Stability Evaluation for Designed Ephemeral Channels In Wyoming

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STABILITY EVALUATION FOR DESIGNED EPHEMERAL CHANNELS IN WYOMING

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Final Technical Report
For
Abandoned Coal Mine Lands
Research Program

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ABSTRACT FOR
STABILITY EVALUATION FOR DESIGNED EPHEMERAL CHANNELS IN WYOMING

by

S.L. Rathburn, T. Hanlin, P.A. Rechard, D.R. Jensen

Evaluating the performance of reconstructed ephemeral channels at coal mine sites in Wyoming is a great challenge because major channel adjustments typically occur only in response to infrequent flood events. A risk-based channel stability analysis was developed by Western Water Consultants, Inc. (WWC, 1993) which allows statistical comparison between reclaimed channel designs and similar characteristics of unmined channels. Unmined, natural stream channels can provide critical information about stable channel forms because the natural channel geometry has evolved over long time periods under prevailing climatic conditions. The 1993 research was limited to areas encompassing Abandoned Mine Land (AML) channel reclamation projects near Rock Springs and Hanna, Wyoming. Three channel parameters that are important channel design elements (channel slope, flow velocity, cross sectional flow area) comprised separate stability tests. One-tailed confidence intervals calculated about the mean predicted channel slope, flow velocity, and flow area define the recommended range of acceptable channel designs.

In the current study (1994-1995), the stability evaluation was extended to the active coal-mined regions of the state: northeast of Rock Springs, north of Hanna, west of Kemmerer, eastern Wyoming (Powder River Basin), and north of Glenrock. Stream channel and drainage basin information was compiled for these five coal-bearing areas in Wyoming using mine permit application premining data, published reports, and field data. Additional parameters including sediment characteristics of the channel bed and banks was included in the analysis to better understand how sediment influences channel stability.

Results, in general, showed a high degree of correlation between basin parameters and ephemeral channel hydraulic parameters. Recommended channel design criteria which provide for stability are presented. Results of the study provide mine reclamation specialists and regulatory personnel with a quantitative method to evaluate reclaimed designs for ephemeral channels in the main coalmined areas of Wyoming.

Additional Key Words: reclamation, geomorphology, channel design, channel stability, stability evaluation

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1.0 INTRODUCTION

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1.0 INTRODUCTION

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

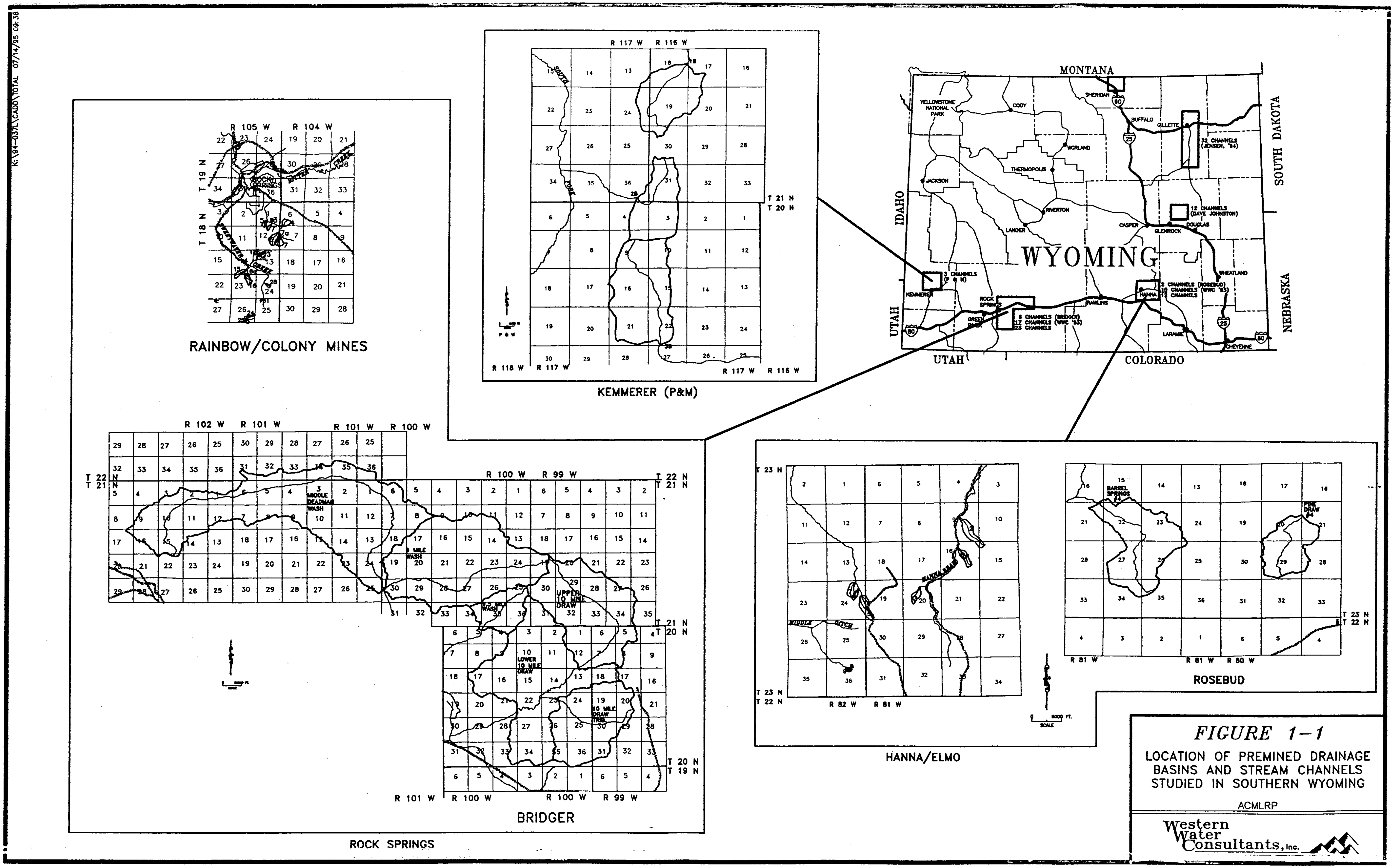

FIGURE 1–1

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

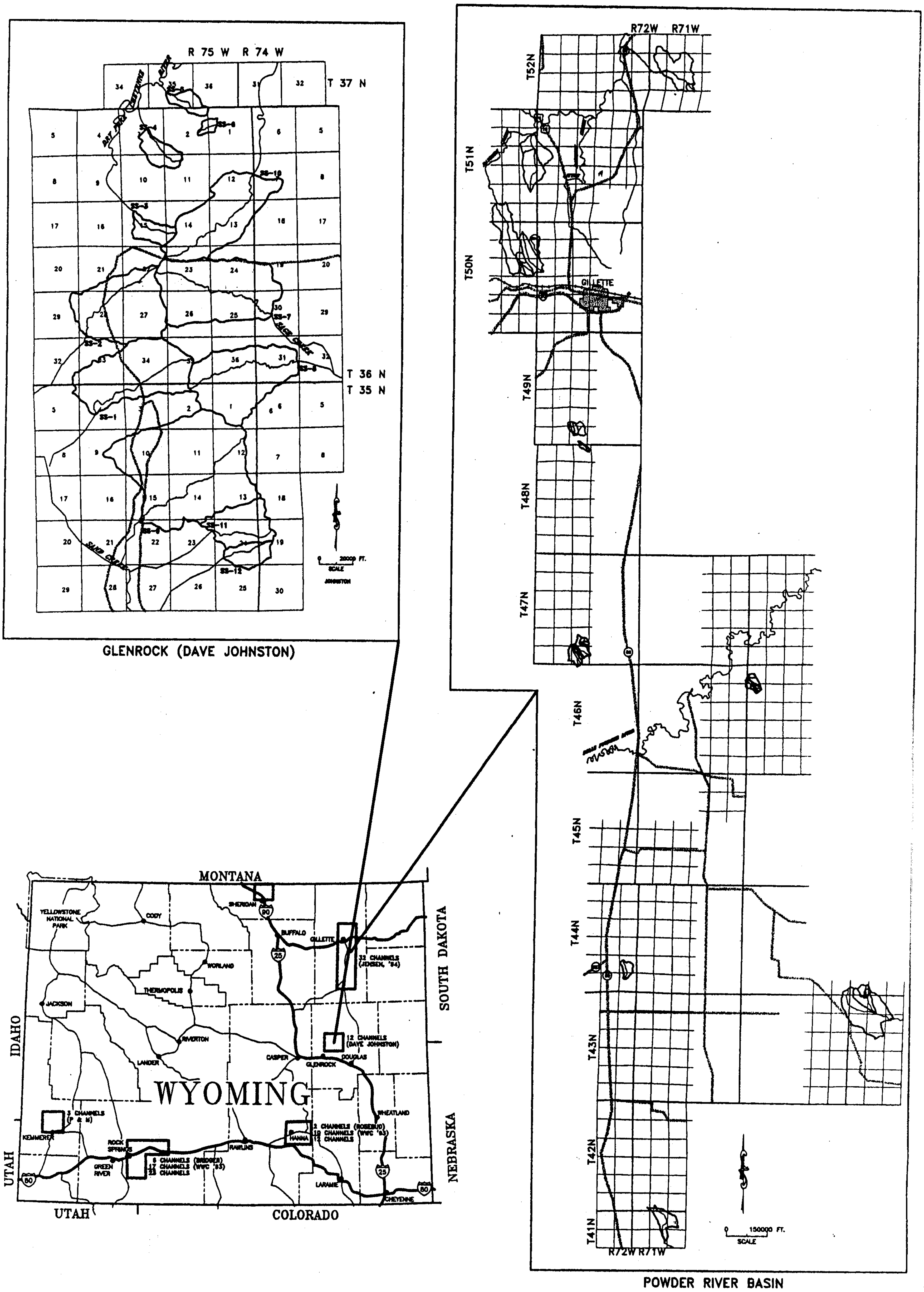

FIGURE 1–2

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.

2.0 METHODS

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2.0 METHODS

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.

