2.0 METHODS

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Data were collected on natural drainage basins and stream channels from four sources: 1) WWC (1993), 2) Jensen (1994) and Anderson (1994), unpublished Master's theses, 3) mine permit applications, especially Appendix D-6 on mine hydrology and geomorphology at the Wyoming Department of Environmental Quality/Land Quality Division (WDEQ/LQD), and 4) bed sediment data for Powder River Basin streams (Table 2-1). These sources are a mixture of field-based data and data retrieved from existing reports and are summarized in Table 2-1. Each source shown in Table 2-1 is briefly described below.

The WWC (1993) information consists of a report submitted to the University of Wyoming, Office of Research under an earlier ACMLRP project entitled 'Long-term Stability of Designed Ephemeral Channels at Reclaimed Coal Mines, Wyoming.' WWC surveyed 27 unmined channels in the area of Rock Springs and Hanna areas. The Jensen (1994) and Anderson (1994) data consist of 31 surveyed undisturbed channels studied in the Powder River coal field. Mine permit application information consists of premined channel and basin data supplied to WDEQ/LQD by mine operators. To obtain a surface mining permit, the applicant must first collect baseline data on the hydrologic system to be disturbed by mining. This information is used by regulatory personnel to evaluate the feasibility of the mining operation, the probable environmental impact, and the adequacy of the reclamation plan. As a result, the mining permit application tends to be a voluminous document. Toy and Hadley (1981) recognize "mining permit applications could become a valuable source of geomorphic and hydrologic data for earth scientists in the future." Finally, the bed sediment data were collected by Jensen (1994) as part of his Master's thesis, and sieved by WWC for grain size distribution.

Once the initial channel information was obtained from the various sources, additional work was completed to derive the suite of required parameters to generate a consistent database. Topographic maps (1:24,000 scale) were obtained and basins were outlined to digitize basin area, stream length, and elevation difference from divide to basin mouth. Mean basin slope was then calculated.

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	Channel Cross-Section	Drainage Area	Mean Basin Slope	Hydraulics	Bed Sediment	Bankfull w, d	Bankfull Q	Source
Rock Springs Area								
Bridger	●	●	●	●		●	●	Mine Permit Application
Rainbow/Colony	●	●	●	●		●	●	WWC (1993)
Hanna Area								
Rosebud	●	●	●	●		●	●	Mine Permit Application
Hanna/Elmo	●	●	●	●		●	●	WWC (1993)
Kemmerer Area								
P&M	●	●	●	●		●	●	Mine Permit Application
Powder River Basin	●	●	●	●	●	●	●	Jensen(1994);Anderson(1994)
Glenrock Area								
Dave Johnston	●	●	●	●		●	●	Mine Permit Application

Table 2-1. Pre-mined channel information for coal-bearing regions of Wyoming from existing literature.

2.1 Flood Discharge Estimates

A computerized version of the National Oceanic and Atmospheric Administration's (NOAA) Precipitation Atlas called PREFRE was used to determine precipitation quantities for each basin. Since streamflows in Wyoming are closely related to climate, especially precipitation, a reliable estimate of precipitation is important. In the absence of rain gage data, NOAA's Atlas is an acceptable substitute.

Next, rainfall-runoff simulation based on the Soil Conservation Service's (SCS) Triangular Hydrograph Method of calculating flow discharge was used (TRIHYDRO is the computerized model) to estimate flood discharges for various return intervals (10-, and 100-year events). Discharge estimates using TRIHYDRO compare favorably to those obtained using STORM, a program also based on the SCS Triangular Hydrograph Method, but favored by personnel at WDEQ/LQD. The main difference between TRIHYDRO and STORM is the flexibility of input parameters; TRIHYDRO allows a minimum infiltration rate to be specified, and allows a wider range of precipitation distribution and precipitation durations to be specified.

Based on basin parameters and following a review of available soil, hydrologic soil group, curve number (CN), and minimum infiltration rate data, computed flood discharges using rainfall-runoff simulation were derived for each basin. Flood discharges for the 10 and 100-year floods based on 1, 6, and 24 hour precipitation events were computed. Only the maximum of these discharges for each return period were used for each basin.

While SCS rainfall-runoff simulation techniques are commonly used among mine reclamation specialists, hydrologists, and design engineers, a second technique of deriving channel flow magnitudes from basin characteristics is available in the literature and is also frequently used. Lowham (1988) conducted a regional analysis of streamflows in Wyoming using basin parameters and gage records to estimate discharge on ungaged streams. Flood discharge estimates obtained from Laramie Regional Analysis are frequently higher than those obtained through rainfall-runoff simulation methods. Discharge estimates using Regional Analysis were also computed for each basin, so that reclaimed channel designs based on floods discharge estimates derived by this method might also be evaluated.

