headward or downstream into the reclaimed reach is considered to be within the natural evolution of drainage basins and stream channels. Initiation of headcuts, knickzones, or deposition **within** the reclaimed channel reach, however, would be indicative of an instability, or a design failure.

Undisturbed areas adjacent to mined lands provide natural analogs of pre-disturbance conditions, or stable channels. Given the absence of premining baseline information at AML sites, and the limited time of exposure of reclaimed channels at active mines, it is generally accepted that stable, natural channels should be used as analogs for designing reclaimed channels (Stiller et al., 1980; Bishop, 1981; Wells and Potter, 1986; Lidstone and Anderson, 1989; Erion, 1991; Waldo, 1991).

2.0 METHODS

Research methods to evaluate long-term, ephemeral channel stability utilized two data sources; 1) an inventory of existing information on channel reclamation design from reports and plans in the AML library, and 2) field-derived measurements consisting of geomorphic parameters of unmined ephemeral channels in natural analog sites adjacent to mined lands. Regression analyses and statistical evaluation were used to develop a risk-based stability test to serve as a channel design and a regulatory evaluation tool. In this way, reclaimed channel designs can be quantitatively compared to adjacent, stable unmined areas.

2.1 Inventory

Mined lands disrupted prior to the 1977 enactment of the Surface Mine Reclamation Control Act qualify for AML reclamation funding and oversight. Under the guidance of Wyoming's AML program, approximately 125 abandoned coal mine sites have been reclaimed. Of these 125 sites, 14 entailed channel reclamation and engineering design of earthen channels (Table 1).

A review of consultant's reports, engineering design plans, construction as-builts, and AML site files for the 14 AML sites with channel restoration was completed. Information was readily available in the AML library, Herschler Building, Cheyenne, Wyoming, and from the AML archives. Compiled data included channel design criteria, specific channel and basin characteristics, and final design features of top soil depths and surface amendments. Information from sites reviewed during the inventory are tabulated in Appendix A (Table A-1 through A-4).

The inventory was further embellished by adding information that was easily measured from topographic maps and design plans, or calculated using Manning's equation. As an example, where channel geometry was not fully reported, Manning's equation was used to calculate the missing parameters, based on available information. These calculations helped verify reported channel design hydraulics. In addition, drainage basin information was estimated, where possible, using topographic maps and design plans (e.g. mean basin slope).

2.2 Study Area

Results of the inventory indicated that AML projects 6C-2 and 6C-8, the Rainbow and Colony mine sites, south of Rock Springs, are the only reclamation sites with a complete suite

Table 1. Abandoned Coal Mine Land Projects With Channel Reclamation

Project	County	Reclamation Work/Comment	Owner	Certified Complete
6C-2 Rainbow Mine	Sweetwater	Large site, abundant channel reclamation, rolling mature topography	Sweetwater, Upland Resources, BLM	1991
6C-4 College Hill	Sweetwater	Deeply incised drainage with bedrock grade control, joins Bitter Creek	Jessica Longston	1991
6C-8 Colony Coal Co.	Sweetwater	Abundant, variable topography; anomalously stable due to lack of vegetation	Upland Resources, W.R. Grace & Co.	Under project 17B
7B-1 Elk Mtn. area	Carbon	Abundant large drainages, impoundments, steep slopes	Edison Corp.	1991, with continued transect monitoring
7-26	Carbon	Impoundment with riprapped spillway, designed channel pattern	BLM	1991, with continued transect monitoring
7-28 Toilet Bowl	Carbon	Underground mine with surface drainage work, rock gallery	Union Pacific Railroad	1988
8-8	Johnson	Large gully reclaimed with riprap	Collins Ranch, Inc	1991
8-13 Mine Fire Site	Sheridan	Large drainage, gentle slope, riprap used	Big Horn Coal	Certification pending
8-19 Hidden Waters	Sheridan	Surface drainage work	Padlock Ranch et al.	Transect monitoring continued
8-23 Hidden Waters	Sheridan	Reclaimed drainage washed out, migrating under boundary fence	Annakersten Randall	Remediation pending
8-24	Sheridan	Underground mine with surface drainage work, subsided drainage reclaimed	United Mine Workers	Certification pending
9B-15	Fremont	Underground mine with surface drainage work	BLM	1989
15A-22 Kaycee Site	Sheridan	Reestablished northward drainage; recent minor settling below highwall	William Welch	Certification pending
15A-24 Pugsley Mine	Johnson	Small 5-acre site, minor drainage work	Winter Gardens Prod. Credit Assoc	Certification pending