	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

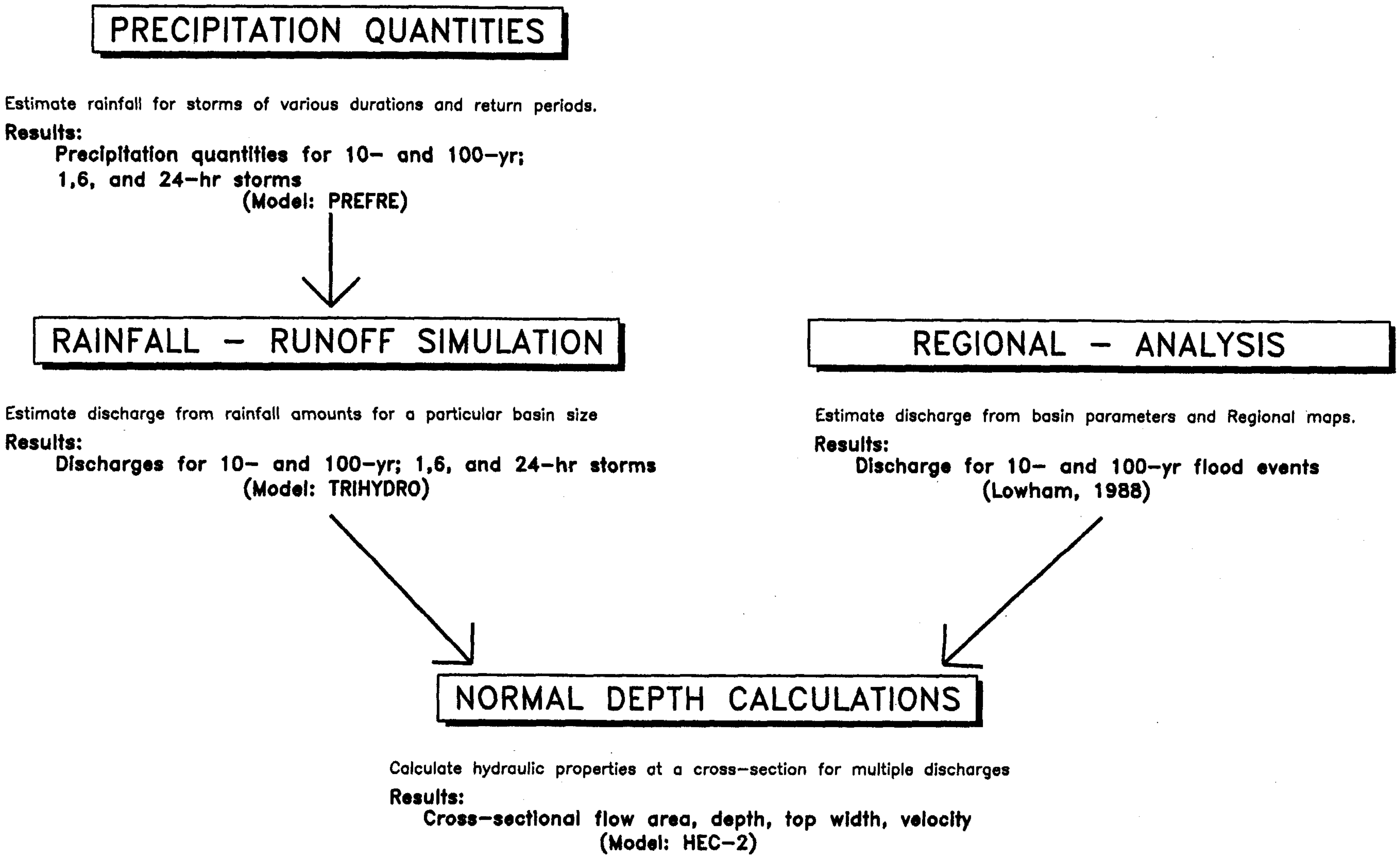

Figure 2-1. Methods used to determine flood discharges and hydraulic characteristics for undisturbed ephemeral channels.

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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.

3.0 RESULTS

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3.0 RESULTS

This section presents the results of the analysis performed on the collected data from the five sample locations.

3.1 Flood Discharge

Natural basin data and computed flood discharge values for all study areas are provided in Tables 3-1 through 3-5. A comparison of the flood discharge values indicates that regional analysis estimates vary from approximately 0.7 to 7 times greater than discharge estimates obtained using rainfall-runoff simulation.

3.2 Hydraulic Parameters

Based on the computed flood discharge values and using surveyed cross section and slope values, hydraulic parameters (flow area, velocity, depth, and topwidth) based on normal flow conditions at each cross-section for the various flood events were calculated. These results are presented in Tables 3-6 through 3-10 for the various study areas.

3.3 Channel Bed Sediment

Channel bed sediment data analyzed from the Powder River Basin Area are presented in Table 3-11 and range from well graded gravels to inorganic silt and clay soils.

3.4 Regression Analysis and Confidence Intervals

Regression analysis was performed on all five study areas to assess the use of basin parameters (drainage area, basin slope, and AGI) to predict measured channel slope and computed 10 and 100-year hydraulic parameters (flow area, velocity, depth, and topwidth). Of the independent parameters examined, drainage area and AGI typically provided the smallest standard errors of estimate. By including basin slope in a multiple regression with drainage area in many instances did not increase the predictive accuracy of the regressions significantly due to the often highly correlated nature of basin slope with drainage area.

TABLE 3-1. ROCK SPRINGS AREA DATA

BASIN PARAMETERS

DRAINAGE		Drainage Area (mi2)	Mean Basin Slope BS (ft/mi)	AGI (1) (Acres)	Rainfall Runoff Analysis: Curve Number	Rainfall Runoff Analysis: Minimum Infiltration Rate (in/hr)	Regional Analysis (2): Avg. Ann. Precip. Pr (in)	Regional Analysis (2): Geographical Factor Gf
RAINBOW/	3	0.010	733.33	0.89	83	0.15	9	0.8
COLONY	4	0.073	571.43	5.06			9	0.8
	5	0.033	700.00	2.80			9	0.8
	6	0.122	441.18	6.52			9	0.8
	7	0.093	675.68	7.62			9	0.8
	7a	0.008	578.95	0.56			9	0.8
	7'	0.026	769.23	2.42			9	0.8
	12a	0.005	692.31	0.42			9	0.8
	12b	0.001	777.78	0.09			9	0.8
	13	0.022	676.47	1.80			9	0.8
	15	0.073	417.91	3.70			9	0.8
	16	0.088	448.28	4.78			9	0.8
	16a	0.013	1411.76	2.22			9	0.8
	24	0.031	962.96	3.62			9	0.8
	25	0.014	500.00	0.85			9	0.8
	28	0.020	476.26	1.16			9	0.8
	31	0.005	763.16	0.46			9	0.8
BRIDGER	9-5MW	3.100	199.63	75.01			9	0.8
	LTD	37.300	64.04	289.56			9	0.8
	MDW	29.300	54.73	194.38			9	0.8
	NW	17.400	84.09	177.35			9	0.8
	TDT	8.100	100.78	96.94			9	0.8
	UDT	12.100	88.05	129.14			9	0.8

(1) AGI is the product of Drainage Area and mean Basin Slope
(2) Parameters Pr and Gf after Lowham (1988)

FLOOD DISCHARGES

DRAINAGE		Rainfall Runoff Analysis: Max 10-Year Discharge (cfs)	Rainfall Runoff Analysis: Max 100-Year Discharge (cfs)	Regional Analysis: 10-Year Discharge (cfs)	Regional Analysis: 100-Year Discharge (cfs)	Ratio of Computed Discharges: 10-Year Regional/Rainfall-Runoff	Ratio of Computed Discharges: 100-Year Regional/Rainfall-Runoff
RAINBOW/	3	1.20	4.90	4.4	16.3	3.63	3.33
COLONY	4	6.20	30.50	16.8	57.1	2.71	1.87
	5	3.20	14.90	10.0	35.2	3.12	2.36
	6	8.00	43.30	23.3	77.1	2.91	1.78
	7	8.50	40.40	19.6	65.9	2.31	1.63
	7a	0.90	3.80	3.7	14.0	4.12	3.70
	7'	2.70	12.10	8.5	30.3	3.15	2.51
	12a	0.60	2.50	2.6	10.2	4.37	4.07
	12b	0.10	0.50	0.7	3.2	7.44	6.34
	13	2.10	9.70	7.6	27.3	3.61	2.81
	15	4.80	25.90	16.8	57.1	3.50	2.20
	16	6.20	33.00	18.9	63.8	3.05	1.93
	16a	1.50	6.50	5.2	19.4	3.50	2.99
	24	3.30	14.50	9.6	33.9	2.90	2.34
	25	1.50	6.50	5.5	20.4	3.69	3.13
	28	2.00	9.10	7.1	25.7	3.55	2.82
	31	0.60	2.40	2.6	10.2	4.37	4.24
BRIDGER	9-5MW	173.60	474.20	145.6	422.5	0.84	0.89
	LTD	913.10	2640.20	475.7	1266.8	0.52	0.48
	MDW	545.30	1630.10	427.4	1147.2	0.78	0.70
	NW	523.40	1520.80	337.3	921.2	0.64	0.61
	TDT	300.70	860.70	235.0	658.8	0.78	0.77
	UDT	388.30	1104.20	284.7	787.1	0.73	0.71

TABLE 3-2. HANNA AREA DATA

BASIN PARAMETERS

DRAINAGE		Drainage Area (mi2)	Mean Slope BS (ft/mi)	AGI (1) (Acres)	Rainfall Runoff Analysis: Curve Number	Rainfall Runoff Analysis: Minimum Infiltration Rate (in/hr)	Regional Analysis (2): Avg. Ann. Precip. Pr (in)	Regional Analysis (2): Geo-graphical Factor Gf
HANNA/ELMO	1	0.069	635.45	5.31	80	0.15	9.5	1.4
	1a	0.007	967.74	0.82			9.5	1.4
	2	0.160	473.53	9.18			9.5	1.4
	3	0.052	543.48	3.43			9.5	1.4
	4	0.030	589.29	2.14			9.5	1.4
	5	0.084	363.01	3.70			9.5	1.4
	6	0.022	650.00	1.73			9.5	1.4
	7	0.047	612.50	3.49			9.5	1.4
	8	0.004	409.09	0.20			9.5	1.4
	9	0.004	346.15	0.17			9.5	1.4
ROSEBUD	BS4	3.200	129.03	50.05			9.5	1.4
	PD4	1.500	146.23	26.59			9.5	1.4

(1) AGI is the product of Drainage Area and mean Basin Slope
(2) Parameters Pr and Gf after Lowham (1988)

FLOOD DISCHARGES

DRAINAGE		Rainfall Runoff Analysis: Max 10-Year Discharge (cfs)	Rainfall Runoff Analysis: Max 100-Year Discharge (cfs)	Regional Analysis: 10-Year Discharge (cfs)	Regional Analysis: 100-Year Discharge (cfs)	Ratio of Computed Discharges: 10-Year Regional/Rainfall-Runoff	Ratio of Computed Discharges: 100-Year Regional/Rainfall-Runoff
HANNA/ELMO	1	12.90	48.40	29.78	102.25	2.31	2.11
	1a	1.80	5.80	6.17	23.76	3.43	4.10
	2	22.80	92.30	50.52	166.90	2.22	1.81
	3	10.30	37.60	24.79	86.24	2.41	2.29
	4	6.80	23.40	17.20	61.44	2.53	2.63
	5	13.10	52.00	33.78	114.91	2.58	2.21
	6	4.90	17.10	13.92	50.51	2.84	2.95
	7	9.80	35.10	23.20	81.10	2.37	2.31
	8	1.00	3.30	4.07	16.14	4.07	4.89
	9	1.00	3.30	4.07	16.14	4.07	4.89
ROSEBUD	BS4	90.00	405.10	271.81	794.50	3.02	1.96
	PD4	44.60	286.80	182.66	549.57	4.10	1.92

TABLE 3-3. KEMMERER AREA DATA

BASIN PARAMETERS

DRAINAGE		Drainage Area (mi2)	Mean Basin Slope BS (ft/mi)	AGI (1) (Acres)	Rainfall Runoff Analysis		Regional Analysis (2)	
					Curve Number	Minimum Infiltration Rate (in/hr)	Avg. Ann. Precip. Pr (in)	Geo-graphical Factor Gf
P&M	T2	2.13	240.94	62.21	75	0.1	9.5	0.8
	T4	1.96	316.95	75.30	81	0.1	9.5	0.8
	M11	3.65	212.35	93.95	79	0.1	9.5	0.8

(1) AGI is the product of Drainage Area and mean Basin Slope
(2) Parameters BS and Gf after Lowham (1988)

