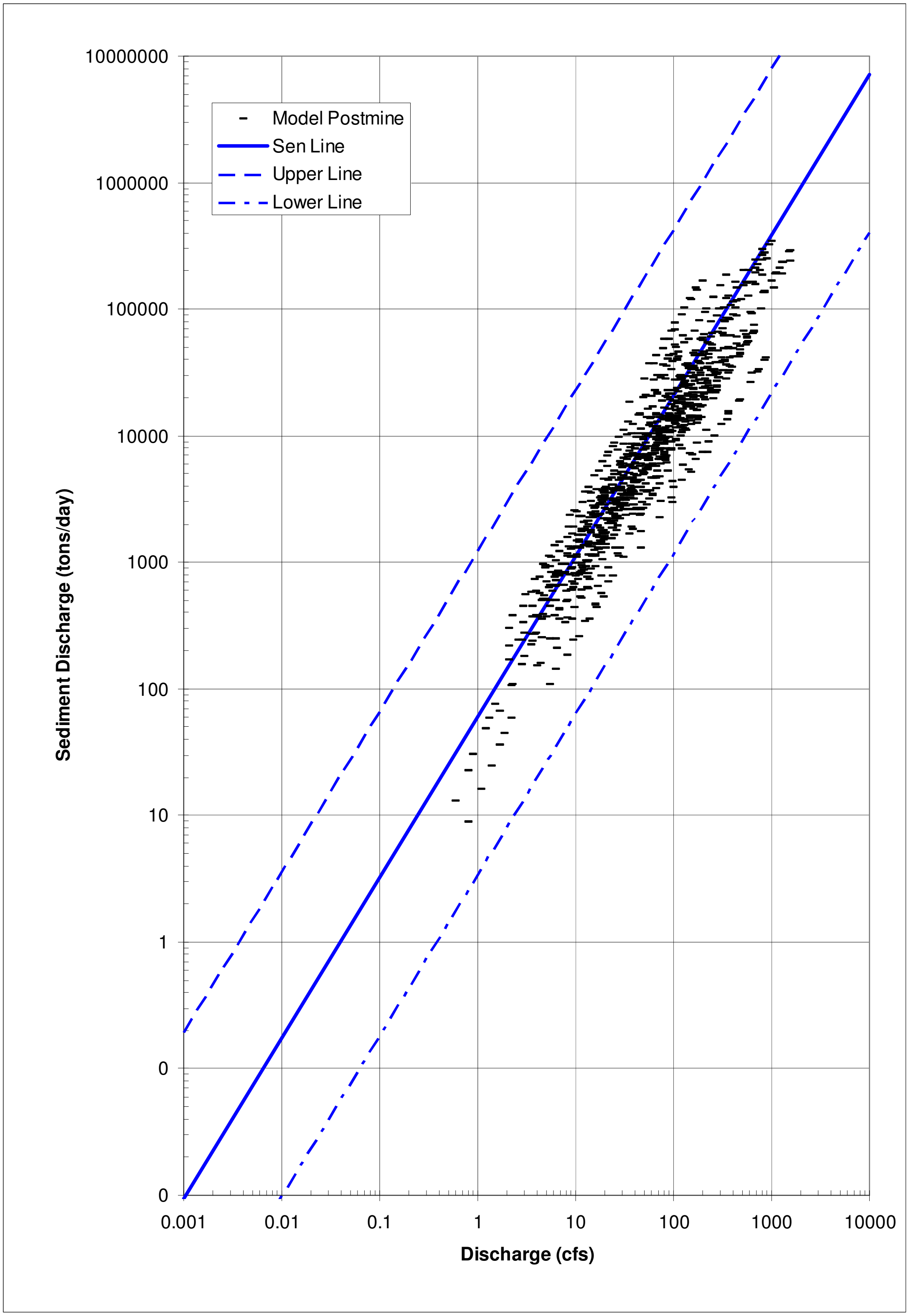

Figure 2.6. Modeled postmine sediment and water discharge for J1/N6 and N6 East Central.

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EXHIBIT 1
Postmine Topography

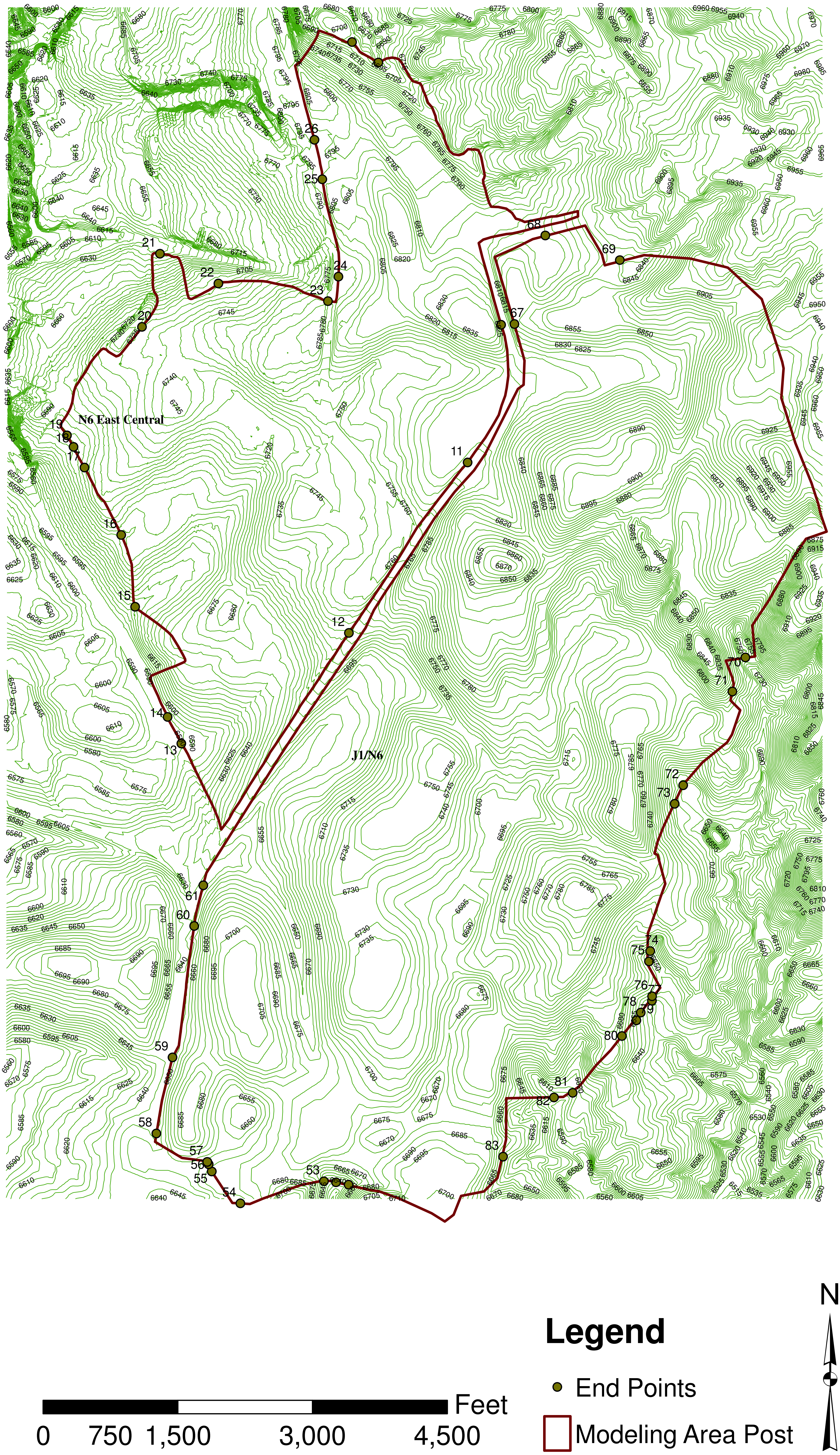

Exhibit 1. Postmine Topography
(5 foot contour)