(modified from Appendix C, AML 1990 Reclamation Monitoring Summary) of design information (Table A-1 - A-4). Our research into channel stability has thus focused on this area near Rock Springs, encompassing the Rainbow and Colony mines which were recently reclaimed by AML (Table 1). In addition, Hanna was chosen as a test site to apply the stability analysis developed using the Rock Springs unmined and reclaimed channel data. Abundant active mining continues in the Hanna area, and one abandoned mine site (AML 7-26) has been reclaimed in the vicinity of Hanna, although complete design information is lacking. Figure 1 illustrates the selected study locations.

2.2.1 Rock Springs

In general, the Rock Springs study area occupies a semi-arid climatic zone where ephemeral streams dissect horizontally-bedded sedimentary rocks, forming buttes with variable, steep topographic relief. Elevation of the area ranges between approximately 6,500 and 6,700 feet above mean sea level. Precipitation in Rock Springs ranges between 7 and 9 inches per year, a majority of it falling in spring and early summer. Most streams flow only in response to precipitation events. Grasses and woody vegetation (sagebrush, rabbitbrush) provide the most common types of ground cover in the area. Near surface geology of the Rock Springs study site is the Cretaceous-age Mesa Verde formation, a heterogeneous unit comprised of sandstone interbedded with shale, siltstone and coal lenses.

2.2.2 Hanna

The Hanna study area lies within an intermontane structural basin. The elevated flanks of the basin receive approximately 12-16 inches of yearly precipitation (Richter, 1981).