FLOOD DISCHARGES

DRAINAGE		Rainfall Runoff Analysis		Regional Analysis		Ratio of Computed Discharges	
		Max 10-Year Discharge (cfs)	Max 100-Year Discharge (cfs)	Max 10-Year Discharge (cfs)	Max 100-Year Discharge (cfs)	10-Year Regional/ Rainfall-Runoff	100-Year Regional/ Rainfall-Runoff
P&M	T2	39.20	147.70	125.7	373.2	3.21	2.53
	T4	80.30	395.90	120.4	358.4	1.50	0.91
	M11	110.70	355.50	166.1	483.2	1.50	1.36

TABLE 3-4. POWDER RIVER AREA DATA

BASIN PARAMETERS

DRAINAGE		Drainage Area (mi2)	Mean Basin Slope BS (ft/mi)	AGI (1) (Acres)	Rainfall Runoff Analysis: Curve Number	Rainfall Runoff Analysis: Minimum Infiltration Rate (in/hr)	Regional Analysis (2): Basin Slope SB (ft/mi)	Regional Analysis (2): Geographical Factor Gf
Russel Draw	0500	3.13	127.61	48.42	70	0.15	230.6	1.3
	05B0	1.80	157.80	34.41			1071.7	1.3
Unnamed Trib.	07E0	1.29	143.02	22.31			1006.7	1.3
Rawhide Creek	07D3	0.11	279.80	3.73			677.5	1.3
	07D4	0.35	297.43	12.61			715.7	1.3
Lone Tree Prong	12B0	0.68	158.86	13.16			331.7	1.3
	12B1	0.30	174.13	6.42			725.9	1.3
	12B2	0.13	454.45	7.00			1137.2	1.3
Windmill Draw	0900	3.18	119.88	46.27			824.3	1.3
	09D1	0.16	227.31	4.27			682.0	1.3
Unnamed Trib.	19A1	0.17	201.38	4.15			641.4	1.3
Bone Pile Creek	19A2	0.43	221.96	11.65			641.4	1.3
	19B2	0.16	227.21	4.53			932.1	1.3
Theilen Draw	22B0	0.66	148.76	11.90			396.4	1.3
	22C0	0.64	136.67	10.60			173.8	1.3
	22B1	0.09	290.57	3.33			734.6	1.3
	22B2	0.09	212.67	2.43			640.5	1.3
	22C2	0.48	144.98	8.52			533.6	1.3
Unnamed Trib.	30A0	0.27	211.11	6.91			687.6	1.3
Belle Fourche	30B0	0.31	173.65	6.59			722.3	1.3
	30A1	0.08	259.21	2.62			668.9	1.3
E. Fk. Hay Ck	36A0	0.47	143.97	8.18			533.7	1.3
H A Creek	4700	4.99	52.28	31.62			446.3	1.3
	47C0	1.03	131.67	16.39			279.2	1.3
	47C2	0.27	212.50	6.95			438.0	1.3
	47C3	0.10	245.73	3.13			874.6	1.3
Horse Creek	5400	1.25	99.66	15.04			320.7	1.3
	54A2	0.10	194.06	2.36			467.1	1.3
School Creek	64B0	0.49	223.48	13.21			147.9	1.3
	64B1	0.28	190.19	6.36			582.7	1.3
	64B2	0.05	164.94	1.03			499.2	1.3

(1) AGI is the product of Drainage Area and mean Basin Slope
(2) Parameters BS and Gf after Lowham (1988)

TABLE 3-4 (Continued)

FLOOD DISCHARGES

DRAINAGE		Rainfall Runoff Analysis		Regional Analysis		Ratio of Computed Discharges	
		Max 10-Year Discharge (cfs)	Max 100-Year Discharge (cfs)	Max 10-Year Discharge (cfs)	Max 100-Year Discharge (cfs)	10-Year Regional/ Rainfall-Runoff	100-Year Regional/ Rainfall-Runoff
Russel Draw	0500	217.0	813.9	404.4	1230.5	1.86	1.51
	05B0	152.8	589.7	371.7	1346.0	2.43	2.28
Unnamed Trib.	07E0	100.9	377.4	304.9	1100.0	3.02	2.91
Rawhide Creek	07D3	18.8	78.2	58.2	206.4	3.09	2.64
	07D4	52.1	220.7	130.6	459.9	2.51	2.08
Love Tree Prong	12B0	68.5	278.5	179.3	576.0	2.62	2.07
	12B1	36.1	153.0	119.3	421.7	3.31	2.76
	12B2	25.4	104.7	69.5	260.5	2.74	2.49
Windmill Draw	0900	248.5	942.9	487.7	1707.0	1.96	1.81
	09D1	27.6	115.8	74.5	263.7	2.70	2.28
Unnamed Trib.	19A1	34.7	130.7	78.9	276.9	2.27	2.12
Bone Pile Creek	19A2	75.2	286.5	147.6	512.6	1.96	1.79
	19B2	31.5	117.3	81.2	297.1	2.58	2.53
Theilen Draw	22B0	120.3	404.7	179.8	589.6	1.49	1.46
	22C0	102.9	345.1	157.2	470.9	1.53	1.36
	22B1	29.9	97.2	52.6	188.6	1.76	1.94
	22B2	26.8	89.0	51.4	181.8	1.92	2.04
	22C2	81.3	276.3	154.6	525.4	1.90	1.90
Unnamed Trib.	30A0	38.3	159.4	109.4	384.7	2.86	2.41
Belle Fourche	30B0	37.8	158.4	121.6	429.2	3.22	2.71
	30A1	14.0	58.2	47.3	168.4	3.38	2.89
E. Fk. Hay Ck	36A0	81.5	302.5	151.3	514.5	1.86	1.70
H A Creek	4700	226.3	889.7	563.4	1836.1	2.49	2.06
	47C0	86.4	351.2	223.4	701.6	2.59	2.00
	47C2	36.2	161.2	102.7	343.7	2.84	2.13
	47C3	15.8	69.5	58.3	212.8	3.69	3.06
Horse Creek	5400	101.8	360.6	254.9	811.2	2.50	2.25
	54A2	16.5	64.7	51.6	175.9	3.13	2.72
School Creek	64B0	59.0	259.6	129.7	382.8	2.20	1.47
	64B1	33.7	148.3	108.4	374.3	3.22	2.52
	64B2	7.9	34.5	31.2	108.3	3.96	3.14

TABLE 3-5. GLENROCK AREA DATA

BASIN PARAMETERS

DRAINAGE	Drainage Area (mi2)	Mean Basin Slope BS (ft/mi)	AGI (1) (Acres)	Rainfall Runoff Analysis		Regional Analysis (2)	
				Curve Number	Minimum Infiltration Rate (in/hr)	Basin Slope SB (ft/mi)	Geographical Factor Gf
SS-1	2.80	130.58	44.32	80	0.1	498.95	1.1
SS-2	2.90	139.44	49.02			420.19	1.1
SS-3	0.30	276.42	10.05			940.03	1.1
SS-4	0.60	302.48	22.00			442.01	1.1
SS-5	0.30	200.00	7.27			663.20	1.1
SS-6	0.10	326.53	3.96			508.9	1.1
SS-7	3.40	124.63	51.36			64.17	1.1
SS-8	2.80	131.15	44.51			560.42	1.1
SS-9	5.90	123.97	88.66			497.05	1.1
SS-10	2.90	137.72	48.41			604.28	1.1
SS-11	1.10	169.93	22.66			581.54	1.1
SS-12	0.50	229.51	13.91			595.34	1.1

(1) AGI is the product of Drainage Area and mean Basin Slope
(2) Parameters Pr and Gf after Lowham (1988)

FLOOD DISCHARGES

DRAINAGE	Rainfall Runoff Analysis		Regional Analysis		Ratio of Computed Discharges	
	Max 10-Year Discharge (cfs)	Max 100-Year Discharge (cfs)	10-Year Discharge (cfs)	100-Year Discharge (cfs)	10-Year Regional/ Rainfall-Runoff	100-Year Regional/ Rainfall-Runoff
SS-1	419.28	1158.33	359.44	1191.76	0.86	1.03
SS-2	477.23	1328.42	357.50	1162.74	0.75	0.88
SS-3	83.26	227.53	103.73	377.17	1.25	1.66
SS-4	171.46	466.31	145.68	483.83	0.85	1.04
SS-5	80.14	220.52	98.79	345.67	1.23	1.57
SS-6	40.68	105.96	44.08	151.78	1.08	1.43
SS-7	466.93	1286.60	298.75	789.10	0.64	0.61
SS-8	408.74	1142.05	365.34	1226.88	0.89	1.07
SS-9	778.97	2152.02	526.01	1732.05	0.68	0.80
SS-10	410.49	1140.13	376.15	1273.31	0.92	1.12
SS-11	245.40	684.12	218.11	741.95	0.89	1.08
SS-12	133.89	366.95	135.49	465.88	1.01	1.27

TABLE 3-6. ROCK SPRINGS AREA HYDRAULIC DATA

			Rainfall Runoff Analysis								Regional Analysis							
			Max 10-Year Event				Max 100-Year Event				10-Year Event				100-Year Event			
	DRAINAGE	Channel Slope	FLOW AREA	VEL	DEPTH	TOPWID	FLOW AREA	VEL	DEPTH	TOPWID	FLOW AREA	VEL	DEPTH	TOPWID	FLOW AREA	VEL	DEPTH	TOPWID
RAINBOW/	3	0.072	0.51	2.37	0.30	2.90	2.05	2.39	0.62	11.65	1.82	2.42	0.60	10.06	5.21	3.13	0.82	18.20
COLONY	4	0.077	1.72	3.60	0.63	4.30	5.79	5.27	1.35	6.82	3.69	4.55	1.02	5.87	9.63	5.93	1.85	8.90
	5	0.134	0.92	3.49	0.63	2.43	2.92	5.10	1.28	3.67	2.16	4.64	1.06	3.26	5.70	6.18	1.93	4.87
	6	0.038	2.03	3.94	0.63	4.22	7.23	5.99	1.59	6.57	4.51	5.17	1.14	5.47	11.37	6.78	2.16	8.08
	7	0.051	2.21	3.85	0.66	4.76	6.53	6.19	1.49	5.56	3.92	5.00	1.00	5.15	9.29	7.09	1.97	5.97
	7a	0.070	0.39	2.28	0.27	2.40	1.10	3.45	0.53	2.99	1.08	3.42	0.52	2.97	2.86	4.89	1.03	4.02
	7'	0.048	0.83	3.24	0.63	2.63	2.69	4.50	1.15	4.38	2.04	4.16	1.00	3.90	5.21	5.81	1.68	5.16
	12a	0.128	0.26	2.29	0.21	1.68	0.77	3.24	0.46	2.40	0.80	3.25	0.47	2.44	2.25	4.54	0.96	3.49
	12b	0.131	0.07	1.47	0.11	0.96	0.23	2.17	0.24	1.59	0.30	2.34	0.28	1.79	1.30	2.46	0.61	7.01
	13	0.087	0.68	3.09	0.47	2.33	2.14	4.53	0.98	3.40	1.77	4.29	0.87	3.16	4.67	5.85	1.61	4.49
	15	0.049	1.36	3.52	0.53	3.64	4.88	5.31	1.28	5.71	3.55	4.74	1.03	5.09	10.15	5.63	2.00	10.41
	16	0.026	1.91	3.24	0.94	5.04	6.75	4.89	1.73	9.18	3.99	4.73	1.32	5.76	11.72	5.43	2.15	13.74
	16a	0.058	0.57	2.61	0.36	2.83	1.81	3.59	0.69	4.55	1.53	3.40	0.63	4.31	4.25	4.56	1.14	6.74
	24	0.049	1.08	3.05	0.51	3.88	3.18	4.56	0.98	4.92	2.35	4.09	0.80	4.58	5.90	5.74	1.48	5.89
	25	0.100	0.53	2.84	0.33	2.15	1.54	4.21	0.74	2.84	1.37	4.01	0.67	2.73	3.67	5.56	1.37	3.89
	28	0.078	0.93	2.16	0.20	6.29	2.52	3.62	0.45	6.58	2.16	3.28	0.39	6.52	5.20	4.94	0.84	7.03
	31	0.075	0.27	2.24	0.30	1.77	0.78	3.09	0.53	2.61	0.81	3.20	0.55	2.65	2.34	4.36	1.01	4.02
BRIDGER	9-5MW	0.017	22.94	7.81	2.93	13.57	53.02	10.48	4.76	19.36	20.44	7.28	2.75	12.97	47.96	10.14	4.49	16.52
	LTD	0.004	179.91	5.12	3.35	73.84	467.00	7.37	5.55	221.99	118.33	4.02	2.42	63.43	226.79	5.79	3.94	85.51
	MDW	0.010	59.14	9.65	4.64	17.78	189.21	12.53	8.60	64.84	50.47	8.75	4.15	17.20	100.73	12.82	6.66	27.34
	NW	0.009	60.27	9.51	4.65	20.42	276.29	11.08	7.99	124.16	44.54	8.00	3.74	15.91	128.75	10.51	6.44	66.83
	TDT	0.010	46.23	6.51	3.57	22.89	100.34	8.58	5.52	32.62	38.46	6.11	3.22	21.14	82.36	7.97	4.95	29.74
	UDT	0.010	67.93	5.72	2.60	42.92	134.55	8.21	4.06	48.22	55.80	5.10	2.31	41.88	107.23	7.34	3.48	46.12