EXHIBIT 2
Premine Topography

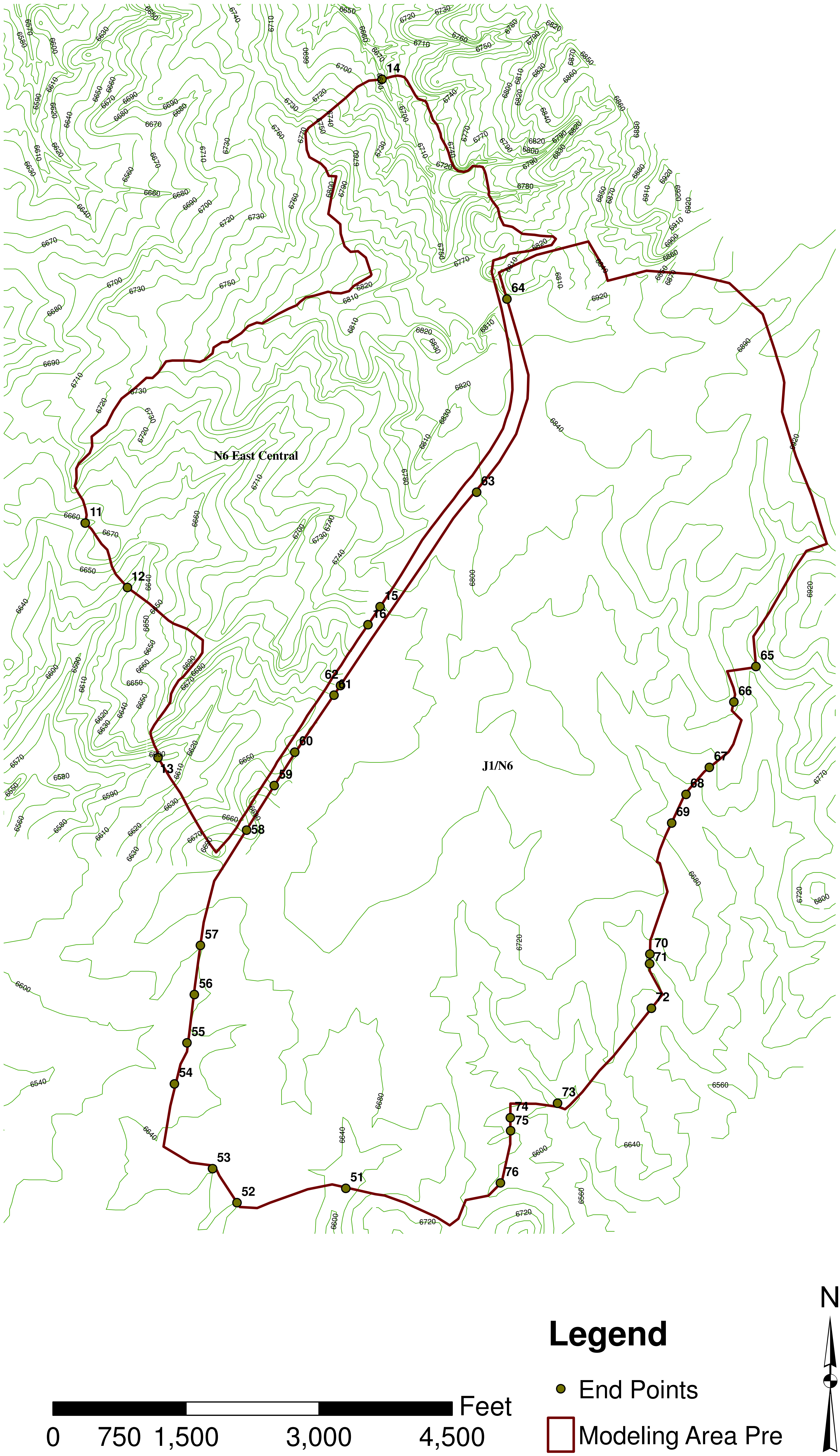

Exhibit 2. Premine Topography
(10 & 40 foot contour)

SURFACE WATER MODELING OF RECLAIMED PARCELS AT THE J19 COAL RESOURCE AREA, KAYENTA COMPLEX

Peabody Western Coal Company
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

SURFACE WATER MODELING OF RECLAIMED PARCELS AT THE J19 COAL RESOURCE AREA, KAYENTA COMPLEX

Peabody Western Coal Co.
Highway 160, Navajo Route 41
Kayenta, Arizona 86033

September 2011

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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 Kayenta Complex (previously identified as the Black Mesa and Kayenta Mines) to predict mean annual runoff and sediment yields from the reclaimed parcel J19. 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 J19 Coal Resource Area (CRA) at the Kayenta Complex that is the focus of this project was reclaimed between 1989 and 2010. This reclaimed area is now eligible for Phase II Bond Release from the Office of Surface Mining Reclamation and Enforcement (OSM). 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 reclamation 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, rock down drains, and where practicable, contour terraces. The natural watersheds on Black 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 J19 CRA. 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 CRA were modeled using EASI. Results were determined for concentration points at the outlets of the reclaimed watersheds. 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 J19 premining watersheds.

1.3 Data

1.3.1 Soils

Soils data used for the current study (CRA J19) 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 CRA J19 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 CRA J19.

1.3.2 Vegetation

Vegetative cover data representative of both pre- and postmine conditions in CRA J19 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 J19 CRA premine condition appears in **Figure 1.2**. Average cover properties for CRAs N1/N2 and J27 of the previous study and CRA J19 of the current study appear in **Table 1.2**. 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 J19 CRA. 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 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 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.

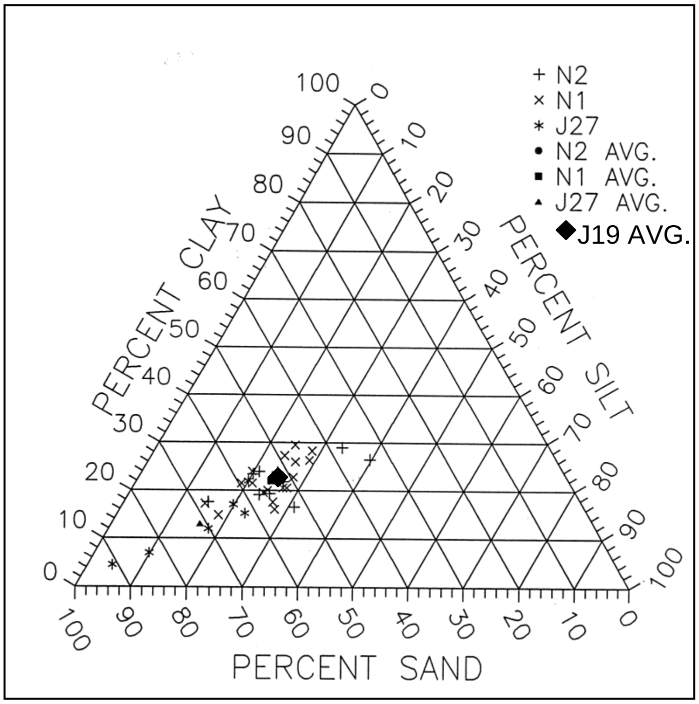

Figure 1.1. Reclaimed Area Soils Trilinear Graph.