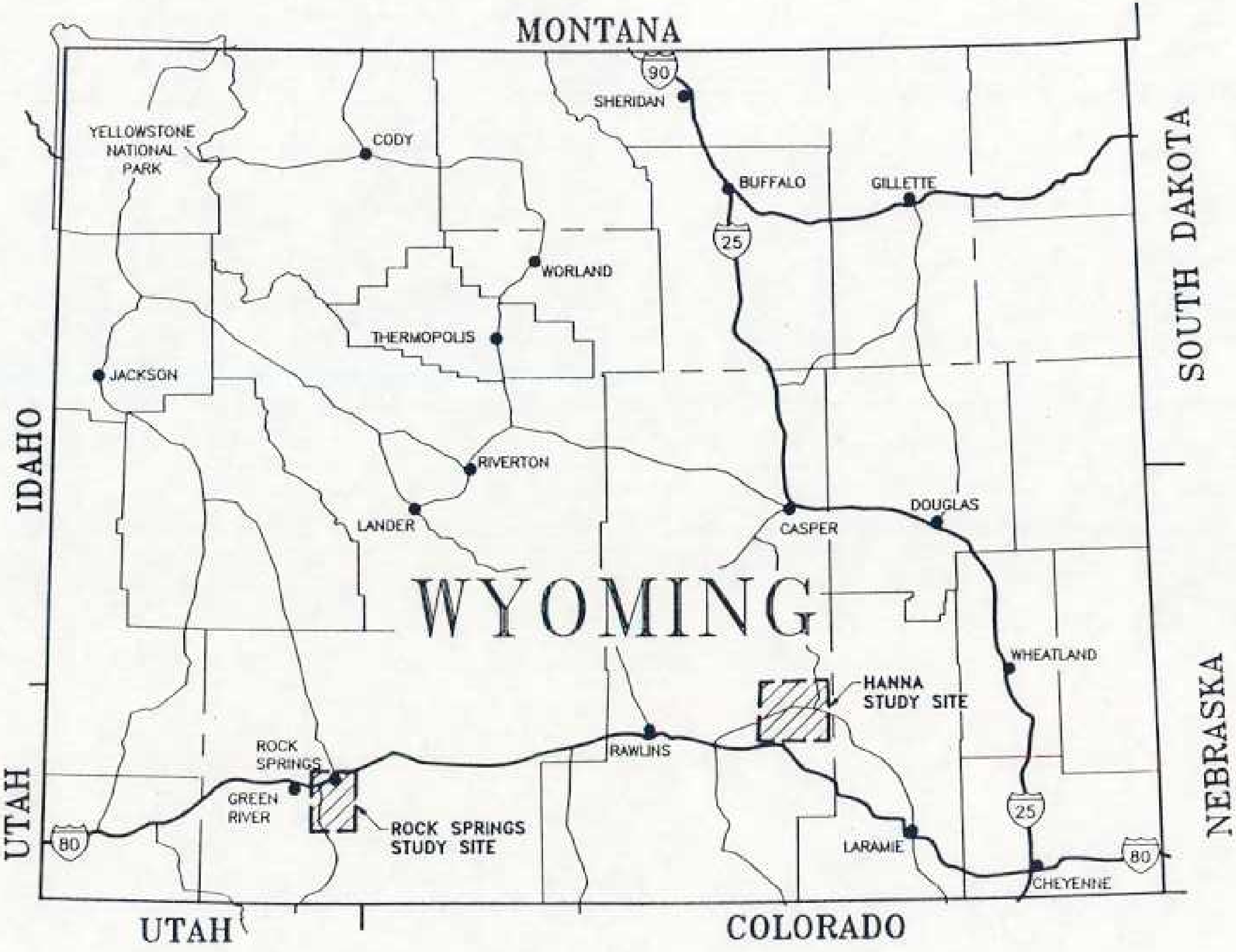


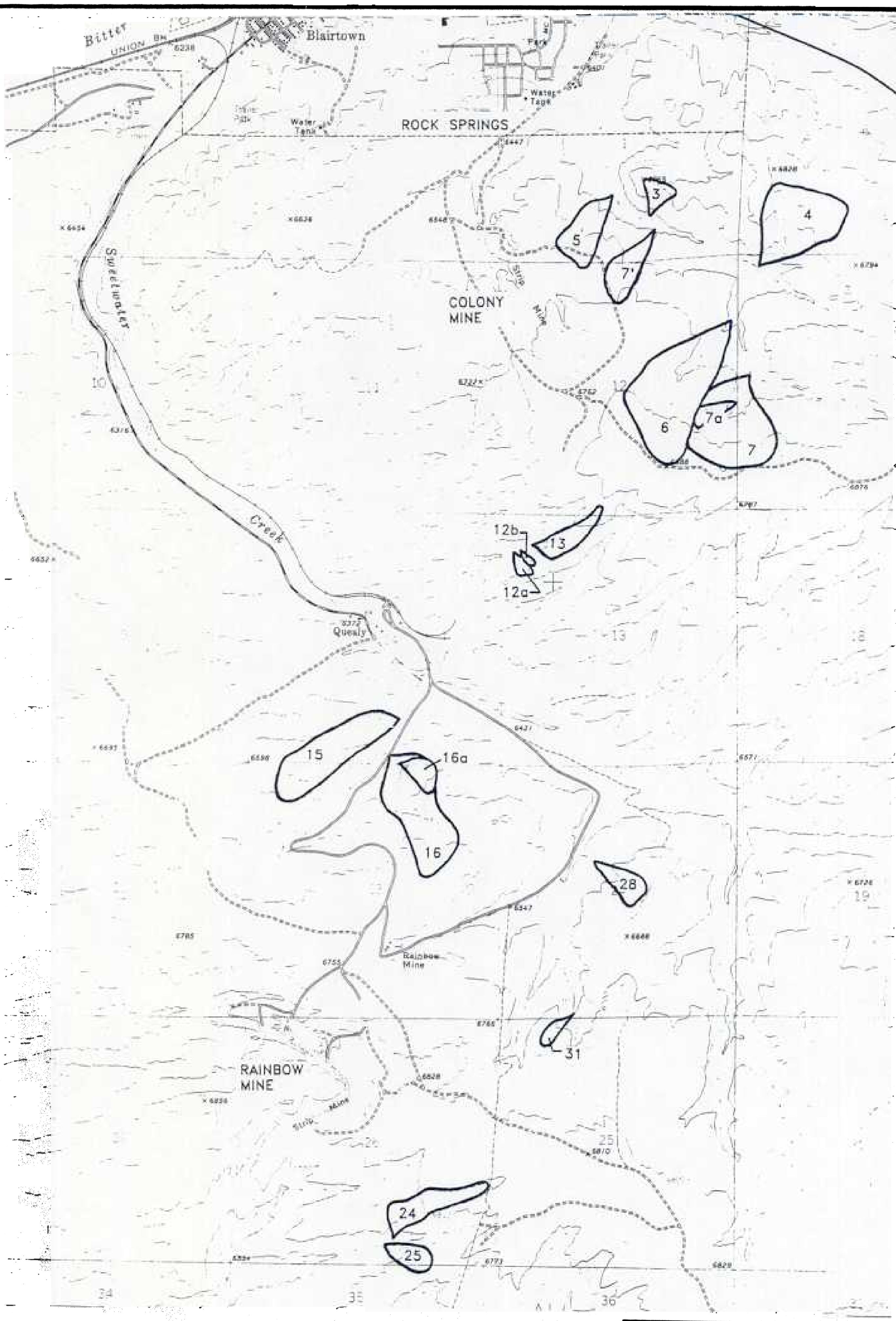
FIGURE 1. NATURAL ANALOG STUDY SITES BASED ON LOCATIONS OF RECLAIMED COAL MINES WITH CHANNEL RESTORATION