TABLE 3-7. HANNA AREA HYDRAULIC DATA

			Rainfall Runoff Analysis								Regional Analysis							
			Max 10-Year Event				Max 100-Year Event				10-Year Event				100-Year Event			
	DRAINAGE	Channel Slope	FLOW AREA	VEL	DEPTH	TOPWID	FLOW AREA	VEL	DEPTH	TOPWID	FLOW AREA	VEL	DEPTH	TOPWID	FLOW AREA	VEL	DEPTH	TOPWID
HANNA/ELMO	1	0.016	3.70	3.48	0.96	6.77	10.35	4.67	1.65	12.20	7.21	4.13	1.372	10.27	17.28	5.91	2.184	13.7
	1a	0.106	0.59	3.07	0.47	2.05	1.47	3.94	0.81	3.11	1.54	4.02	0.829	3.15	4.25	5.6	1.542	4.44
	2	0.047	5.06	4.51	1.29	8.32	14.44	6.39	2.23	11.71	9.19	5.49	1.74	9.97	22.81	7.32	2.875	14.03
	3	0.082	2.74	3.75	0.63	6.40	7.37	5.10	1.22	9.21	5.32	4.62	0.987	8.12	13.93	6.19	1.843	11.94
	4	0.109	2.35	2.89	0.61	9.61	6.03	3.88	0.93	13.38	4.76	3.61	0.835	12.21	12.68	4.84	1.357	17.97
	5	0.057	3.12	4.20	0.82	5.78	8.95	5.81	1.63	8.70	6.4	5.28	1.315	7.54	16.7	6.88	2.395	11.58
	6	0.198	1.60	3.06	0.43	5.62	4.19	4.08	0.81	8.13	3.53	3.94	0.727	7.46	9.87	5.12	1.366	12.2
	7	0.090	3.17	3.10	0.51	10.91	7.96	4.41	0.89	13.48	5.94	3.9	0.736	12.91	14.47	5.6	1.343	15.13
	8	0.053	0.41	2.42	0.27	2.32	1.03	3.21	0.49	3.27	1.22	3.37	0.546	3.52	3.44	4.68	1.058	5.11
	9	0.097	0.36	2.77	0.37	1.56	0.87	3.78	0.65	2.01	1.03	4	0.723	2.11	2.89	5.56	1.449	3.04
ROSEBUD	BS4	0.012	23.21	3.88	2.29	28.88	62.63	6.47	3.46	35.64	48.62	5.59	3.063	34.53	96.79	8.21	4.392	37.83
	PD4	0.009	13.42	3.32	1.53	17.45	57.15	6.14	2.90	46.05	40.08	5.22	2.486	37.06	99.6	7.65	3.652	67.91

TABLE 3-8. KEMMERER AREA HYDRAULIC DATA

			Rainfall Runoff Analysis								Regional Analysis							
			Max 10-Year Event				Max 100-Year Event				10-Year Event				100-Year Event			
		Channel	FLOW				FLOW				FLOW				FLOW			
	DRAINAGE	Slope	AREA	VEL	DEPTH	TOPWID	AREA	VEL	DEPTH	TOPWID	AREA	VEL	DEPTH	TOPWID	AREA	VEL	DEPTH	TOPWID
P&M	T2	0.017	12.05	3.25	0.74	26.36	27.46	5.38	1.31	27.84	24.72	5.08	1.21	27.58	56.52	7.03	2.18	56.90
	T4	0.026	17.55	4.58	1.11	28.16	54.95	7.20	2.30	34.99	23.47	5.13	1.32	29.35	51.21	7.00	2.19	34.37
	M11	0.025	29.14	3.80	1.52	67.41	69.41	5.12	2.05	78.80	39.27	4.23	1.66	75.98	86.39	5.59	2.26	79.93

TABLE 3-9. POWDER RIVER BASIN AREA HYDRAULIC DATA

			Rainfall Runoff Analysis								Regional Analysis							
			Max 10-Year Event				Max 100-Year Event				10-Year Event				100-Year Event			
		Channel	FLOW				FLOW				FLOW				FLOW			
	DRAINAGE	Slope	AREA	VEL	DEPTH	TOPWID	AREA	VEL	DEPTH	TOPWID	AREA	VEL	DEPTH	TOPWID	AREA	VEL	DEPTH	TOPWID
WESCHE																		
Russel Draw	0500	0.0142	37.89	5.73	1.94	31.10	100.06	8.13	3.54	48.47	59.13	6.84	2.57	37.00	137.85	8.93	4.26	56.55
	05B0	0.0112	34.01	4.49	2.03	33.46	93.90	6.28	3.38	55.60	66.38	5.60	2.84	46.75	252.21	5.34	4.76	193.31
Unnamed Trib.	07E0	0.0226	22.85	4.42	1.09	37.88	59.06	6.39	1.95	46.48	50.10	6.09	1.75	44.54	130.04	8.46	3.29	59.64
Rawhide Creek	07D3	0.0100	12.81	1.47	0.36	62.83	31.16	2.51	0.64	68.44	25.67	2.25	0.56	66.67	58.17	3.55	1.01	75.96
	07D4	0.0340	15.77	3.30	0.39	47.20	43.73	5.05	0.93	55.45	29.98	4.36	0.66	51.55	74.33	6.19	1.45	63.25
Love Tree Prong	12B0	0.0070	23.41	2.93	1.33	31.10	59.85	4.65	2.34	39.58	44.81	4.00	1.95	37.55	97.19	5.93	3.23	44.14
	12B1	0.0091	18.68	1.93	0.53	56.40	46.81	3.27	0.99	63.85	39.89	2.99	0.88	62.10	90.28	4.67	1.63	72.67
	12B2	0.0119	13.22	1.92	0.44	49.36	36.70	2.85	0.80	75.58	28.55	2.43	0.69	73.93	64.46	4.04	1.15	76.58
Windmill Draw	0900	0.0115	39.78	6.25	3.06	23.31	99.07	9.52	5.24	30.54	62.79	7.77	3.97	26.66	152.24	11.21	6.85	35.58
	09D1	0.0210	12.17	2.27	0.64	53.51	29.26	3.96	0.95	56.32	22.25	3.35	0.83	55.19	50.07	5.27	1.31	59.57
Unnamed Trib.	19A1	0.0168	10.79	3.21	0.96	26.27	26.50	4.93	1.48	33.79	18.79	4.20	1.24	30.48	46.05	6.01	2.01	41.02
Bone Pile Creek	19A2	0.0187	16.63	4.52	1.61	23.73	41.69	6.87	2.55	29.13	25.90	5.70	1.98	25.86	64.96	7.89	3.29	34.09
	19B2	0.0273	8.14	3.87	0.73	17.73	20.21	5.80	1.38	19.68	15.65	5.19	1.14	18.97	40.14	7.40	2.30	23.93
Theilen Draw	22B0	0.0118	26.01	4.29	1.44	30.45	68.21	5.93	2.49	46.13	37.66	4.77	1.73	34.86	90.54	6.51	2.94	53.27
	22C0	0.0206	16.38	6.29	1.91	13.62	63.32	5.45	3.44	63.62	22.68	6.93	2.35	15.50	75.33	6.25	3.62	66.79
	22B1	0.0395	7.20	4.15	0.91	13.77	17.97	5.41	1.53	20.30	11.16	4.70	1.17	16.66	29.79	6.33	2.06	24.46
	22B2	0.0362	6.02	4.45	0.95	9.96	15.13	5.88	1.69	14.39	9.95	5.17	1.31	12.25	27.07	6.72	2.42	19.41
	22C2	0.0126	22.71	3.58	0.87	34.51	50.71	5.45	1.61	40.71	34.55	4.48	1.20	37.26	78.56	6.69	2.25	46.07
Unnamed Trib.	30A0	0.0255	9.60	3.99	1.00	19.84	26.51	5.59	1.77	29.51	21.34	5.13	1.51	26.24	56.24	6.84	2.57	39.69
Belle Fourche	30B0	0.0206	6.36	5.95	1.78	4.65	29.87	5.30	3.47	34.16	22.88	5.31	3.24	26.06	64.24	6.68	4.30	47.46
	30A1	0.0299	4.93	2.84	0.46	20.35	14.22	4.09	0.84	27.93	12.19	3.88	0.77	26.32	31.57	5.33	1.36	36.38
E. Fk. Hay Ck	36A0	0.0117	19.40	4.20	1.36	21.67	46.83	6.46	2.48	27.14	29.32	5.16	1.79	23.80	67.37	7.64	3.19	30.60
H A Creek	4700	0.0014	71.58	3.16	6.18	20.47	190.43	4.67	11.35	23.50	136.92	4.11	9.06	23.50	294.08	6.24	15.77	23.50
	47C0	0.0045	24.25	3.56	2.34	15.96	62.67	5.60	4.53	18.60	45.94	4.86	3.62	17.94	101.62	6.90	6.62	18.60
	47C2	0.0200	14.51	2.49	2.33	52.69	38.58	4.18	2.72	64.73	29.05	3.53	2.57	62.43	62.88	5.47	3.06	70.25
	47C3	0.0109	6.63	2.38	0.59	16.56	17.37	4.00	1.18	19.92	15.44	3.77	1.06	19.36	37.16	5.73	2.07	24.67
Horse Creek	5400	0.0132	21.80	4.67	1.71	22.91	61.60	6.85	2.90	46.84	46.04	5.54	2.53	37.57	107.41	7.55	3.78	54.82
	54A2	0.0346	4.51	3.66	0.59	11.07	13.01	4.97	1.20	17.28	10.90	4.73	1.07	15.95	28.69	6.13	1.94	25.07
School Creek	64B0	0.0076	14.87	3.97	1.97	12.60	44.78	5.80	3.79	21.46	26.21	4.95	2.77	15.88	69.17	5.53	4.65	35.98
	64B1	0.0134	7.90	4.26	1.29	9.35	22.74	6.52	2.57	13.64	18.26	5.94	2.23	12.55	62.34	6.00	4.42	43.54
	64B2	0.0325	2.75	2.87	0.55	10.80	8.76	3.94	0.95	18.77	8.11	3.85	0.91	18.26	21.15	5.12	1.50	26.68