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	

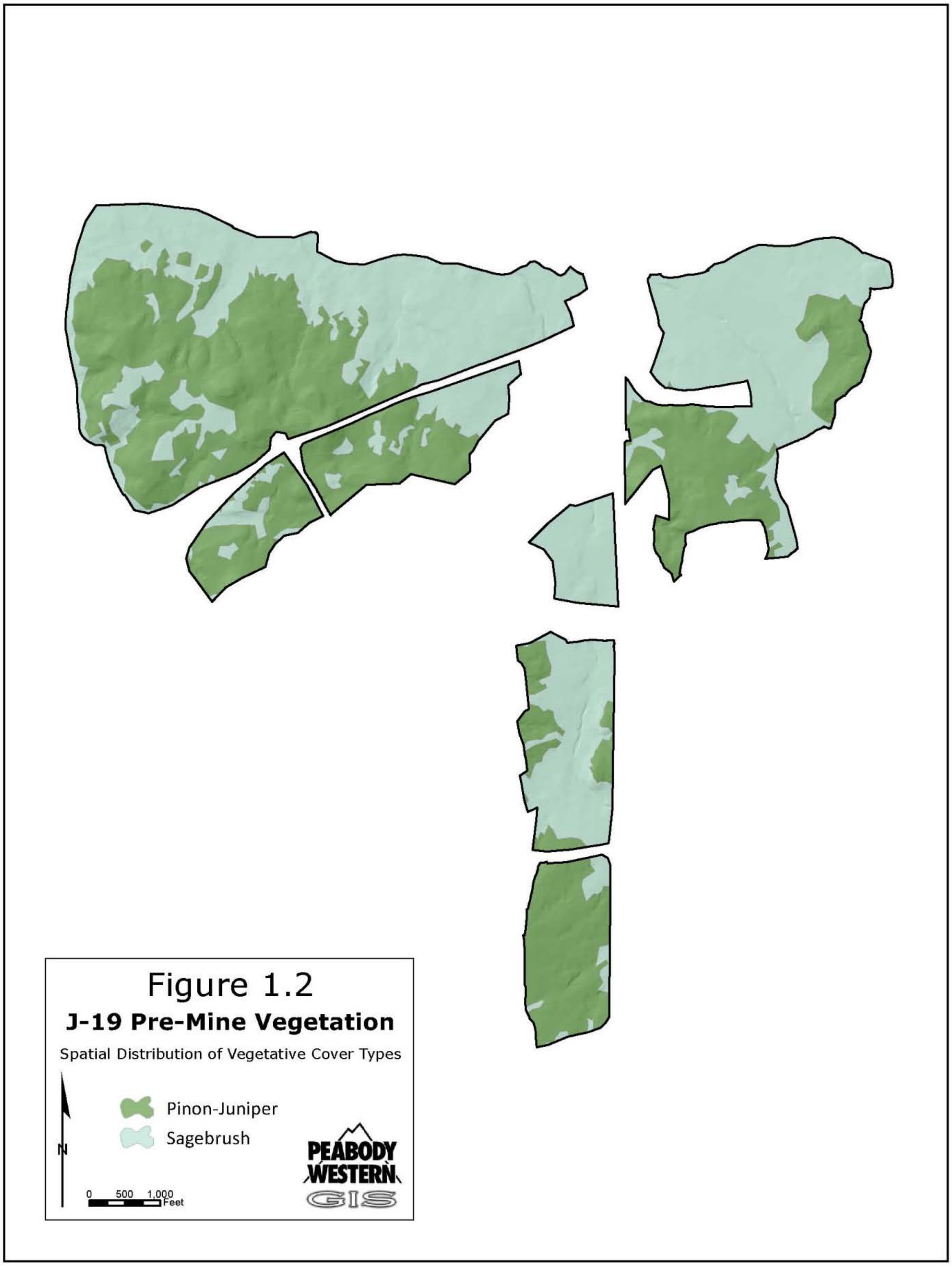

Figure 1.2. Spatial Distribution of Vegetative Cover Types for J19 Pre-Mine Condition.

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
J19	Postmine	Postmine	28.8	0.2	31.3	17.9	6.6	55.8
N1/N2/J27	Premine	Pinon Juniper	32.7	31.1	3.0	44.0	19.7	66.7
J19	Premine	Pinon Juniper	19.1	17.0	2.5	28.8	16.7	48.0
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
J19	Premine	Sagebrush	16.7	3.8	13.4	30.6	1.7	45.7
*Including standing dead litter								

Table 1.3. Cover Data for J19.				
Condition	Pinon Juniper	Sagebrush	Half Pinon Juniper-Half Sagebrush	Postmine
Canopy cover, %	17.0	3.8	10.4	0.2
Ground cover, %	48.0	45.7	46.9	55.8
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 Kayenta 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 Kayenta 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 CRA J19 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 J19 CRA dictated that some areas would be included or excluded from the modeling. The total area modeled for premine conditions is 943.4 acres (Exhibit 2) and for postmine conditions is 943.4 acres (Exhibit 1).

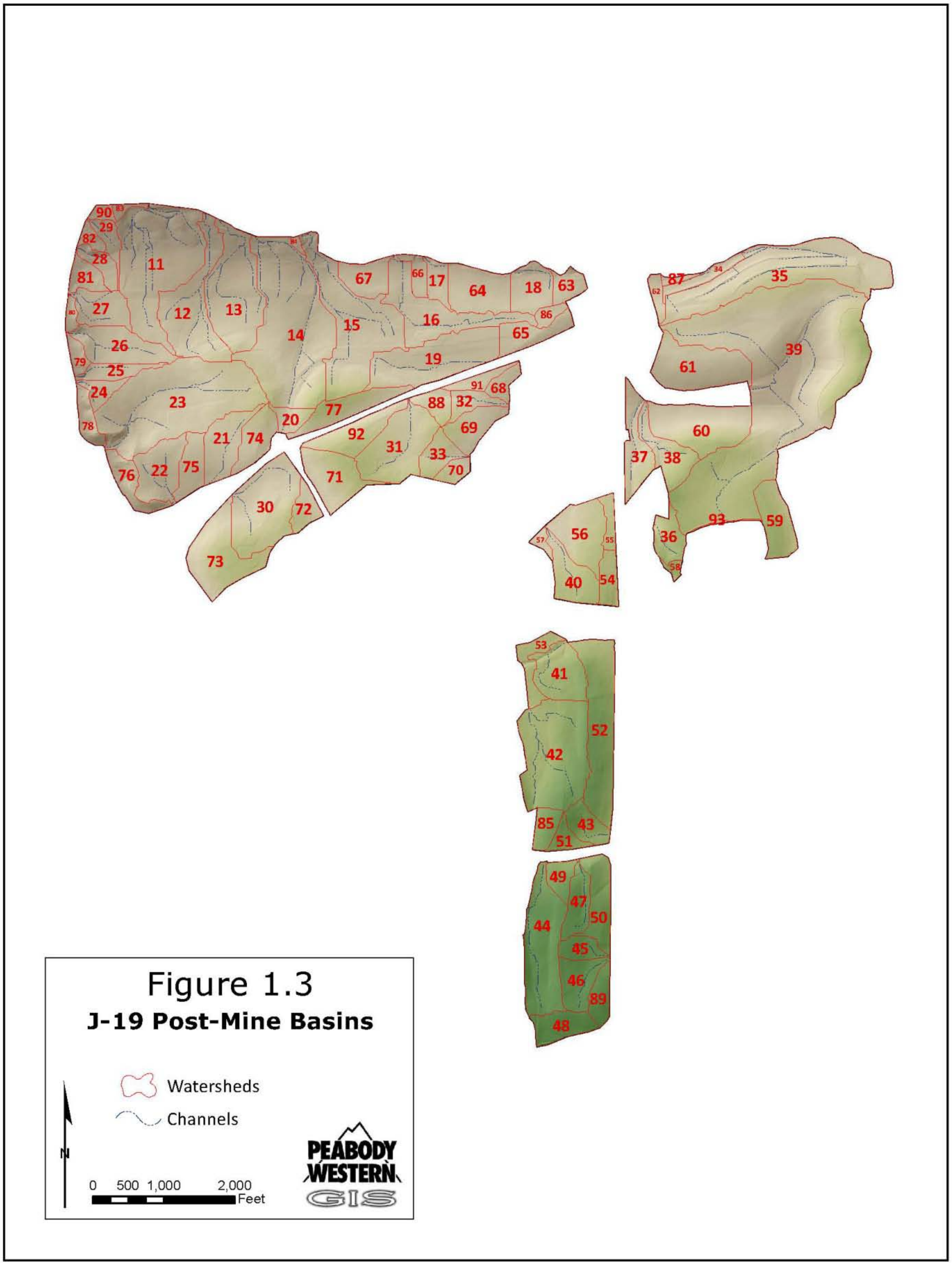

Figure 1.3. J19 Post-Mine Basins.

