1.0 INTRODUCTION

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Surface coal mining disrupts vast tracts of land. The mining process causes surface drainage networks to become blocked by spoils, rerouted, or unearthed; vegetation is destroyed, and soil properties are altered, leaving entire drainage basins vulnerable to erosion. The Federal Surface Mining Control and Reclamation Act (SMCRA) of 1977 requires all mines to post bond to ensure reclamation after mining has ceased. An increasingly important aspect of mined land reclamation is the restoration of surface drainage systems disrupted by mining. Reclamation seeks to control erosion and reestablish channel stability through channel designs that efficiently route surface water and sediment. Since Wyoming is the largest coal producing state in the nation, channel reclamation at abandoned and active coal mines continues to be a central issue of mined land restoration. In northeastern Wyoming alone, 135 square miles of land surface is projected to be disturbed by existing or proposed surface coal mines, and as much as 253 square miles could be disturbed by all anticipated mining in the area (Martin et al., 1988).

One of the greatest challenges facing mine operators and regulators is the evaluation of channel designs. The channel evaluation process progresses from initial design drawings to post-construction field monitoring, to releasing bond money indicating satisfactory design and long-term performance. Design engineers and regulatory personnel involved in channel reclamation are challenged in their efforts for two main reasons: 1) large flows in semiarid environments capable of significant channel modification are infrequent, and 2) completed channel construction at many reclamation sites has occurred only within the recent past; most reclaimed channels at active and abandoned mines in Wyoming have been constructed within the last 4 to 10 years, a limited time of exposure to channel modifying events. Subsequently, field observations of reclaimed channel responses to large flows are difficult to obtain, yet channel designs must incorporate discharge information to ensure stability during high magnitude floods.

In Wyoming, decisions regarding long-term channel stability that continually confront those involved in mined land reclamation are usually based on short-term monitoring. Complete certification at Abandoned Mine Land (AML) sites is evaluated by 3 years of post-construction monitoring (time required to reestablish vegetation), which means the probability of a large magnitude flow occurring within the monitoring period is very small (i.e. the probability of a

50-year event occurring in a 3-year period is a approximately 6%). Likewise, bond release at active mines is based on information provided in mine permit applications, annual reports, and site inspections, which may indicate the channels have not received any significant flow over that time period.

In an effort to assess channel stability independently of short-term monitoring and annual reporting, Western Water Consultants, Inc. (WWC) developed a risk-based statistical technique to evaluate stability of ephemeral channel designs at reclaimed coal mines in southern Wyoming (WWC, 1993). The research described herein extends the application of the stability evaluation to areas of active mining in Wyoming, and expands the scope of investigation into the controls on ephemeral channel stability. Specific objectives for this Abandoned Coal Mined Land Research Program (ACMLRP) grant period are to:

1. collect and compile existing sources of data on premined channel and drainage basin characteristics;

2. test the applicability of regression relationships developed for southern Wyoming (WWC, 1993) to other geographic areas in Wyoming;

3. further investigate controls on channel slope using available channel sediment data; and

4. develop a regional analysis of channel design criteria and apply the developed stability evaluation to assess reclaimed channel designs (WWC, 1993).

1.1 Previous Findings

WWC (1993) presented a risk-based statistical technique to evaluate channel stability for ephemeral channels in semiarid environments. The premise of the original work (WWC, 1993), and adhered to again, is that reclaimed channel designs should be modeled after natural premined channels representative of the geographic area of interest. Natural alluvial channels have evolved over long periods of time with channel cross section characteristics of width, depth, and slope reflecting prevailing climatic and hydrologic conditions. Information about the premined state of surrounding natural channels provides a crucial starting point for the restoration of drainage basins.

The stability evaluation presented by WWC (1993) uses three of the most important parameters in channel design (cross sectional flow area, flow velocity for the design event, and channel slope), and statistically measures how closely designed channels resemble adjacent natural, undisturbed channel conditions when subjected to the same design analyses. First, regression relations were developed for natural channels between drainage basin parameters (difficult and cost prohibitive to modify during reclamation) and the three channel hydraulic properties mentioned previously. The regression relations between drainage basin and hydraulic parameters were then used to develop a risk-based channel stability test based on the natural variation about mean predicted values exhibited by natural channels. One-tailed confidence intervals were computed to allow the determination of conservative channel design parameters.