TABLE 3-10. GLENROCK AREA HYDRAULIC DATA

			Rainfall Runoff Analysis								Regional Analysis							
			Max 10-Year Event				Max 100-Year Event				10-Year Event				100-Year Event			
		Channel	FLOW				FLOW				FLOW				FLOW			
	DRAINAGE	Slope	AREA	VEL	DEPTH	TOPWID	AREA	VEL	DEPTH	TOPWID	AREA	VEL	DEPTH	TOPWID	AREA	VEL	DEPTH	TOPWID
JOHNSTON	SS-1	0.0114	132.34	4.68	4.21	105.37	354.30	5.68	5.44	256.61	115.38	4.52	4.03	89.71	363.82	5.71	5.47	261.15
	SS-2	0.0099	76.77	6.22	3.01	43.85	169.25	8.73	4.47	88.85	64.21	5.57	2.72	42.38	147.16	8.54	4.21	79.24
	SS-3	0.0229	23.28	3.58	1.27	30.78	44.94	5.06	1.93	35.10	26.83	3.87	1.39	31.56	63.01	5.99	2.42	38.08
	SS-4	0.0189	38.52	4.45	1.87	38.06	77.31	6.03	2.76	48.16	34.47	4.23	1.76	36.71	79.23	6.11	2.80	48.54
	SS-5	0.0193	30.36	3.38	3.31	28.44	70.75	4.25	4.32	50.17	36.43	3.56	3.51	31.92	99.50	4.66	4.87	54.63
	SS-6	0.0416	14.63	2.78	1.24	20.33	27.90	3.80	1.83	24.50	15.42	2.86	1.27	20.61	35.93	4.22	2.14	26.70
	SS-7	0.0133	58.77	7.94	3.00	30.62	127.70	10.08	4.92	41.21	42.12	7.09	2.43	27.45	87.58	9.01	3.87	35.43
	SS-8	0.0142	62.08	6.58	2.00	46.96	139.60	8.30	3.37	72.01	57.34	6.37	1.90	45.72	149.34	8.40	3.50	76.00
	SS-9	0.0080	398.26	2.17	4.20	146.05	847.31	3.01	6.48	271.85	305.34	1.93	3.56	142.90	710.91	2.80	5.94	234.89
	SS-10	0.0166	59.79	6.87	2.62	42.70	151.64	8.27	4.25	94.19	56.71	6.63	2.55	41.47	178.62	8.22	4.51	113.39
	SS-11	0.0210	37.44	6.55	3.46	21.42	94.73	7.84	5.15	68.62	34.00	6.42	3.30	19.98	109.87	7.70	5.35	82.72
	SS-12	0.0244	52.96	2.53	2.62	43.39	104.55	3.65	3.60	61.31	53.43	2.54	2.63	43.59	124.29	3.98	3.91	66.75

TABLE 3-11. SIEVE ANALYSIS RESULTS, POWDER RIVER BASIN PREMINED CHANNELS

BASIN	X-SEC	SOIL CLASSIFICATION*	% Passin #200	D50 (mm)
Unnamed Trib. Rawhide Creek	07D3	SP	42.50	0.130
	07D4	ML	59.20	0.055
Theilen Draw	22B0	SP	46.10	0.084
	22C0	SP	45.50	0.088
	22B1	ML	84.90	0.037
	22B2	ML	51.60	0.069
	22C2	ML	53.40	0.067
Unnamed Trib. Belle Fourche	30A0	SP	35.10	0.140
	30B0	ML	50.10	0.075
	30A1	ML	51.70	0.070
East Fork Hay Creek	36A0	SP	13.90	0.300
H A Creek	4700	GW	1.40	6.900
	47C0	SW	1.70	4.100
	47C2	SP	25.90	0.210
	47C3	ML	69.70	0.040
Horse Creek	54A2	SP	2.90	0.350
School Creek	64B0	SP	3.70	4.300
	64B1	SW	4.00	1.900
	64B2	SP	14.80	0.730

NOTES:

* SOIL CLASSIFICATION DESCRIPTION
GW - Well-graded gravels and gravel-sand mixtures, little or no fines
ML - Inorganic silts, very fine sands, rock flour, silty or clayey fine sands
SP - Poorly graded sands and gravelly sands, little or no fines
SW - Well-graded sands and gravelly sands, little or no fines

"% Passing #200" represents the percent of sample passing the #200 standard sieve
"D50" represents median grain size in millimeters

During regression analysis, it was noted that drainage area could serve equally as well as an independent basin parameter as AGI; drainage area is simpler to derive than AGI and gave strong correlations with channel slope and hydraulic parameters. Confidence intervals are plotted about the mean regression line and provide a range of acceptable design criteria for the stability test. The stability test is described in an example application in a later section.

3.4.1 Rock Springs Area

The results of the regression analysis for the Rock Springs area are presented in Table 3-12. Figures presenting these results graphically, including one- and two-tailed confidence bands as described in the Methods section, are included in Appendix A.

As can be seen from the correlation coefficients and the graphics, both the rainfall-runoff and regional analyses show very good correlation, with correlation coefficients in the 0.80 to 0.99 range. Of the more important design parameters, (channel slope, flow area, and flow velocity) flow area consistently shows the highest degree of correlation with drainage basin parameters. Nevertheless, good results were also obtained for flow velocity and channel slope as well as the channel shape variables of flow depth and topwidth. It would have been desirable to have a continuous range of drainage basin sizes but the availability of data from mine permit applications limited the selection of drainage basins.

3.4.2 Hanna Area

The results of the regression analysis for the Hanna area are presented in Table 3-13. Appendix B contains figures presenting these results graphically along with one and two-tailed confidence bands.

The Hanna area results mirror those found for the Rock Springs area. Excellent correlation exists between the drainage basin parameters of drainage area and AGI against the hydraulic channel parameters. Flow area, again, exhibits the strongest relationships. However, very high correlation coefficients also were found for channel slope and flow velocity. Similar again to the Rock Springs data set, a more continuous range of drainage basins sizes would have been desirable.

TABLE 3-12. REGRESSION RESULTS FOR ROCK SPRINGS AREA (1)

where, DA = Drainage Area ($mi.^2$)
AGI = Area Gradient Index (acres)

and $Y = Bo * (X)^{B1}$

Dependent Parameter, Y	Independent Parameter, X	B0	B1	Correlation Coefficient, r
Channel Slope	DA	0.021	-0.302	0.95
	AGI	0.474	0.943	0.90
RAINFALL-RUNOFF ANALYSIS				
10-Year Flow Area	DA	10.138	0.685	0.996
	AGI	0.478	0.938	0.99
10-Year Flow Velocity	DA	4.957	0.147	0.94
	AGI	2.557	0.205	0.95
10-Year Flow Depth	DA	1.483	0.339	0.97
	AGI	0.323	0.471	0.98
10-Year Flow Topwidth	DA	10.875	0.340	0.96
	AGI	2.396	0.463	0.94
100-Year Flow Area	DA	29.725	0.668	0.996
	AGI	1.507	0.916	0.99
100-Year Flow Velocity	DA	6.895	0.139	0.92
	AGI	3.689	0.194	0.94
100-Year Flow Depth	DA	2.742	0.312	0.97
	AGI	0.676	0.433	0.98
100-Year Flow Topwidth	DA	21.197	0.400	0.94
	AGI	3.603	0.541	0.92
REGIONAL ANALYSIS				
10-Year Flow Area	DA	13.082	0.510	0.99
	AGI	1.341	0.700	0.99
10-Year Flow Velocity	DA	5.257	0.085	0.80
	AGI	3.568	0.121	0.82
10-Year Flow Depth	DA	1.731	0.227	0.95
	AGI	0.624	0.316	0.96
10-Year Flow Topwidth	DA	11.706	0.270	0.91
	AGI	3.524	0.367	0.90
100-Year Flow Area	DA	30.946	0.469	0.99
	AGI	3.805	0.643	0.98
100-Year Flow Velocity	DA	7.186	0.093	0.81
	AGI	4.702	0.132	0.83
100-Year Flow Depth	DA	2.954	0.205	0.95
	AGI	1.177	0.285	0.95
100-Year Flow Topwidth	DA	18.523	0.266	0.88
	AGI	5.723	0.356	0.85

(1) n = 23 drainages

TABLE 3-13. REGRESSION RESULTS FOR HANNA AREA (1)

where, DA = Drainage Area ($mi.^2$)
AGI = Area Gradient Index (acres)

and Y = $Bo * (X)^{B1}$

Dependent Parameter, Y	Independent Parameter, X	B0	B1	Correlation Coefficient, r
Channel Slope	DA	0.019	-0.355	0.76
	AGI	1.032	1.186	0.73
RAINFALL-RUNOFF ANALYSIS				
10-Year Flow Area	DA	13.981	0.598	0.98
	AGI	1.137	0.739	0.99
10-Year Flow Velocity	DA	3.907	0.056	0.65
	AGI	3.066	0.076	0.72
10-Year Flow Depth	DA	1.608	0.287	0.95
	AGI	0.487	0.348	0.94
10-Year Flow Topwidth	DA	19.113	0.379	0.92
	AGI	3.899	0.470	0.93
100-Year Flow Area	DA	44.071	0.647	0.98
	AGI	2.946	0.793	0.99
100-Year Flow Velocity	DA	6.276	0.010	0.89
	AGI	4.139	0.122	0.89
100-Year Flow Depth	DA	2.774	0.279	0.95
	AGI	0.867	0.338	0.94
100-Year Flow Topwidth	DA	31.615	0.414	0.93
	AGI	5.576	0.511	0.94
REGIONAL ANALYSIS				
10-Year Flow Area	DA	29.201	0.573	0.99
	AGI	2.696	0.689	0.98
10-Year Flow Velocity	DA	5.304	0.067	0.81
	AGI	4.025	0.079	0.78
10-Year Flow Depth	DA	2.233	0.212	0.94
	AGI	0.825	0.282	0.90
10-Year Flow Topwidth	DA	27.023	0.387	0.93
	AGI	5.377	0.472	0.93
100-Year Flow Area	DA	66.648	0.534	0.99
	AGI	1.309	0.641	0.97
100-Year Flow Velocity	DA	7.513	0.075	0.87
	AGI	5.510	0.087	0.82
100-Year Flow Depth	DA	3.393	0.195	0.92
	AGI	1.519	0.227	0.87
100-Year Flow Topwidth	DA	37.617	0.378	0.92
	AGI	7.768	0.459	0.91

(1) n = 12 drainages

3.4.3 Kemmerer Area

As only three basins were available for study in existing permits, the Kemmerer area has insufficient data to develop regression relationships. These data were used to test differences between study areas which are discussed in a later section.