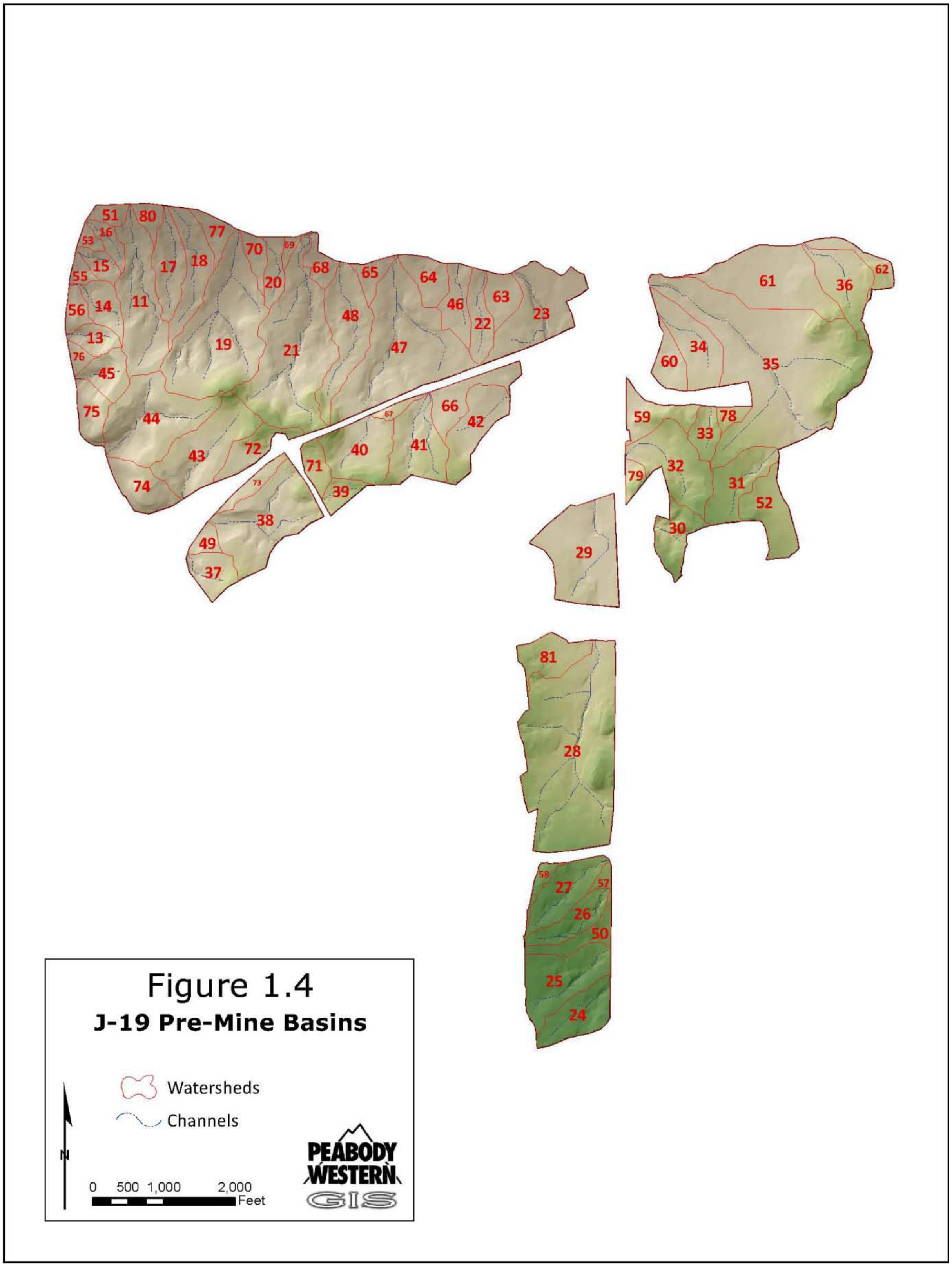

Figure 1.4. J19 Pre-Mine Basins.

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 CRA. **Table 1.4** shows pre- and postmine drainage area, runoff, sediment yield, and erosion for the J19 CRA. Runoff is defined as the total volume of water leaving the CRA 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 CRA on an average annual basis computed using the equation of Lagasse et al. (1985). The sediment yield is the production from the hillslope and subwatershed 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.

For the postmine condition, sediment yield is substantially less than the premine condition. Postmining sediment yield is approximately 71% of the premine amount. Runoff is the same as the premine amount for the J19 CRA. Hillslope and subwatershed erosion rates are about 9% higher for the reclaimed (postmine) condition than the premine condition. However, the erosion rates are comparable between both conditions, and remain below 1.0 tons/acre/year. The reduction of sediment yield is due to effective hydrologic cover combined with effective channel erosion control measures in the postmining landscape.

1.6 Discussion

Table 1.5 gives an overview of the geometric properties of the pre- and postmine topographies for the J19 CRA. Postmine hillslopes are generally about 15% shorter and 7% steeper than premine hillslopes, postmine channels are slightly less steep than premine channels, and the drainage density of the postmine condition is about 13% greater than that of the premine condition. These properties agree with the postmine versus premine topography: the premine topography is fully dissected.

Table 1.4. Average Runoff and Sediment Yield Results.					
Area	Condition	Drainage Area (ac)	Runoff (in)	Sediment Yield (t/ac/yr)	Erosion (t/ac/yr)
J19	Premine	943.4	0.42	3.13	0.75
J19	Postmine	943.4	0.42	2.22	0.82

Table 1.5. Average Physical Properties of the J19 CRA.		
	Premine	Postmine
Total Area (ac)	943.4	943.4
Total Channel Length (ft)	70,077	79,298
Mean Channel Slope	0.0662	0.0653
Drainage Density (mi/mi^2)	9.0	10.2
Mean Hillslope Length (ft)	243	206
Mean Hillslope Gradient	0.1115	0.1197

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 (J19 premine) and modeled reclaimed (J19 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 the J19 CRA 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 between 10 and 100 cfs and between 10,000 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 CRA 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**.