While reclamation seeks to replace existing gradients and channel planforms, it is impossible to recreate the premined soil structure within channel bottoms once mining has ceased. Additionally, the newly created channels must be protected from excessive erosion during the first several years, until vegetation is established. The stability assessment derived by WWC (1993) reflects this need for conservatism in the design of reclaimed channels. One-tailed confidence intervals are used to quantify discrepancies between natural and reclaimed channel and allow designs to err on the side of caution. Thus designers and reviewers can determine, with a selected level of probability, whether a given channel has flow velocity and channel slope values less than or equal to the mean exhibited values of undisturbed channels with similar drainage basin parameters. Likewise, flow area values can be compared to determine if they are greater than or equal to expected flow area values of similar natural channels. The method is a risk-based approach because it allows user flexibility in choosing an acceptable level of error, or alpha (α). Alpha, typically selected at either 0.1 or 0.01, indicates the probability or percentage of times (90% or 99% for α=0.1 and 0.01, respectively) a reclaimed channel would have hydraulic characteristics conservatively designed compared with natural channels.

WWC's stability evaluation of reclaimed channels was tested on constructed channels at the abandoned Rainbow and Colony mines located south of Rock Springs, Wyoming (Figure 1-1). WWC concluded that stability tests, if incorporated into regulatory decisions, can quantify

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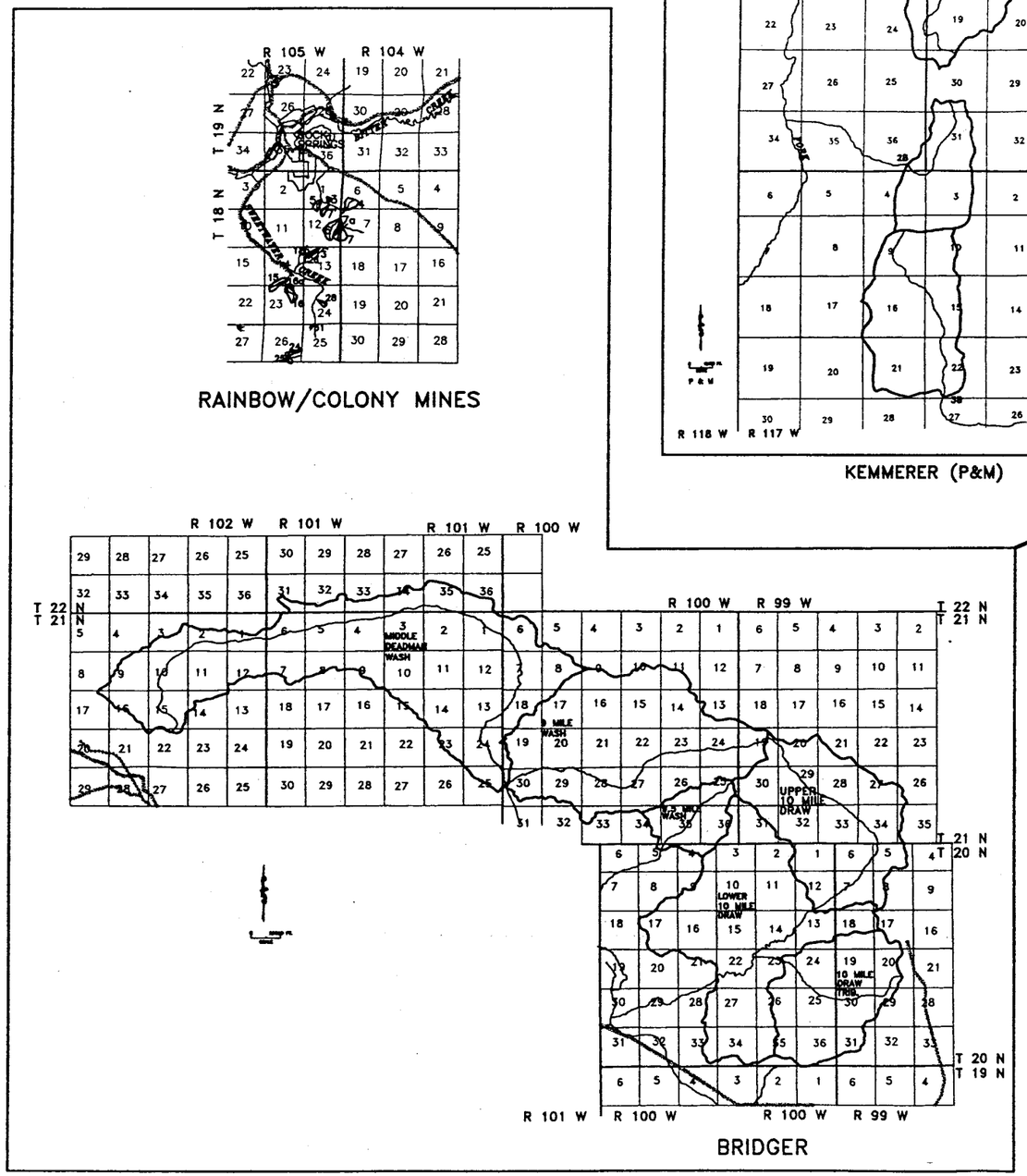