3.4.4 Powder River Basin Area

In addition to the standard regression analyses performed to assess the use of basin parameters to predict measured channel slope and computed hydraulic parameters, channel bed sediment data were available for 19 of the 31 basins. To be consistent, results obtained from the entire data set of 31 basins, without the benefit of bed sediment data will be presented first. Subsequent sections will discuss results based on the use of bed sediment data.

3.4.4.1 General Regressions

The results of the regression analysis are presented in Table 3-14. Figures presenting these results graphically, including confidence bands, are contained in Appendix C.

Regressions for the Powder River Basin show good results for the determination of flow area and flow depth. In contrast with results from previously presented study areas, regression coefficients are less strong for channel slope and flow velocity, and this is reflected in the wider confidence bands determined for these relationships. Very poor regressions were found for the determination of flow topwidth. A portion of the poor relationships encountered may be explained by the fact that this data set encompasses, by far, the largest geographical area of the data sets studied.

The inherent assumption in the regression relationships thus far derived is that the unaccounted for sources of variation within each data set are minimized by selecting basins within a relatively close geographical area. This assumption breaks down when large geographical areas are used.

To this end, methods of dividing the Powder River Basin data set into distinct areas were investigated. The most recent work related to this effect is provided in Jensen (1994) and Anderson (1994). In these related studies, the morphology of drainage basins (shape and size) were found to be influenced primarily by the lithologic unit into which the channels are cut. To

TABLE 3-14. REGRESSION RESULTS FOR POWDER RIVER BASIN AREA (1)

where, DA = Drainage Area ($mi.^2$)
AGI = Area Gradient Index (acres)

and $Y = Bo * (X)^{B1}$

Dependent Parameter, Y	Independent Parameter, X	B0	B1	Correlation Coefficient, r
Channel Slope	DA	0.011	-0.362	0.61
	AGI	0.036	-0.415	0.55
RAINFALL-RUNOFF ANALYSIS				
10-Year Flow Area	DA	24.437	0.556	0.91
	AGI	3.124	0.718	0.91
10-Year Flow Velocity	DA	4.138	0.148	0.49
	AGI	2.484	0.173	0.45
10-Year Flow Depth	DA	1.741	0.448	0.79
	AGI	0.385	0.508	0.69
10-Year Flow Topwidth	DA	24.683	0.084	0.16
	AGI	15.535	0.181	0.27
100-Year Flow Area	DA	65.958	0.550	0.94
	AGI	8.722	0.705	0.94
100-Year Flow Velocity	DA	5.902	0.138	0.58
	AGI	3.605	0.170	0.56
100-Year Flow Depth	DA	3.105	0.449	0.82
	AGI	0.683	0.510	0.72
100-Year Flow Topwidth	DA	37.057	0.099	0.23
	AGI	22.848	0.184	0.34
REGIONAL ANALYSIS				
10-Year Flow Area	DA	44.291	0.491	0.92
	AGI	7.326	0.626	0.91
10-Year Flow Velocity	DA	5.216	0.127	0.54
	AGI	3.366	0.149	0.49
10-Year Flow Depth	DA	2.466	0.415	0.79
	AGI	0.620	0.462	0.68
10-Year Flow Topwidth	DA	30.733	0.061	0.14
	AGI	21.510	0.142	0.25
100-Year Flow Area	DA	110.800	0.487	0.94
	AGI	18.516	0.623	0.93
100-Year Flow Velocity	DA	6.952	0.106	0.56
	AGI	4.820	0.124	0.51
100-Year Flow Depth	DA	4.195	0.405	0.81
	AGI	1.082	0.454	0.71
100-Year Flow Topwidth	DA	47.329	0.099	0.23
	AGI	28.698	0.192	0.35

(1) n = 31 drainages

discuss differences in near surface geology of Powder River Basin channels, a classification of A, B, and C was developed (termed "stratum" by Jensen (1994) and Anderson (1994)). "Stratum A" was applied to channels dominantly within the Fort Union formation with a broad range of basin sizes (0.48-7.43 square miles), "Stratum B" indicates Wasatch and Fort Union formation combined, with smaller basin areas (less than 2.6 square miles), and "Stratum C" was assigned to large basins solely in the Wasatch formation (2.58 to 8.65 square miles).

The "stratum" classification system was tested to see if stronger regression relationships could be derived on the basis of drainage basin lithology. The data set contains nine Strata A basins, nine Strata B basins, and 13 Strata C basins. Only the Strata C basins were significantly different from the rest of the Powder River Basin data. Regression results obtained by splitting the data set along Strata A/B and Strata C division lines show improved correlation coefficients for the Strata A/B data set, but reduced correlation coefficients for the Strata C.

3.4.4.2 Regressions with Channel Bed Sediment Data

Channel bed sediment data were derived for 19 of the 31 basins in the Powder River Basin study area. An analysis of the bed sediment results according to basin strata are summarized below.

	n	Mean D_{50} (mm)	Std. Dev.	Mean % passing #200 sieve	Std. Dev.
Strata A	7	2.60	2.59	17%	25%
Strata B	5	0.19	0.13	31%	22%
Strata C	7	0.08	0.03	55%	14%

These results show the differences between strata found by Anderson (1994) and Jensen (1995), are apparent in the bed sediment data. The Strata A basins have predominantly larger sized bed sediment material, the Strata B consists of a fairly consistent band of mid-sized bed sediments and the Strata C basins contain, quite uniformly, the smallest bed sediment materials.

This may help to explain the previously mentioned findings, that regression correlation coefficients significantly improved with the removal of the Strata C basins and that poorer relationships existed amongst the remaining Strata C basins when considered alone. As the amount of silt and clay material increases in soils, cohesive forces which are difficult to characterize, become more significant.

To test this theory, the 19 basins with bed sediment data were divided according to those with 20% of material passing the #200 sieve. These result are presented in Table 3-15. Correlation coefficients above 0.97 were found for channel slope, flow area and flow depth. Correlation coefficients for flow velocity and topwidth, however, showed marked declines.

Another approach to include bed sediment in the predictive process is to include a bed sediment parameter as an independent variable in a multiple regression. These regression results are also presented in Table 3-15. The resulting correlation coefficient values show the strength of the derived relationships improved with the addition of D_{50} data and statistical test confirmed the significance of this parameter in predicting channel slope, flow area and flow depth. However, good relationships ($R^2 < 0.50$) were not found for flow velocity or flow topwidth.

These results, taken together, seem to support channel sediment as an important parameter in the formation of channels in the Powder River Basin; this probably holds true of all of the study areas. However, differences in channel sediments in smaller geographical areas, typical of the other study areas examined, were insufficient to detract from the strength of the resulting correlation coefficients.

3.4.5 Glenrock Area

The results of the regression analysis are presented in Table 3-16. Figures presenting these results graphically, including one and two-tailed confidence bands are presented in Appendix D. Good correlations were found for channel slope and flow area. Acceptable regression results were obtained for flow depth and topwidth. Flow velocity, however did not show good correlation with either drainage area or AGI. A larger spread of drainage basin sizes may have helped this situation.

TABLE 3-15. REGRESSION RESULTS FOR POWDER RIVER BASIN AREA WITH BED SEDIMENT DATA

Results with channels with less than 20% of bed sediment material passing the #200 sieve (n=7)

where, DA = Drainage Area ($mi.^2$)

and Y = Bo * $(X)^{B1}$

Dependent Parameter, Y	Independent Parameter, X	B0	B1	Correlation Coefficient, r
Channel Slope	DA	0.005	-0.734	0.98
RAINFALL-RUNOFF ANALYSIS				
10-Year Flow Area	DA	24.301	0.722	0.99
10-Year Flow Velocity	DA	3.657	0.006	0.06
10-Year Flow Depth	DA	2.455	0.547	0.99
10-Year Flow Topwidth	DA	16.042	0.157	0.72
100-Year Flow Area	DA	65.467	0.683	0.99
100-Year Flow Velocity	DA	5.495	0.030	0.24
100-Year Flow Depth	DA	4.653	0.548	0.99
100-Year Flow Topwidth	DA	20.829	0.064	0.43

Results using D50 of bed sediment material as independent parameter (n=19)

where, DA = Drainage Area ($mi.^2$)
D_{50} = Median Grain Size (mm)

and Y = Bo * $(X_1)^{B1}$ * $(X_2)^{B1}$

Dependent Parameter, Y	Independent Parameter, X	B0	B1	B2	Correlation Coefficient, r
Channel Slope	DA, D50	0.006	-0.481	-0.162	0.84
RAINFALL-RUNOFF ANALYSIS					
10-Year Flow Area	DA, D50	25.017	0.699	-0.076	0.93
10-Year Flow Velocity	DA, D50	3.859	0.119	-0.045	0.36
10-Year Flow Depth	DA, D50	2.288	0.465	0.089	0.82
10-Year Flow Topwidth	DA, D50	18.804	0.172	-0.124	0.33
100-Year Flow Area	DA, D50	70.426	0.690	-0.066	0.97
100-Year Flow Velocity	DA, D50	5.445	0.089	-0.017	0.39
100-Year Flow Depth	DA, D50	4.230	0.473	0.090	0.87
100-Year Flow Topwidth	DA, D50	28.981	0.220	-0.176	0.56

TABLE 3-16. REGRESSION RESULTS FOR GLENROCK AREA (1)

where, DA = Drainage Area ($mi.^2$)
AGI = Area Gradient Index (acres)

and $Y = Bo * (X)^{B1}$

Dependent Parameter, Y	Independent Parameter, X	B0	B1	Correlation Coefficient, r
Channel Slope	DA	0.017	-0.318	0.91
	AGI	0.065	-0.426	0.90
RAINFALL-RUNOFF ANALYSIS				
10-Year Flow Area	DA	51.172	0.564	0.84
	AGI	4.778	0.763	0.85
10-Year Flow Velocity	DA	4.345	0.158	0.46
	AGI	2.326	0.201	0.43
10-Year Flow Depth	DA	2.482	0.219	0.68
	AGI	1.069	0.272	0.62
10-Year Flow Topwidth	DA	40.078	0.305	0.67
	AGI	10.759	0.423	0.68
100-Year Flow Area	DA	112.344	0.611	0.87
	AGI	8.834	0.819	0.86
100-Year Flow Velocity	DA	5.710	0.141	0.45
	AGI	3.229	0.184	0.43
100-Year Flow Depth	DA	3.681	0.246	0.79
	AGI	1.410	0.309	0.73
100-Year Flow Topwidth	DA	67.174	0.427	0.75
	AGI	11.509	0.568	0.74
REGIONAL ANALYSIS				
10-Year Flow Area	DA	48.124	0.467	0.79
	AGI	6.818	0.629	0.79
10-Year Flow Velocity	DA	4.240	0.117	0.35
	AGI	2.707	0.145	0.32
10-Year Flow Depth	DA	2.389	0.167	0.57
	AGI	1.288	0.199	0.50
10-Year Flow Topwidth	DA	39.148	0.273	0.62
	AGI	12.105	0.378	0.63
100-Year Flow Area	DA	122.276	0.485	0.79
	AGI	16.574	0.644	0.77
100-Year Flow Velocity	DA	5.864	0.089	0.31
	AGI	4.121	0.114	0.29
100-Year Flow Depth	DA	3.823	0.174	0.68
	AGI	1.975	0.213	0.61
100-Year Flow Topwidth	DA	69.690	0.383	0.69
	AGI	14.467	0.506	0.68