Elevation of the drainage basins studied at the Hanna site range from 6,800 to 7,200 feet above mean sea level. Streams are ephemeral, and climate is less arid than at Rock Springs. Vegetation in the basins spans the sagebrush and juniper-woodland communities. Drainage basin geology is dominantly Eocene Hanna formation of variable lithology including sandstone, siltstone, shale and coal beds. Numerous northwest-southeast trending faults are noted within the Hanna formation (Love and Christiansen, 1985) near the towns of Hanna and Elmo.

2.3 Natural Analogs

Data from natural, unmined drainage basins within the study sites were initially collected from topographic maps and aerial photographs. The natural analog channels were selected based on overall similarity to reclaimed basins. Basins with similar geology, basin size, and shape, were selected for study when possible. Basins were chosen for study only if no obvious anthropogenic influence such as roads, utilities, buildings, or channelization was evident. This was verified in the field during reconnaissance work locating selected analog channels.

In the field, a channel cross section was surveyed at the mouth of each unmined basin along with a local channel slope at the cross section. The perimeter of several small basins was surveyed at the Rock Springs study site to increase the overlap of data from the small reclaimed basins (< 10 acres); unmined small basins are difficult to define on topographic maps. In addition, the general condition of each surveyed natural channel was described, noting the presence of bedrock influence, headcuts or knickzones, and bank sloughing or undercutting. A Total Station was used to survey 17 unmined channels south of Rock Springs (Figure 2),



0 2000 FT.
SCALE

FIGURE 2

UNMINED DRAINAGE BASINS, ROCK SPRINGS STUDY SITE

ABANDONED COAL MINE LAND RESEARCH PROGRAM

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whereas, a rod, level and tape proved sufficient to survey 10 analog channels within the Hanna study site (Figure 3). Photographs were taken at each unmined basin measured.

A visit was made to the reclaimed Rainbow and Colony Mine sites (Figure 2) to document site-wide conditions 3 years after construction. Likewise, reclaimed AML site 7-26 near Hanna was observed during field work. No measurements were made at the three reclamation sites, but photographs were taken, and design plans visually compared to constructed topography.

To derive a data set for the natural analogs similar to that compiled from the inventory for reclaimed channels, drainage basin area was determined for unmined channels using U.S.G.S. 1:24,000 topographic quadrangles, and other parameters were estimated using available software. Data tables for the analog sites were developed using both the 10-year and 100-year, 1-hour precipitation event. The 10-year, 1-hour event was selected by the consultant as the design event for reclamation of the Rainbow and Colony mine sites. A computerized version of NOAA's Atlas (PREFREE) was used to determine 10-year precipitation quantities. The SCS Triangular Hydrograph method (TRIHYDRO is a computerized version) was applied to natural analog channels to determine peak discharges. Manning's equation, available in a program called OPEN, was utilized to determine hydraulic parameters (flow velocity, flow area, depth, top width, hydraulic radius) associated with the design discharge and the surveyed cross-section and channel slope.