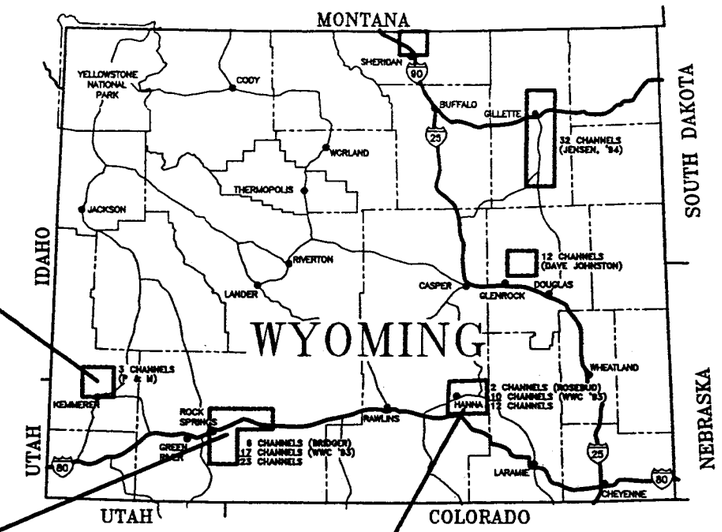

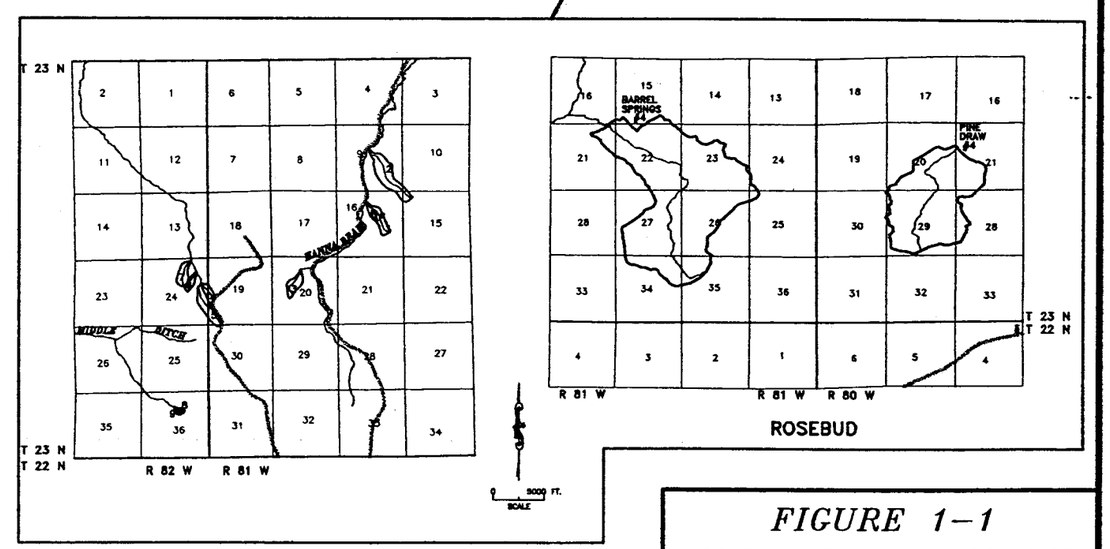

FIGURE 1-1

LOCATION OF PREMINED DRAINAGE BASINS AND STREAM CHANNELS STUDIED IN SOUTHERN WYOMING

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differences between reclaimed channel characteristics and natural premined areas. A standardized, quantitative approach to channel design will help maintain consistency within a process that has historically been subjective and reviewer-specific.