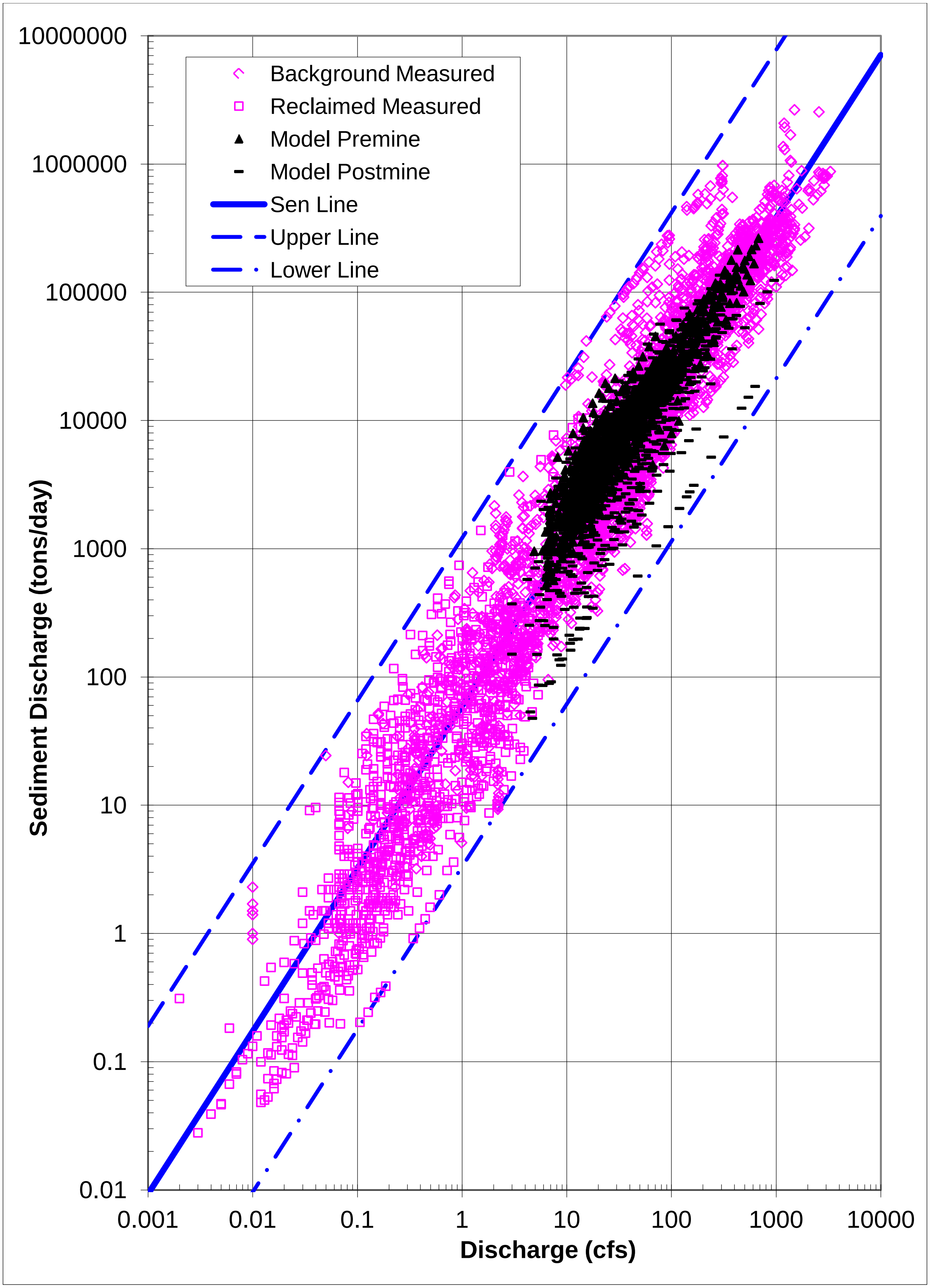

Figure 2.1. Observed and Modeled Sediment Discharge and Water Discharge.

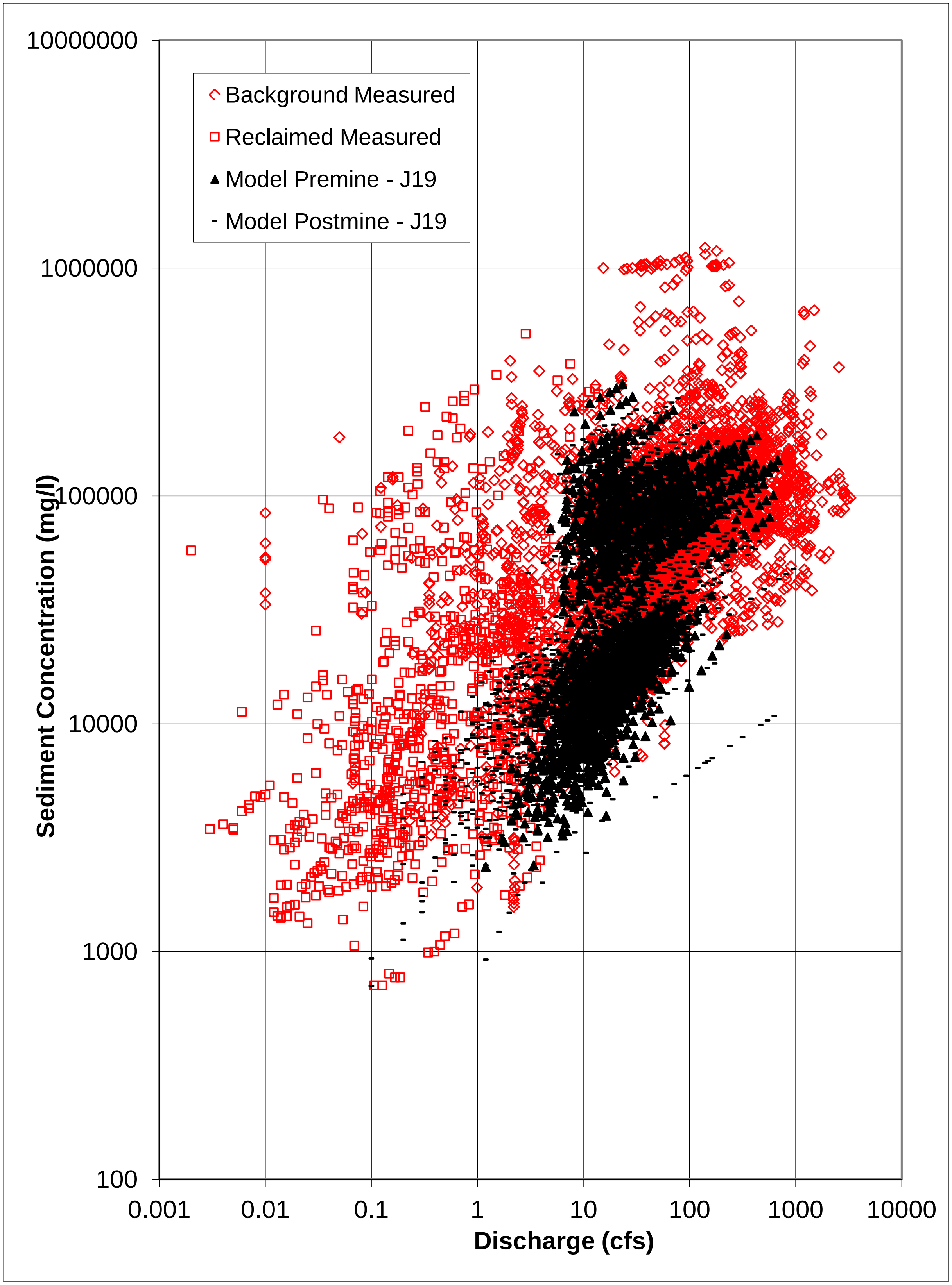

Figure 2.2. Observed versus Modeled Sediment Concentration and Discharge.

However, the sediment yield shown in **Table 1.4** is the amount of sediment leaving the CRA whereas the sediment discharge shown in **Figure 2.1** is the peak rate of sediment in transport occurring in any channel on the CRA, 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 J19 CRA, **Figures 2.5 and 2.6** show the pre- and postmine computed sediment transport rates with the Sen lines and bounds, respectively. 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**) 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 CRA 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 J19 CRA is not contributing additional suspended solids to receiving streams, and related impacts to the hydrologic balance have been minimized.