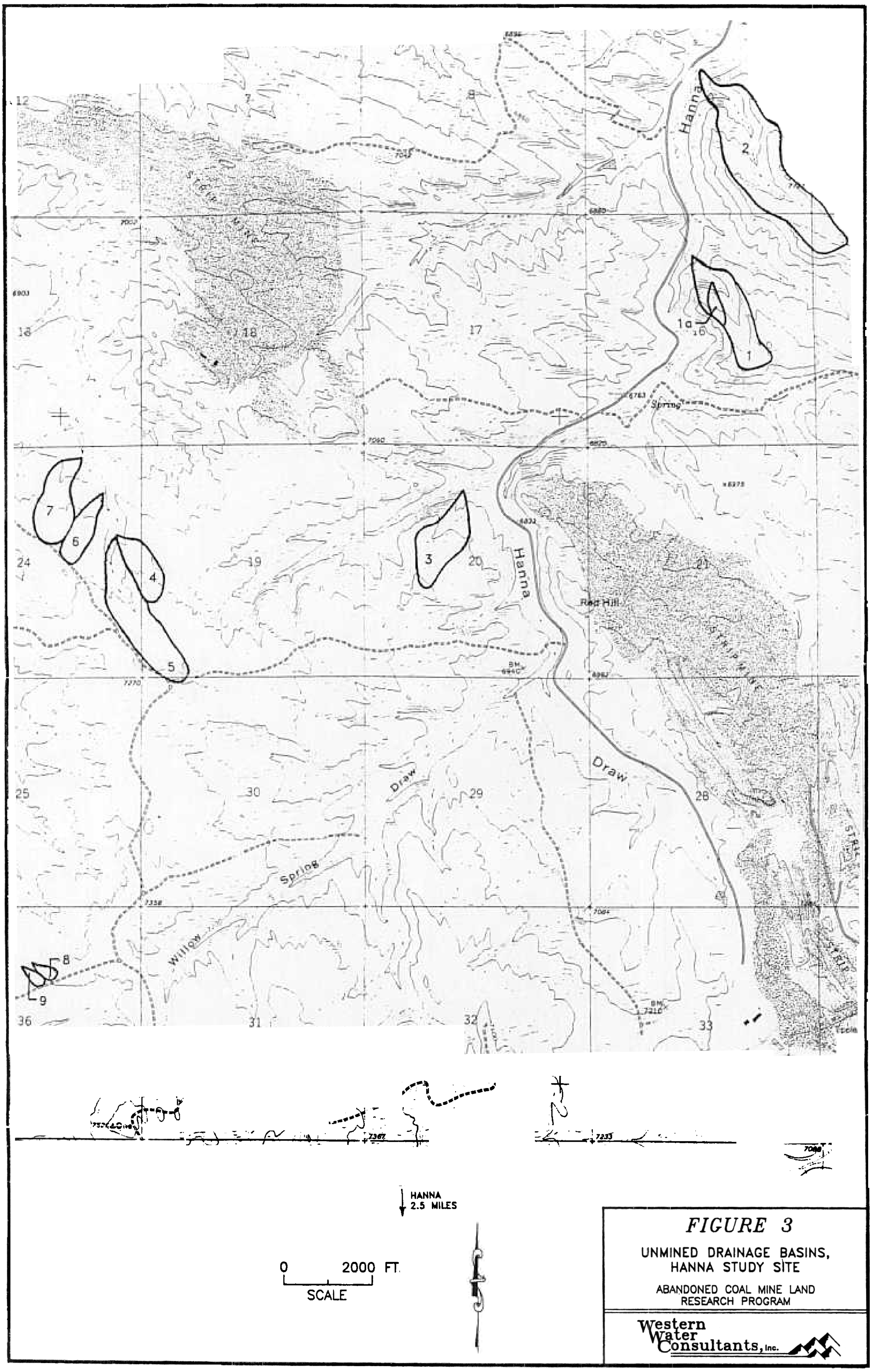

FIGURE 3

UNMINED DRAINAGE BASINS, HANNA STUDY SITE

ABANDONED COAL MINE LAND RESEARCH PROGRAM

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2.4 Statistical Evaluation

During reclamation channel design, hydraulic properties of the channel (cross sectional flow area, channel slope, flow depth, hydraulic radius, etc.) are manipulated by reclamation planners until an acceptable reclaimed design is achieved. In contrast, drainage basin area and mean basin slope, characteristics of the drainage basin, are difficult and cost prohibitive to freely modify during engineering design and construction. However, these rather fixed basin parameters are relatively easy to measure from topographic maps, and provide easily obtained, useful information on geomorphic properties. A major emphasis of this research project was to develop relationships between basin parameters and channel hydraulic parameters that are most important to designing channels and influencing ephemeral channel stability. These relationships could then be used to assess channel stability and as a guide for future channel reclamation.