In related channel stability studies in Wyoming and surrounding states, empirical equations have also been developed by regression analysis of interrelated variables of natural systems. Typically, however there is no means of evaluating the resulting channel designs for long-term performance. Examples of pertinent studies include work by Rechard and Hasfurther (1980) who developed design equations for width-depth ratios, radius of curvature, sinuosity, and meander lengths for reclaimed channels in the eastern Powder River Basin. Divis (1982) developed a relationship for the Powder River Basin where drainage area for first order basins is related to basin length and slope, and Bergstrom (1985) developed a threshold slope for a given relative basin elevation for streams near the Dave Johnston mine in the eastern Powder River Basin. Finally, Harvey and Watson (1985) suggest reclamation plans utilize an equilibrium channel slope that is dependent on the median grain size (D_{50}) and percent silt/clay of the bed and bank material. Similarly, this ACMLRP study makes use of regression equations, but also, serves as a compilation of premined channel parameters that are fundamental to the reclamation process on a statewide basis, and evaluates the regression results statistically for a measure of channel stability.

1.2 Channel Stability

Research into channel stability spans a broad spectrum of disciplines. In mined land reclamation, there appears to be two main camps with differing perspectives on channel stability as pointed out by Toy and Hadley (1987); the engineering perspective, based on the analysis of physical forces at the sediment/water interface, and the geomorphic perspective that is rooted in the concepts of: 1) equilibrium (Hack, 1960), or the balance between channel form and physical process, and 2) geomorphic thresholds (Schumm, 1973), a concept describing landform change resulting from a change in internal or external controls.

In general, the engineering approach to channel stability incorporates regime theory, tractive force analysis, and limitations based on maximum permissible velocities. In Davis' Handbook of Applied Hydraulics (McKiernan, 1993), stable channels are defined as

"Channels formed in alluvial or other granular material are said to be stable if their geometry remains substantially unchanged by scour or sediment deposits" (p. 6.1).

In contrast, geomorphologists view channel stability over much longer time scales. As Schumm (1977) describes it,

"The time span considered is important because erosion and river meander cutoff represent instability during a few years, but during 1000 years these processes are part of normal river behavior "(p. 131).

Similar to engineers, geomorphologists refer to channel stability as a channel possessing a balance between eroding and resisting forces.

"The stable channel is one that shows no progressive change in gradient, dimensions, or shape. Temporary changes occur during floods, but the stable channel, if the classification were not restricted to short segments of the river, would be identical to the graded stream as defined by Mackin (1948)" (pg. 155).

For purposes of this study, our view of channel stability incorporates both the geomorphic and engineering approaches, to develop the most workable means of evaluating channel performance. Geomorphologically, it can be argued that natural, undisturbed drainage networks are by nature, stable, having evolved in response to imposed water and sediment loads for long periods of time. In natural settings, channels develop in response to long and continuous exposure to physical processes plus human-induced changes, establishing a condition of dynamic equilibrium. It is this self-regulating quality, where channels adjust to fluctuations in controlling processes, that reclamation seeks to emulate. Stability, in our view, implies dynamic stability, whereby there is constant change in drainage basins and stream channels. Thus it is reasonable to look to natural systems to determine appropriate levels for those hydraulic parameters most critical in the design of reclaimed channels. Engineering methods which standardize the computation of flow magnitudes and hydraulic performance are used as the basis upon which the comparisons between natural and reclaimed channels are made.