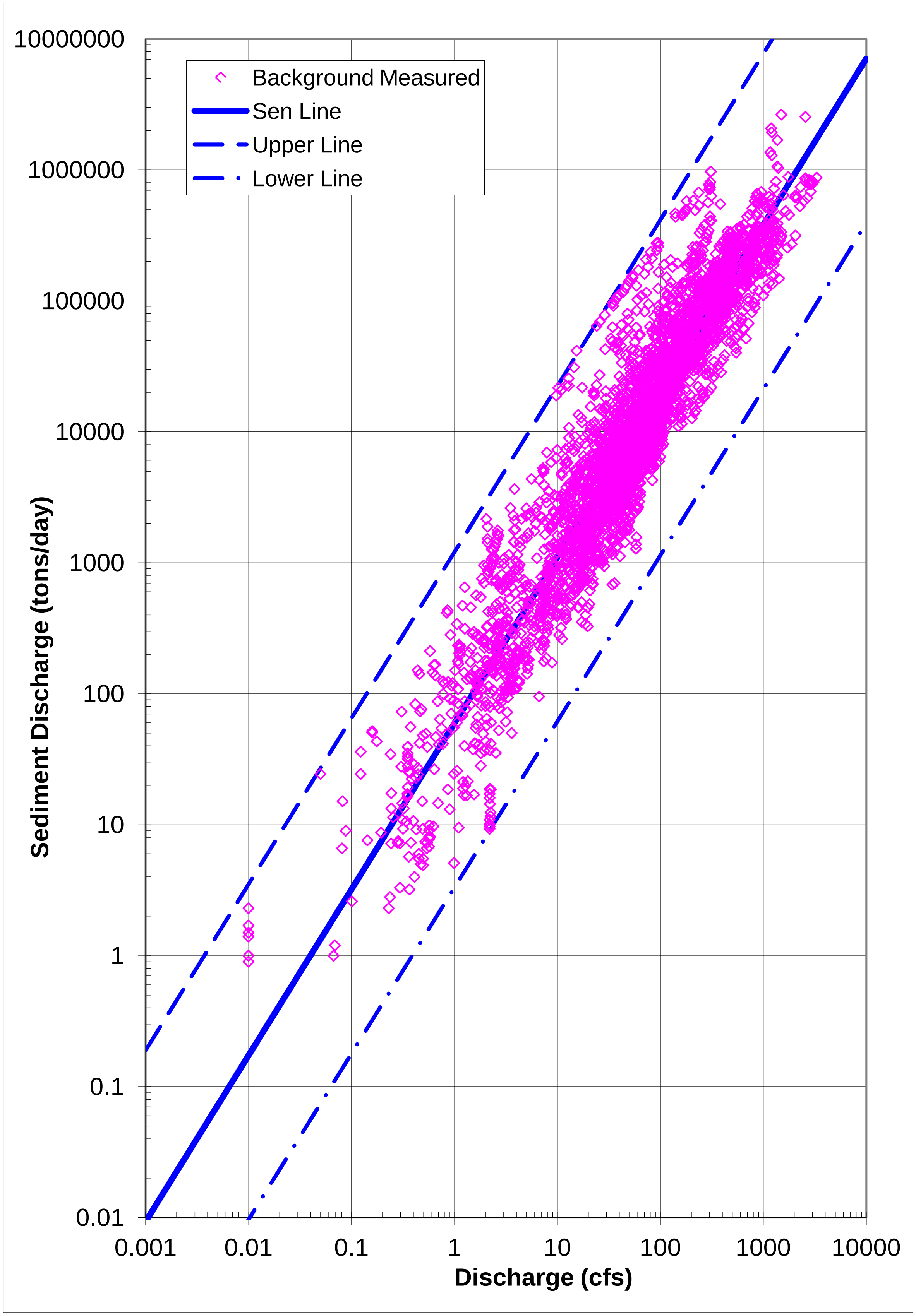

Figure 2.3. Background Measured Sediment and Water Discharge.

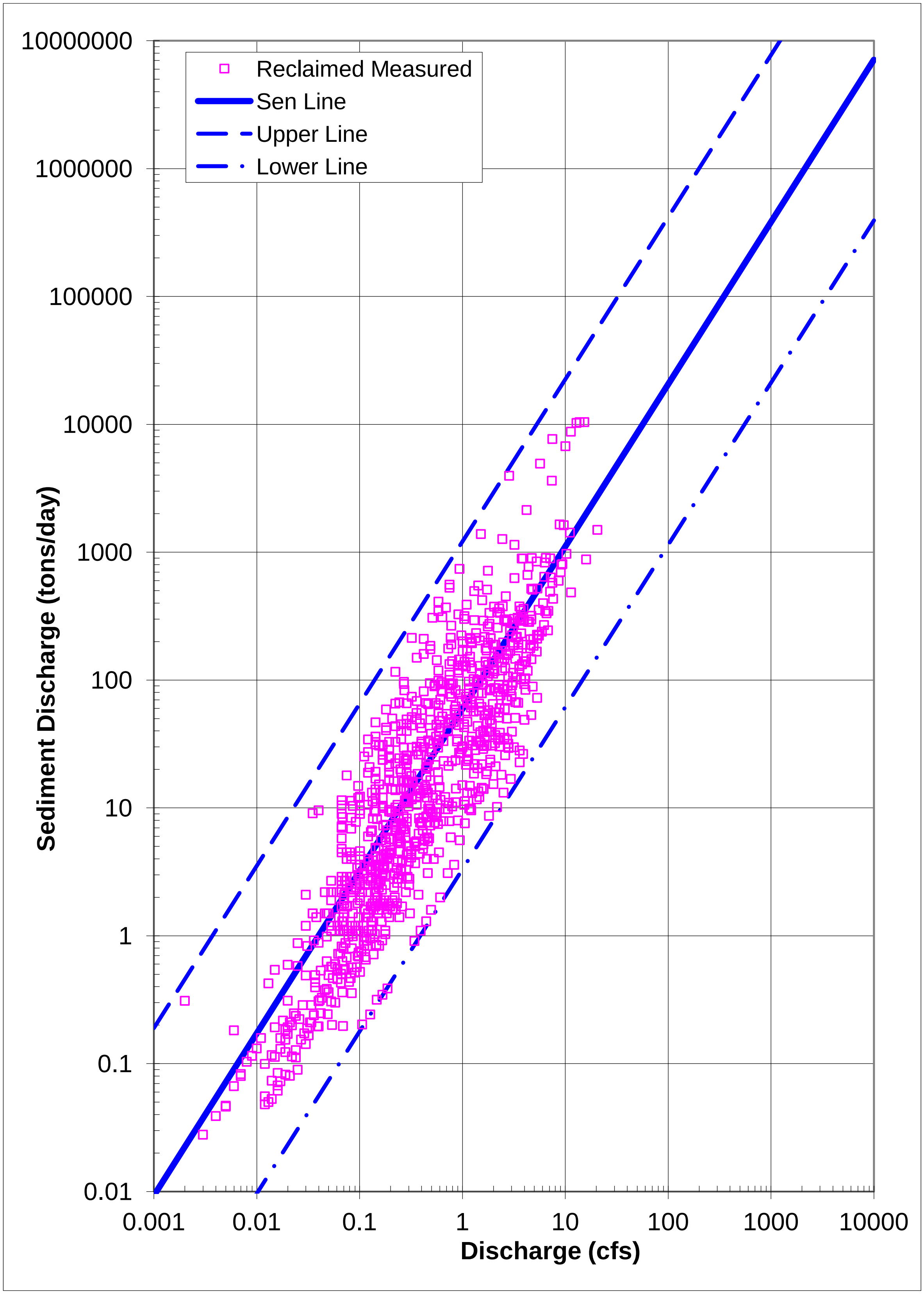

Figure 2.4. Reclaimed Measured Sediment and Water Discharge.