Research regarding long-term channel stability has centered around geomorphic thresholds (Schumm, 1973), a concept describing the landform change resulting from a change in internal or external controls. Previous channel stability studies in Wyoming and surrounding states developed threshold or empirical relationships to predict channel instabilities such as gully initiation (Hadley and Schumm, 1961; Patton and Schumm, 1975; Elliot, 1990). Other studies were specifically directed at developing design equations for reclaimed channels within the actively mined Powder River Basin (Rechard and Hasfurther, 1980; Divis, 1982; Bergstrom, 1985). The utility of previously established regression equations, although based on measurements of natural systems, is limited to the specific drainage basins for which the relationships were developed. Application to channels and basins other than those evaluated, such as the Rock Springs and Hanna areas, is possibly a misuse of the regression data (Williams, 1983).

For this project, surveyed field data on natural channels, and map-derived data on the drainage basins within the Rock Springs and Hanna areas were analyzed by regression analysis. Regression analysis is intended to identify the relationship between two (or more) variables such that information about one of them allows knowledge or prediction of the other. The regression relations between drainage basin and hydraulic parameters were then used to develop a risk-based channel stability test based on the variation exhibited by natural channels about a mean predicted value. The stability assessment provides a quantitative way to evaluate discrepancies between natural analog channels and reclaimed or designed channels.

2.4.1 Confidence Intervals

A method for evaluating the uncertainty in the regression relations for natural channels, or the variance about a mean predicted value, involves the development of confidence intervals. Confidence intervals were calculated using Student's t distribution (Ott, 1984, p. 128). The Student's t distribution is a variation of the normal distribution adjusted to account for small sample sizes. Using this distribution, a confidence interval about the mean value of an independent random sample is calculated as follows:

$$\bar{x} \pm t_{a,n-1} s \sqrt{\frac{1}{n}} \qquad (1)$$

where $\bar{x}$ is the sample mean, $t_{\alpha,n-1}$ is the test statistic from standard tables for a specified error level (alpha) with n-1 degrees of freedom, s is the standard deviation, and n is the sample size. The error level (alpha) is related to the confidence level as follows:

$$\text{confidence interval} = 100\,(1-\alpha)\%$$

Estimation of a population mean can become more involved if the variable of interest is correlated with one or more independent variables. Inferences concerning the population mean for data showing strong correlation coefficients were treated by calculating confidence intervals using the Student t distribution (Devore, 1982; p. 443) as follows:

$$\hat{y} \pm [t_{\alpha,n-2}(s\sqrt{\frac{1}{n} + \frac{n(x_o-\bar{x})^2}{n\Sigma x_i^2 - (\Sigma x_i)^2}})] \qquad (2)$$

where $\hat{y}$ is the predicted value of the dependent parameter, $t_{\alpha,n-2}$ is the test statistic from standard tables for a specified alpha and n-2 degrees of freedom, s is the sample standard deviation, n is the sample size, x_0 is the independent variable, and $\bar{x}$ is the mean of the independent parameter.

2.4.2 Limiting Type I Error

An important component in statistical testing is specifying an acceptance level to control the probability of an erroneous result. Typically, the user chooses an acceptable Type I error, or alpha level, in this case specifying the amount of acceptable risk associated with approving a given channel design; herein lies the risk-based approach to this channel stability evaluation. Alpha typically is selected at either 0.1 and 0.01, and indicates the probability or percentage of times an error in design acceptance will occur. Selecting an alpha of 0.1 means there is a 10 percent probability of accepting a reclaimed channel design that does not meet the test criteria.

3.0 RESULTS

Based on the results of the inventory and the field investigation, reclaimed and natural channel characteristics were compiled for the two selected study sites. Results of the regression analysis indicate certain relationships between channel and drainage basin parameters predict ephemeral channel configuration. Three important channel design parameters were incorporated into a long-term stability evaluation.

3.1 Reclaimed Channel Characteristics

3.1.1 Rock Springs

The twenty reclaimed channels at the Colony and Rainbow mines south of Rock Springs form broad, shallow swales (Figure 4). Flow depths associated with the 10-year, 1-hour design event range from 0.1-0.3 feet deep, and top widths range from 5-7 feet (Tables A-1 through A-4). Minor incision of 1-4 inches was observed during field work in channel bottoms at the two abandoned mines (Figure 4). Design flow hydraulics described in AML reports accounted for a pilot channel, but it was not constructed as part of reclamation.