Currently, in the reclamation literature, most researchers concur that stable, natural

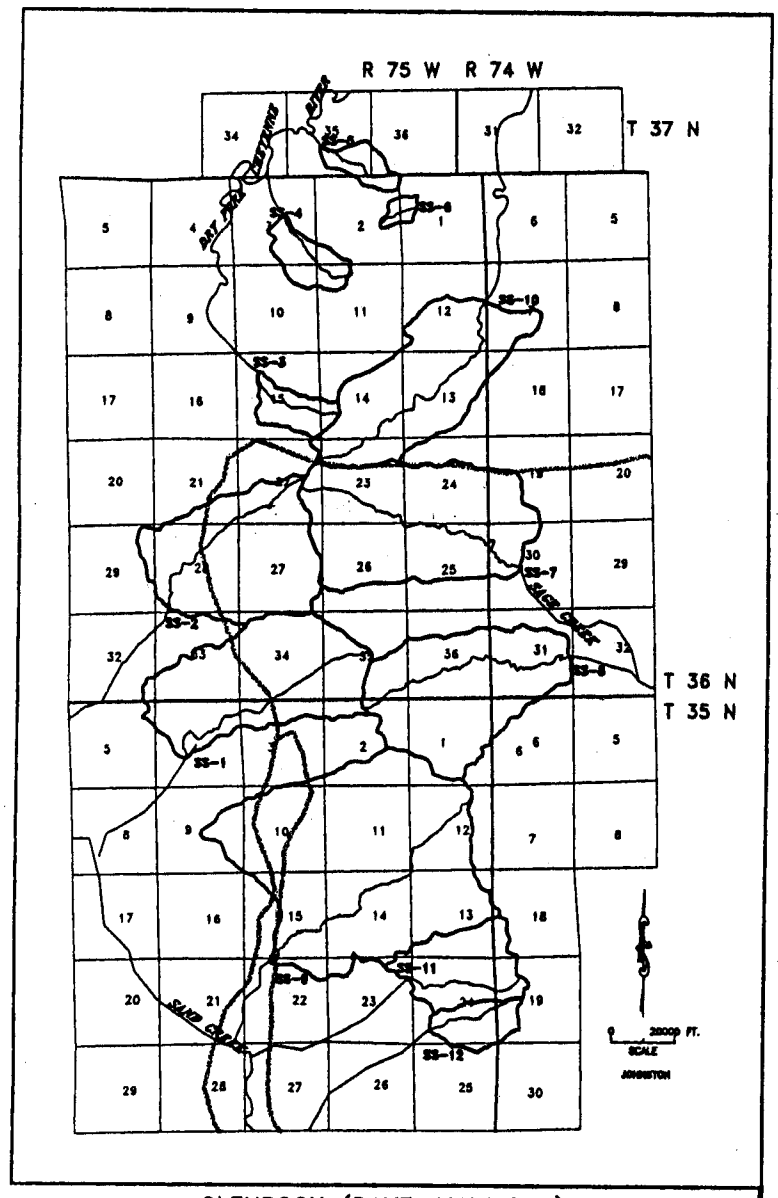
channels should be used as analogs for designing reclaimed channels (Stiller et al., 1980; Bishop, 1980; Wells and Potter, 1986; Lidstone and Anderson, 1989; Erion, 1991; Waldo, 1991). Recent work on channel stability demonstrates that stability should be viewed as a direction of change rather than a single, instantaneous condition, so reclaimed and natural channels respond similarly to external and internal stimuli.