2.2 Hydraulic Parameter Computation

Channel hydraulic parameters were computed for each basin using the HEC-2 model. This open channel hydraulic model is commonly used in reclamation design and was employed to determine cross sectional flow area, topwidth, depth, and flow velocity for each flood discharge assuming normal flow conditions. Manning's 'n' values characteristic of small ephemeral streams in Wyoming were determined (0.035 and 0.065 for the channel and overbank areas, respectively). At Glenrock, Manning's 'n' values were calibrated based on gaging information provided in the Dave Johnston mine permit application. Figure 2-1 summarizes the methods used to determine flood discharges and hydraulic properties at each channel cross section.

2.3 Channel Bed Sediment Analysis

A data set on channel bed sediments was developed by sieving 21 samples of channel bed sediment collected for Jensen's (1994) Master's thesis on Powder River Basin drainages. The samples were dried, split, and run through a nest of sieves to determine the distribution of sediment particles by size and general classification of percent sand and silt/clay by weight. Bed sediment largely influences erosion and deposition within the channel during water flows, and hence figures prominently in channel stability. Fine-grained sediment within a channel bottom is more easily eroded and transported than coarse sediments. Channel slopes develop according to the characteristics of the natural channel, depending on what grain size can be supported at a particular gradient. During the mining process, disruption of the bed material changes compaction properties and destroys soil structure and stabilizing vegetation. While reclamation seeks to replace existing gradients and channel planforms, it is impossible to recreate the premined soil structure and bedrock control within channel bottoms once mining has ceased. Thus, information on premined channel bed sediments is critical to an understanding of successful postmining channel reconstruction.

2.4 Statistical Analysis

During reclaimed channel design, hydraulic properties of the channel (cross sectional flow area, channel slope, depth, topwidth) are manipulated by reclamation planners until an