(1) n = 12 drainages

3.5 Geographic Transferability of Regression Results

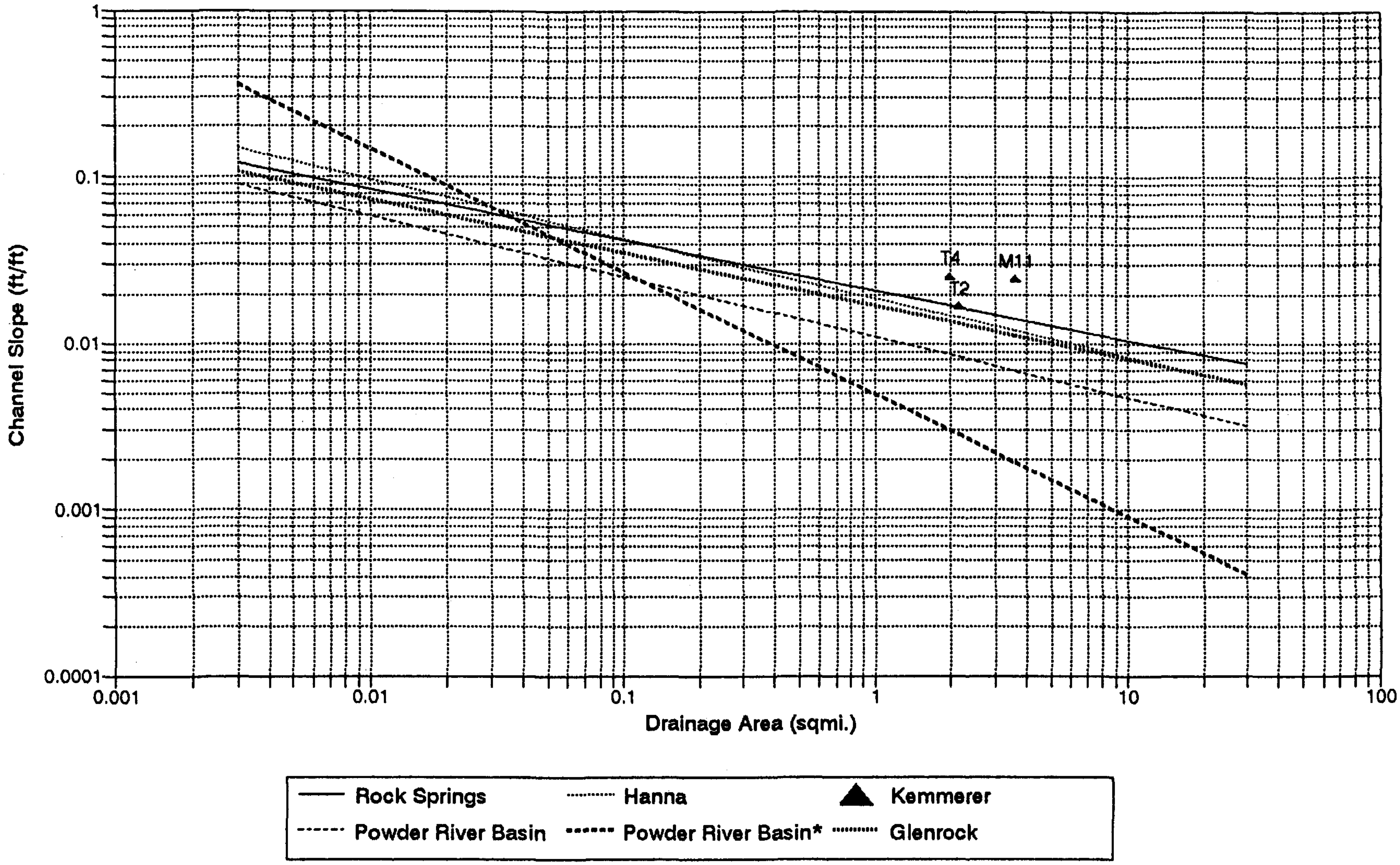
In WWC's 1993 work it was found that there were no significant differences between natural channel data for the Rock Springs and Hanna areas and, therefore, the two sites could be considered one population. Analyses were performed to test whether or not regression equations are applicable to larger areas. Figure 3-1 presents the results for each of the four study areas using drainage area to predict channel slope. As can be seen, and as was borne out in the performance of statistical tests, only the Powder River Basin area is significantly different from the derived relationships for the other study areas (Rock Springs, Hanna, and Glenrock).

Checks of the significance of geographical factors for the remaining hydraulic parameters revealed a variety of results which, in general, showed the existence of differences between study sites, especially where very strong local regression relationships were found.

In general, these results indicate that when available, data from nearby channels is preferred. This result was not completely unexpected. Differences between study sites probably are manifested in a continuous manner. The inherent assumption in the relatively simple relationships thus far derived is that unaccounted for sources of variation within each data set are minimized by selecting basins within a relatively close geographical area. As basins from further distances are grouped together, more opportunities exist for variation. The results presented in Figure 3-1 shows the relationships between drainage area and channel slope to be similar for Rock Springs, Hanna, Kemmerer and Glenrock.

Since the Kemmerer study site lacked sufficient data to determine local regression coefficients, Kemmerer data were tested with the Rock Springs data set to determine the existence of statistical differences. The limited Kemmerer data were not statistically different from the Rock Springs data. Until better local equations are determined for the Kemmerer area, the regression equations and graphs derived for the Rock Springs area be used as a guide to the selection of appropriate ephemeral channel design values for the Kemmerer area.

Figure 3-1. Regression Lines for
Channel Slope by Study Area



* Powder River Channels with less than 20% passing the #200 sieve

3.6 Channel Design Example and Stability Evaluation

To illustrate the use of our stability assessment of a channel design based on regression results, a hypothetical example is provided. Suppose a mine in the Powder River Basin is faced with reclaiming an ephemeral channel. The basin to be reclaimed is situated within the range of premined ephemeral channel information presented in this report, has a drainage basin area of 0.5 mi^2, and no bed sediment data are available. Using the graphs presented in Appendix C (Figures C-1 through C-5), the following characteristics are determined based on varying levels of confidence for the 100-year event determined by rainfall-runoff analysis.

	Confidence Level		
Parameter	99%	90%	50%[(1)]
channel slope, (ft/ft)	.011	.013	.014
flow area, (ft^2)	52	49	45
flow velocity, (fps)	4.8	5.1	5.4
flow depth, (ft)	--	--	2.3
flow topwidth, (ft)	--	--	35

[(1)] As depicted by mean regression line

Depending on the level of confidence determined suitable for the channel to be reclaimed, then the above parameters represent the criteria to which the complete reclaimed channel design should conform. To complete the design, the designer should also examine hydraulic performance during the 10-year event and consider the suitability of a low-flow guide channel.

4.0 CONCLUSIONS

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4.0 CONCLUSIONS

Design and evaluation of stable, reclaimed channels at active and abandoned coal mines in Wyoming and throughout the western U.S. will continue to be a challenging endeavor. While field-based methods of evaluating channel stability are most desirable, the infrequency of channel-modifying events, the remoteness of many reclaimed channel projects, and the cost of field monitoring equipment renders a real-time assessment infeasible.

Channel reclamation design and regulatory evaluation of designs can be improved, in spite of a lack of field data, with knowledge of the premined physical characteristics of the landscape to be mined or slated for reclamation. We have shown that accurate information on drainage basin area allows prediction of channel design parameters of cross sectional flow area, channel topwidth, depth, and slope. Prediction of channel properties is strengthened by including bed sediment grain-size.

Channel slope and flow velocity were previously uncorrelated with independent basin parameters (WWC, 1993). It was not until the data sets were expanded, incorporating basins varying by several log factors in size, that relationships for these parameters became evident. Further work along these lines should include a continuous, wide span of drainage basin sizes.

Channel sediment is an important parameter in the formation of channels. If small geographical areas are used, differences in channel sediments are probably insufficient to detract from the strength of the resulting correlations. However, we suspect that information on **both** bed and bank sediments (bank sediment composition influences meander migration, bank undercutting and sloughing), will add additional strength to the predictive equations and allow the determination of more widely applicable design equations. Further work examining the role of channel sediment in ephemeral channel formation would be a fruitful endeavor.

The relationships derived for the computed hydraulic parameters of flow area, velocity, depth and topwidth assumes the existence of a certain level of consistency in the engineering methods used in reclamation design. In this regard, caution must be exercised. Possible variation in the determination of runoff curve numbers and Manning's 'n' values could be significant. Flood derived by regional analysis should show very little variation as there are fewer parameters requiring estimation. However, the selection of Manning's 'n' values remains an important parameter.

It is important to ensure that, prior to applying the regression equations and stability evaluations presented herein, the channel to be reclaimed is within the range of data presented. Application of predictive equations to areas outside the geographical areas studied introduces uncertainty.

The one-tailed statistical test accepts shallower channel slopes or larger flow areas than natural channel systems, desirable conditions that minimize flow velocity within a channel and favor more conservative designs. The risk-based approach of selecting acceptable error adds an additional level of flexibility for regulatory design review and channel stability evaluations.

Stability tests, if incorporated into regulatory decisions, can quantify differences between reclaimed channel characteristics and natural, premined areas. A standardized, quantitative approach will help maintain consistency in the design and review process at all levels.

The information presented herein is the largest data set of Wyoming ephemeral channels and allows users to select site specific equations. In the end, sound judgement and appropriate use of existing data will ensure a successful channel design at reclaimed lands in the state of Wyoming.

5.0 RECOMMENDATIONS

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5.0 RECOMMENDATIONS

Specific recommendations that became evident during this project include:

1. Standardize WDEQ/LQD reporting methods. There is an abundance of useful premined channel information dispersed among several sources at WDEQ, which presently is difficult to extract. Mine permit applications, in particular, provide an enormous resource (above and beyond premined channel data) if rigid guidelines for acceptable contents are established and enforced.

2. When incorporating this stability evaluation into channel design, use the most site specific data available for the area to be reclaimed. Channel data from distant areas aids channel design only when more specific information is not available. Channel bed sediment data may improve channel parameter predictions.

3. If a statistical evaluation for evaluating channel designs is a desirable approach for regulators to assess channel designs, and mine operators want premined information for designing reclaimed channels, then additional data are necessary to fill in gaps in drainage basin sizes studied in the main coal bearing areas of Wyoming. Regression analyses are only as complete as the initial data set. While 81 channels provides reasonable coverage, further premined data from important coal-rich regions of Wyoming would further test and verify these findings.

4. Reclamation practices have generally proven quite successful in reestablishing vegetation cover on disturbed lands. However, the technology does not presently exist to restore physical properties of soil or geologic bedrock with the same success. Much can be gained in reclamation science if a concerted effort is launched to address and rectify the influence of a disturbed substrate on channel stability.

5. Making the data available on the newly developed TIPS database (especially the Cumulative Hydrologic Impact Assessment (CHIA) data) is consistent with our goals of making the data set available to a wide array of users. Arrangements for data transfer are currently in progress.