1.3 Study Sites

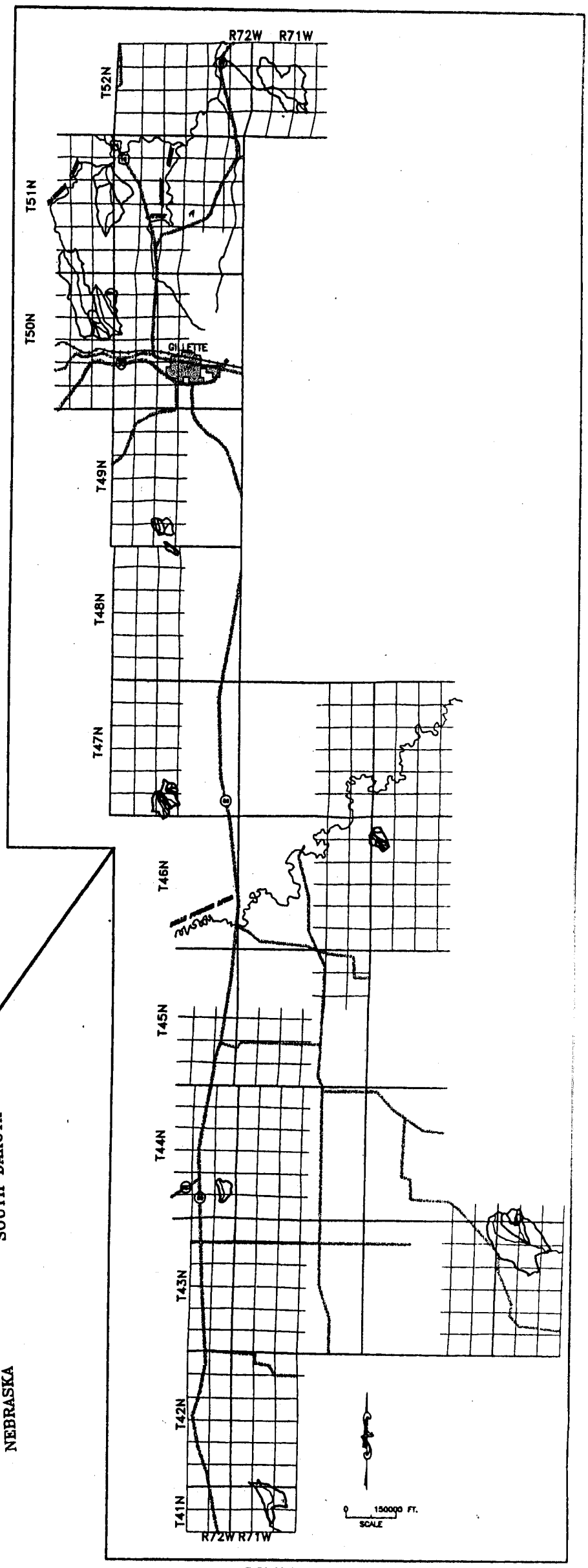
The main coal-bearing regions of Wyoming were selected for study to include areas of Wyoming where there is active mining of coal and channel restoration, and areas that receive a majority of the regulatory attention and interest. Our expanded data set includes 82 drainage basins and stream channel cross sections from the main coal-bearing regions of Wyoming, including: 1) Rock Springs; 2) Hanna; 3) Kemmerer; 4) Powder River Basin; and 5) Glenrock (Figure 1-1 and 1-2). Information on premined channel characteristics was collected from existing sources. The region around Sheridan was originally included in this study, but was removed after difficulty with locating premining channels indicative of stable conditions. Natural underground burning of coal in the Sheridan area has created a pocked topography, with sink holes in channels never disturbed by mining. Although the sink holes are a natural occurrence within the channels, they are not a land feature that should be replicated during reclamation.

1.3.1 Rock Springs

The Rock Springs area (Figure 1-1) includes 17 natural channels adjacent to the abandoned Rainbow and Colony coal mines, and 6 premining channels within the Jim Bridger permit boundary. Elevation of the Rainbow/Colony area ranges between approximately 6500 and 6700 feet above mean sea level. Precipitation in Rock Springs varies from 7-9 inches per year, on average, with a majority of it falling in spring and summer. In general, the Rock



GLENROCK (DAVE JOHNSTON)