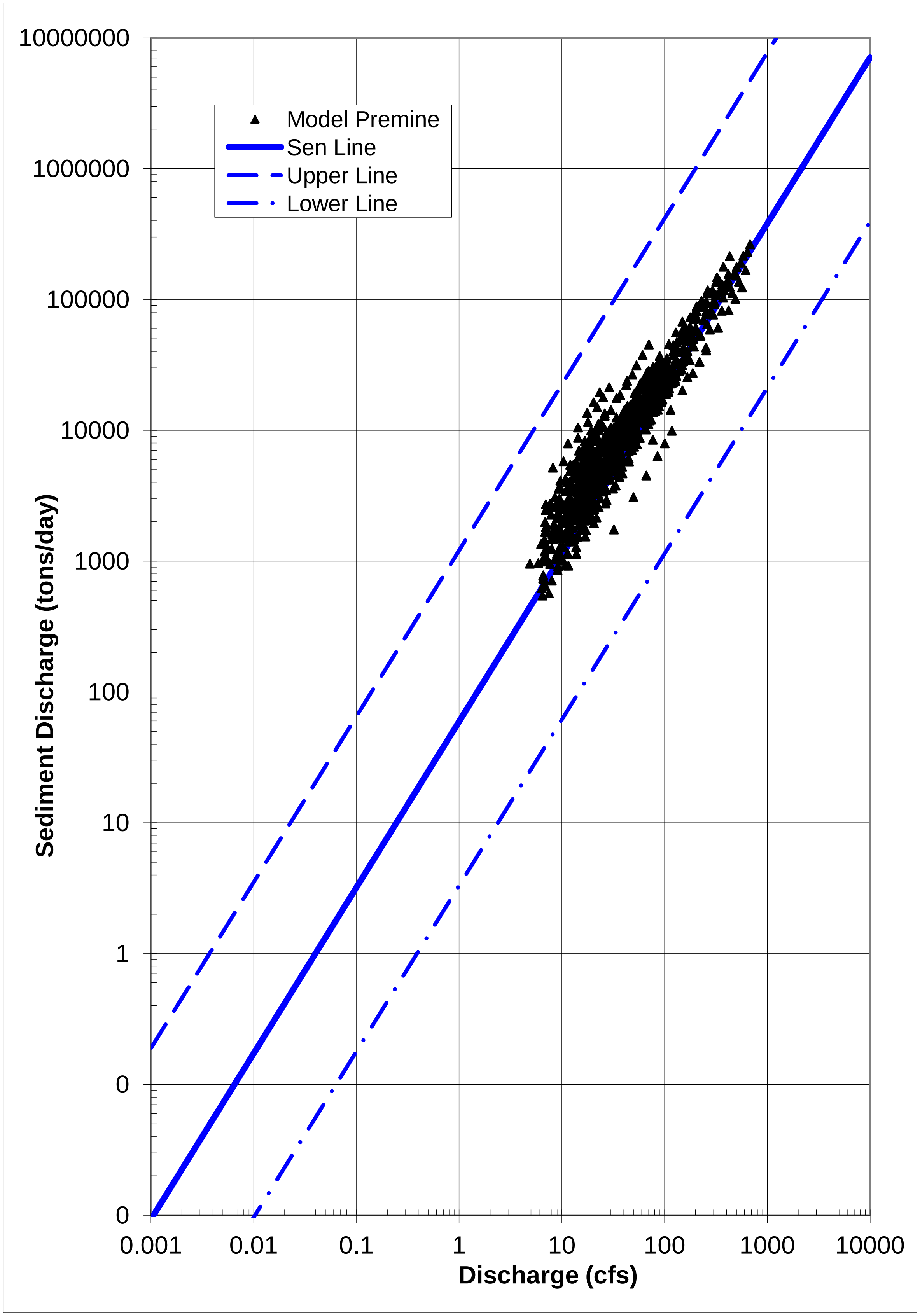

Figure 2.5. Modeled Pre-Mine Sediment and Water Discharge for J19.

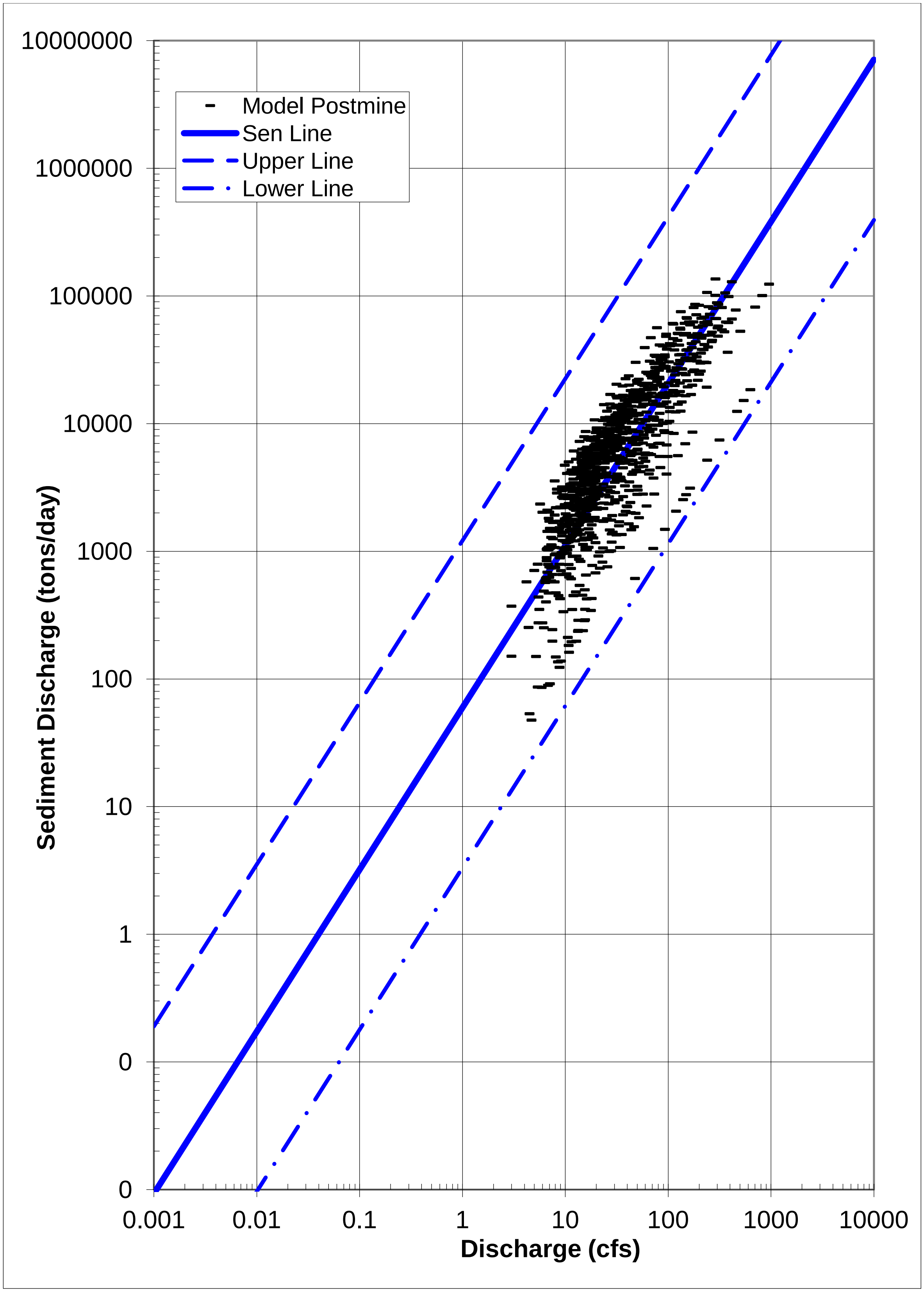

Figure 2.6. Modeled Post-Mine Sediment and Water Discharge for J19.