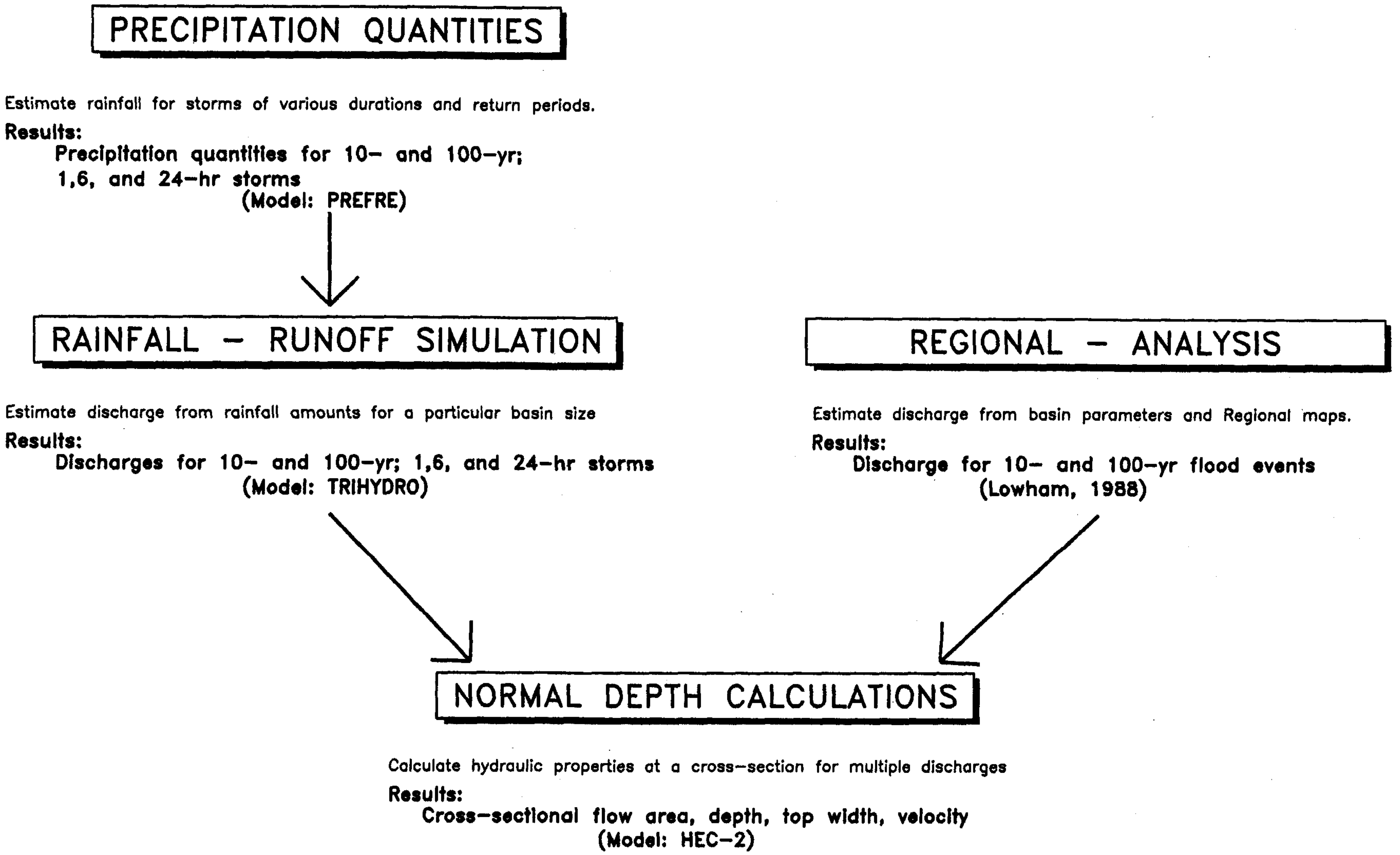

Figure 2-1. Methods used to determine flood discharges and hydraulic characteristics for undisturbed ephemeral channels.

acceptable reclaimed design is achieved. 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 useful information on geomorphic properties of drainage basins. A major emphasis of this research project was to develop relationships from natural, undisturbed streams between basin parameters and channel hydraulic parameters that are most important to designing channels and influencing ephemeral channel stability. In fact, our goal was to use field- or map-derived basin parameters to predict, with good confidence, slope and channel hydraulic parameters exhibited by natural channels and thus to be used as guides in reclamation design. In this way, the relationship between drainage basin and channel hydraulic parameters used in reclaimed channels mirrors those found in natural premined channels, and deviations are statistically quantifiable.

2.4.1 Regression Analysis

Regression analysis identifies the relationship between two (or more) variables such that information about one variable allows knowledge or prediction of the other. Regression analysis was conducted by regressing the independent basin variables of drainage basin area (DA), mean drainage basin slope (BS), and Area Gradient Index (AGI, defined as the product of drainage area and mean basin slope (WWC, 1993)) against dependent channel variables; cross sectional flow area, velocity, topwidth, depth, and channel slope.

Once the initial regression analyses were completed, bed sediment information, where available, was included to strengthen relations by adding additional information relating to channel stability.

Differences between the regression equations for each area were also investigated. Statistical tests described in Ott (1984) and based on the probability that derived regression coefficients for variables representing geographical differences between study areas differ from zero were conducted to test the significance of differences among study sites. F-tests based on the drop in mean square error between "full" (including independent parameters related to geography) and "reduced" (not including geographical variables) regression models were also used to confirm findings in certain situations (Johnson, 1984; Devore, 1982; Ott, 1984).

2.4.2 Confidence Intervals

A method for evaluating the uncertainty in the regression relations for premined channels, or the variance about a mean predicted value, involves the development of confidence intervals. A confidence interval is typically defined by an upper and lower limit having a known probability (or confidence level) of containing the true parameter value of an estimated parameter. For example, to say that the 95% confidence interval for the natural channel slope of basins with a drainage area of 1.0 square miles is between 0.018 and 0.025 feet per feet means that the assertion "natural basins with a 1.0 square mile drainage area have a mean channel slope between 0.018 and 0.025" will be true 95% of the time.

Confidence bands were computed for the regression relations derived between drainage basin and channel hydraulic parameters to develop a risk-based channel stability test. Confidence intervals were calculated 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, $t_{\alpha/2,n-2}$ is the test statistic from standard tables for a specified confidence limit ($100(1-\alpha)\%$) and n-2 degrees of freedom, s is the sample standard deviation, n is the sample size, x_o is the independent variable, and $\bar{x}$ is the mean of the independent parameter.

To account for the need for conservative reclaimed channel designs, due to uncertainties concerning the reclamation of pre-existing soil structures, one-tailed confidence intervals are used to define regions of acceptable channel hydraulic values. This allows designers and reviewers to make assertions like "the reclaimed channel slope is equal to, or shallower than, the mean slope which would be exhibited from natural basins of the same size" with a known degree of certainty. One-tailed confidence intervals at 90% and 99% probability levels were calculated for the more critical hydraulic parameters of channel slope, flow area, and flow velocity. For the less significant parameters of flow depth and flow topwidth, only the 90% confidence intervals about the mean prediction line were calculated. These results can be taken as guides to derive suitable channel dimensions once the more important parameters of channel slope, flow velocity and flow area have been determined. The method is a risk-based approach to evaluating channel stability because it allows user flexibility in choosing an acceptable level of error, or alpha (α) which can be adjusted according to the seriousness of the effects of a reclamation failure.