POWDER RIVER BASIN

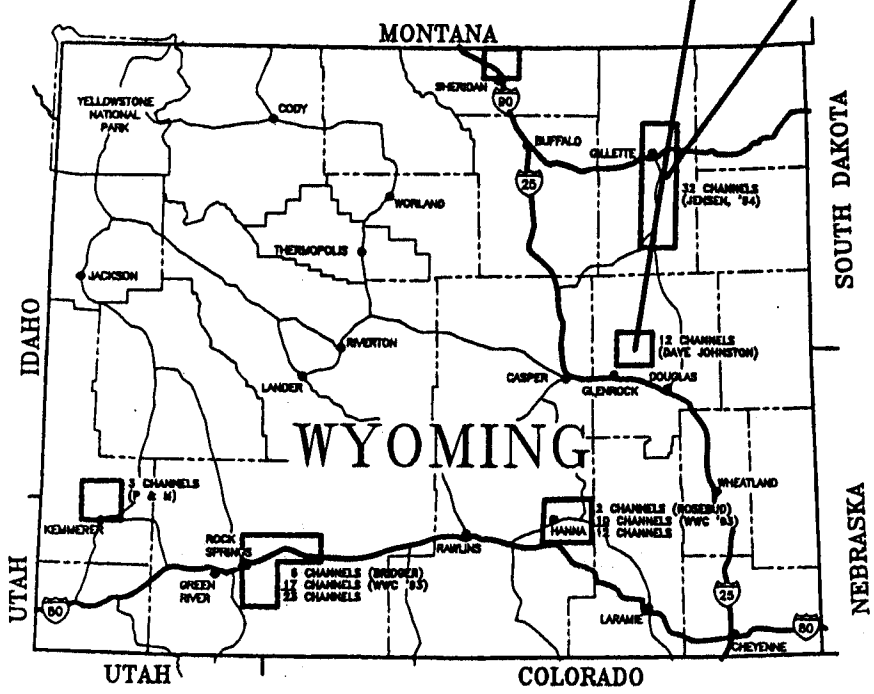


FIGURE 1–2

LOCATION OF PREMINED DRAINAGE BASINS AND STREAM CHANNELS STUDIED IN EASTERN WYOMING

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Springs study area occupies a semi-arid climatic zone where ephemeral streams dissect horizontally-bedded sedimentary rocks, forming buttes with variable, steep topographic relief. Most streams flow only in response to precipitation events. Near surface geology of the Rock Springs study site is formed by the Cretaceous-age Mesa Verde formation, a heterogeneous unit comprised of sandstone, interbedded with shale, siltstone, and coal lenses. The Fort Union formation is the minable coal seam at the Jim Bridger mine. The selected drainage basins which were surveyed in the field are considered natural, but may include the effects of human-controlled land uses common to Wyoming, such as grazing of livestock and the presence of roads, powerlines, and small stock ponds.

1.3.2 Hanna

The Hanna study area lies within an intermontane structural basin. Twelve premining channels were studied in the Hanna area (Figure 1-1), around the Rosebud, Seminoe #1 and #2, and Medicine Bow coal mines. Average annual precipitation is approximately 9-10 inches. Elevation of the drainage basins studied at the Hanna site range from 6800 to 7200 feet above mean sea level, with all streams being ephemeral. 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.

1.3.3 Kemmerer

The Kemmerer study area (Figure 1-1) includes 3 premined channels within the Pittsburgh & Midway (P&M) Coal Mining Co. permit boundary. Annual long-term precipitation recorded at the P&M mine is 9.53 inches, a majority of the precipitation occurring in spring and early summer from thunderstorm activity. Elevation at the Kemmerer site ranges from 6900 to 7500 feet above mean sea level. Surficial geology in the Kemmerer area consists of interbedded, fine-grained sandstone, siltstone, and claystone of the Adaville formation. The sedimentary rocks have been folded into a syncline with an axis striking generally north-south.

1.3.4 Powder River Basin

Thirty-one premined ephemeral channels were selected for this study (Figure 1-2) from two Master's theses funded by a related ACMLRP project (Jensen, 1994; Anderson, 1994). Average annual precipitation of the Powder River Basin site varies from approximately 12 to 14 inches, with over 2/3 of the precipitation occurring as rainfall during the months of March through August (Martin et al., 1988). All of the streams studied within the Powder River Basin are part of the Missouri River drainage basin, which originate in and drain interbedded deposits of shale, siltstone, sandstone, and coal of the Paleocene Fort Union and Tertiary Wasatch geologic formations. The study site is located within the north-trending Powder River structural basin.

1.3.5 Glenrock

The Glenrock study area contains 12 premining channels (Figure 1-2) reported in the Dave Johnston mine permit application. Average annual precipitation at the mine is 12.9 inches, with most occurring as rainfall during the spring months. Due to orthographic effects, a 0.5 inch variation in precipitation has been observed at the Dave Johnston mine (K. Wendtland, personal communication, 1994). Surficial geology is dominated by the Eocene Wasatch formation and the Paleocene Fort Union formation, consisting of alternating beds of sandstone, shale, and coal. High sand content in older Wasatch formation rocks causes significant infiltration differences across the permit boundary (K. Wendtland, personal communication, 1994), which influences the amount of surface water runoff to channels. Vegetation in the vicinity of the permit area is sagebrush and pinon-juniper woodland.