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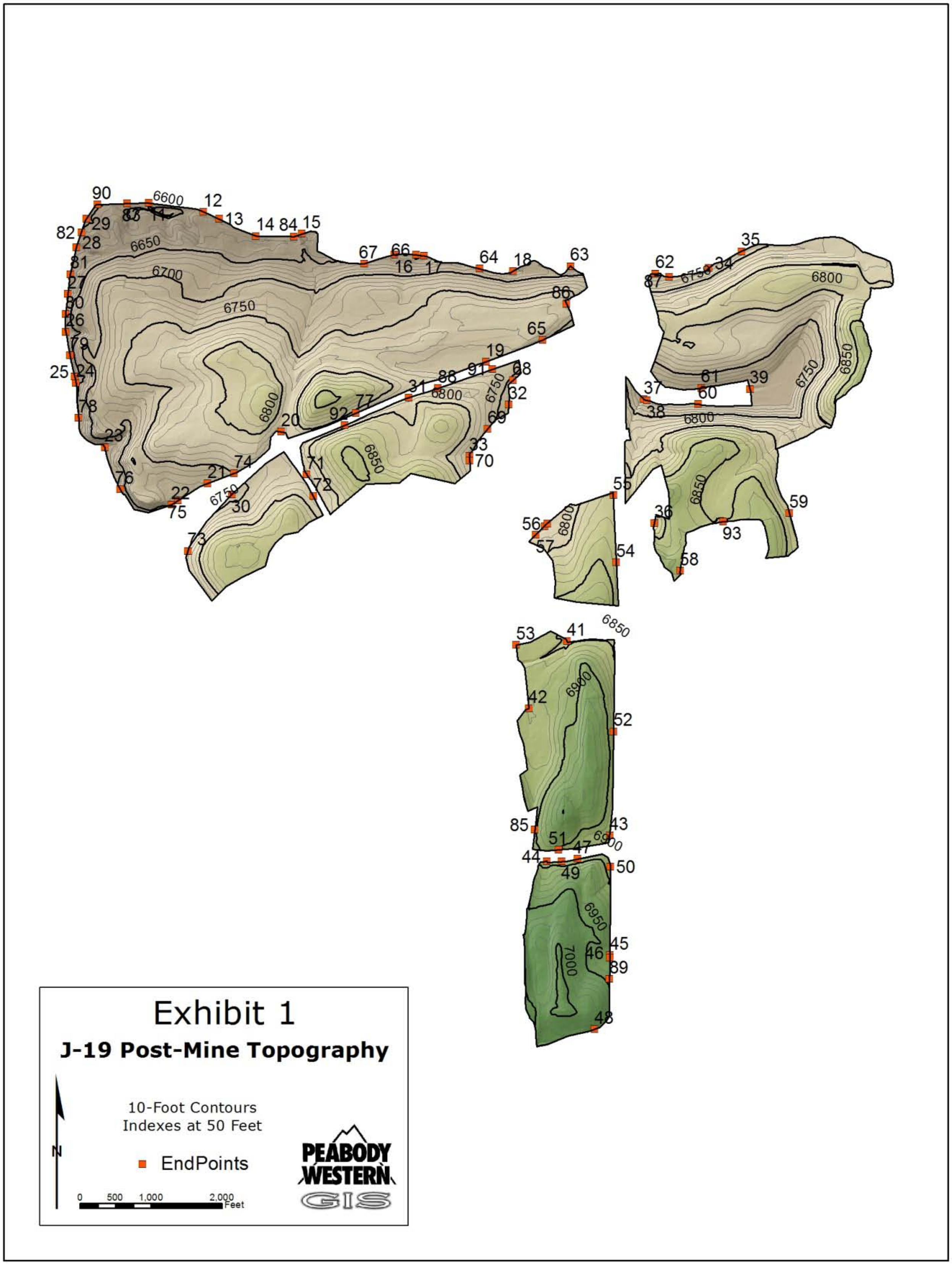
Exhibit 1
J-19 Post-Mine Topography
10-Foot Contours
Indexes at 50 Feet
EndPoints
0 500 1,000 2,000
Feet
PEABODY WESTERN
GIS

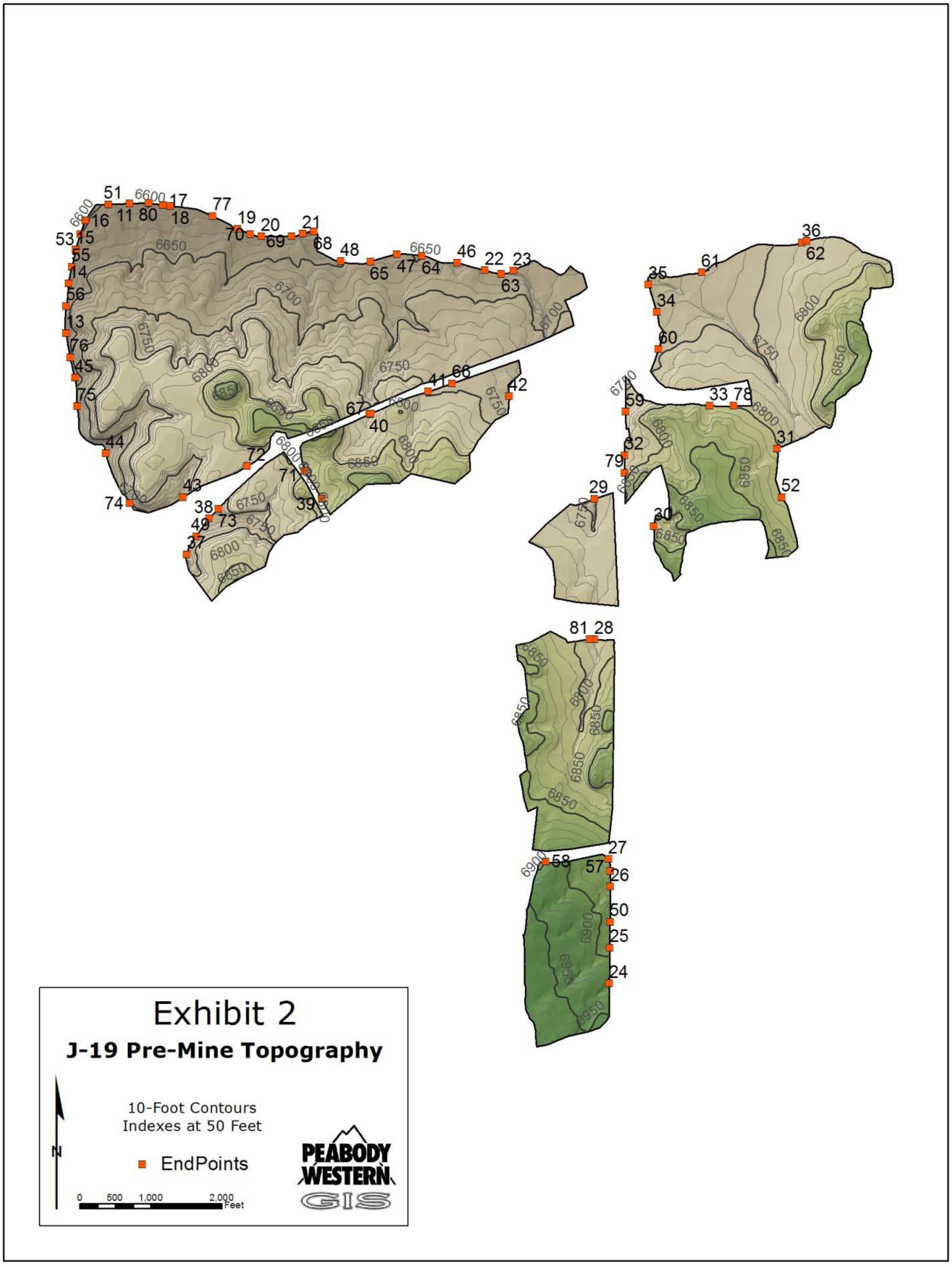
Exhibit 2
J-19 Pre-Mine Topography
10-Foot Contours
Indexes at 50 Feet
EndPoints
N
0 500 1,000 2,000
Feet
PEABODY WESTERN
GIS