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APPENDIX A

Rock Springs Area
Regression Results

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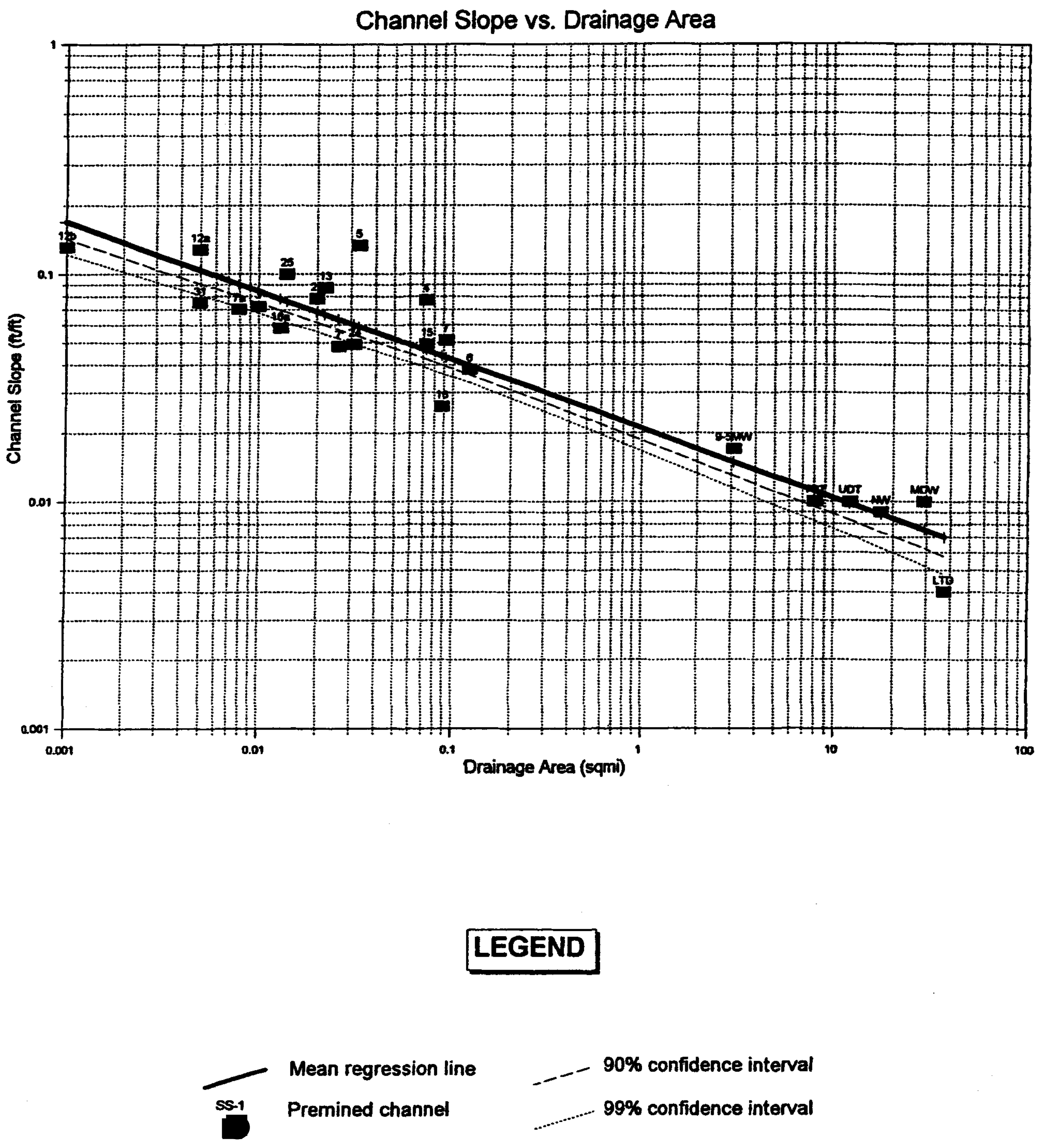


Figure A-1. Channel slope, Rock Springs area.

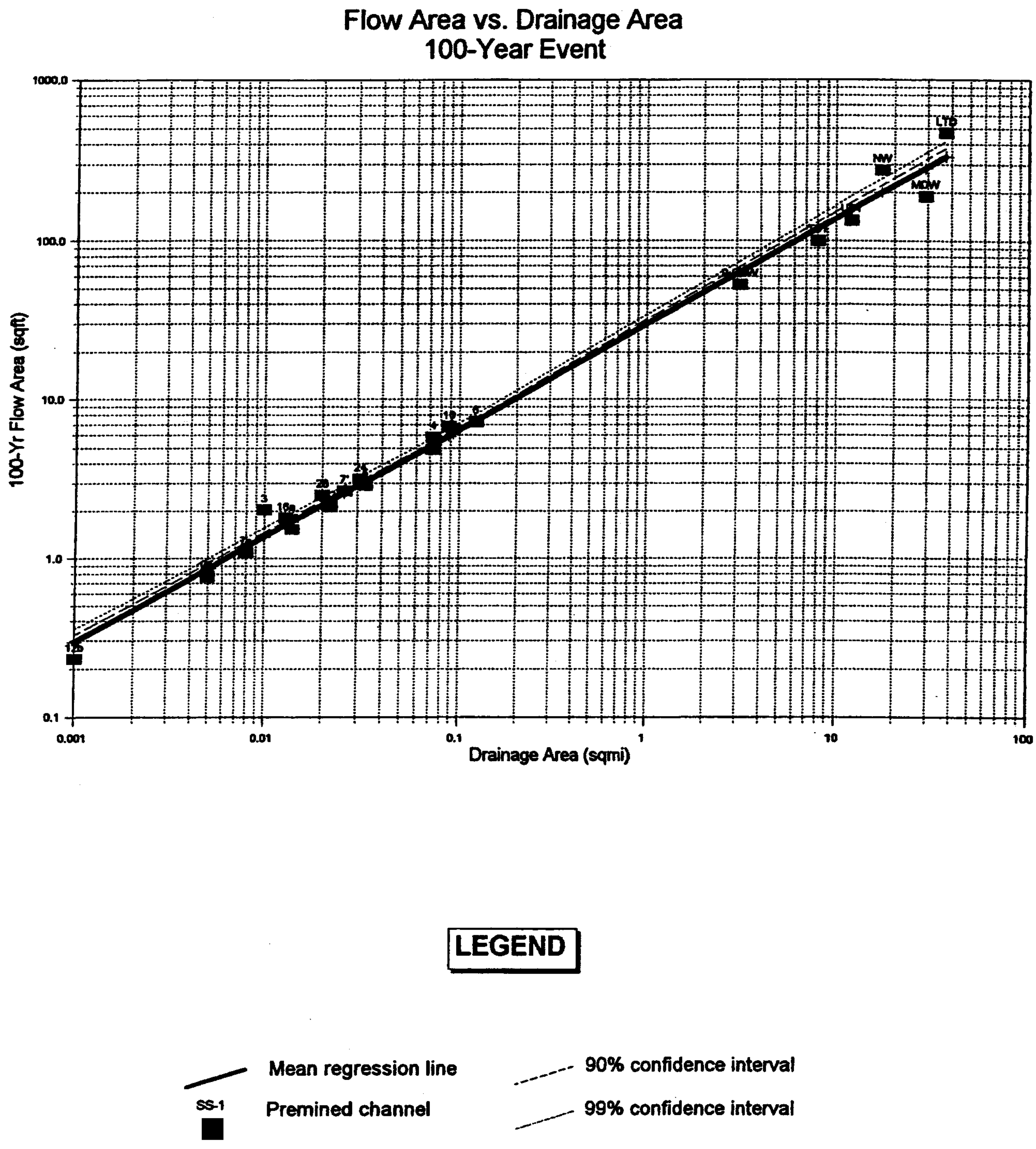


Figure A-2. Rainfall-runoff regression plot for 100-year channel design parameters, Rock Springs area.

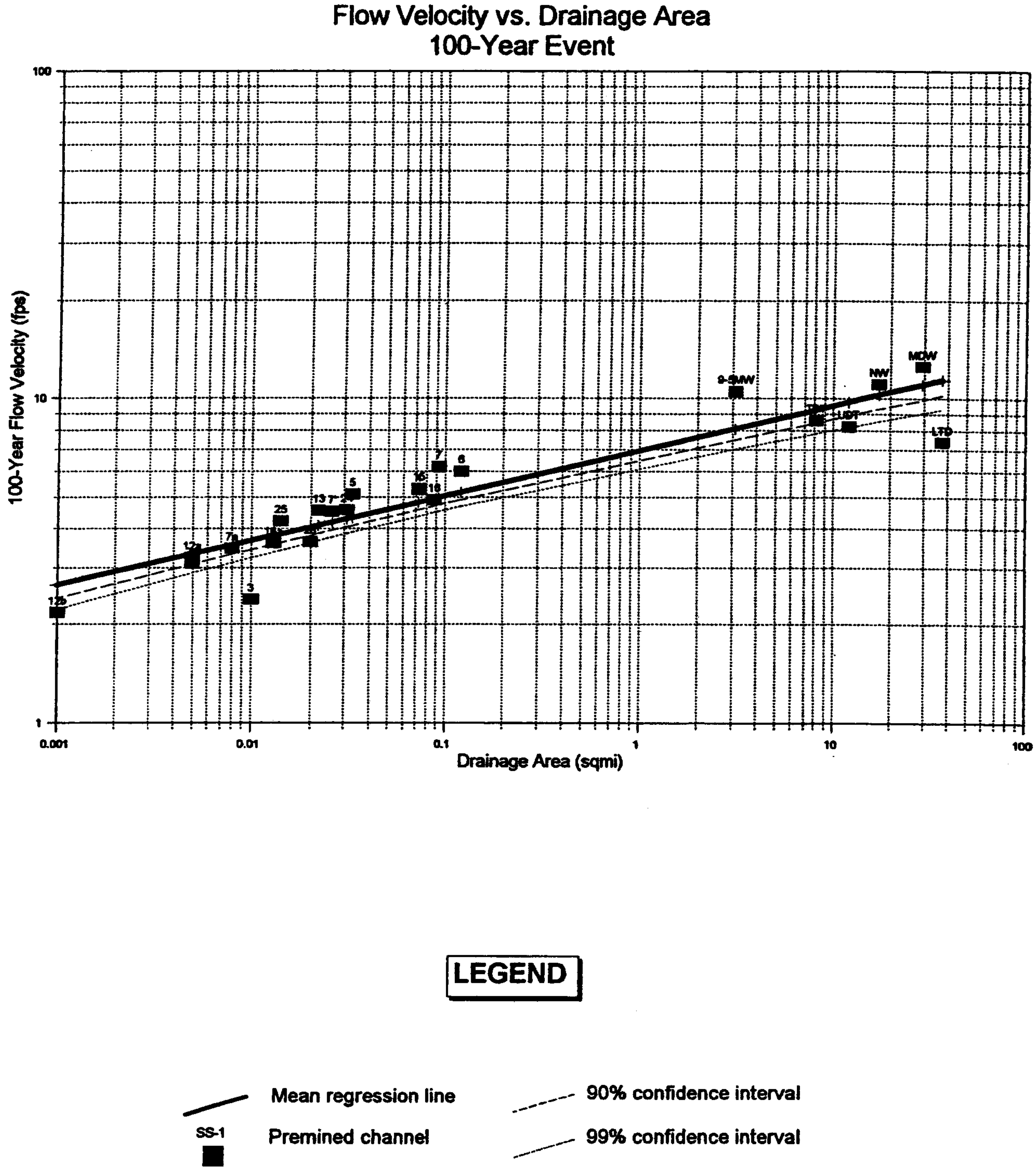


Figure A-3. Rainfall-runoff regression plot for 100-year channel design parameters, Rock Springs area.

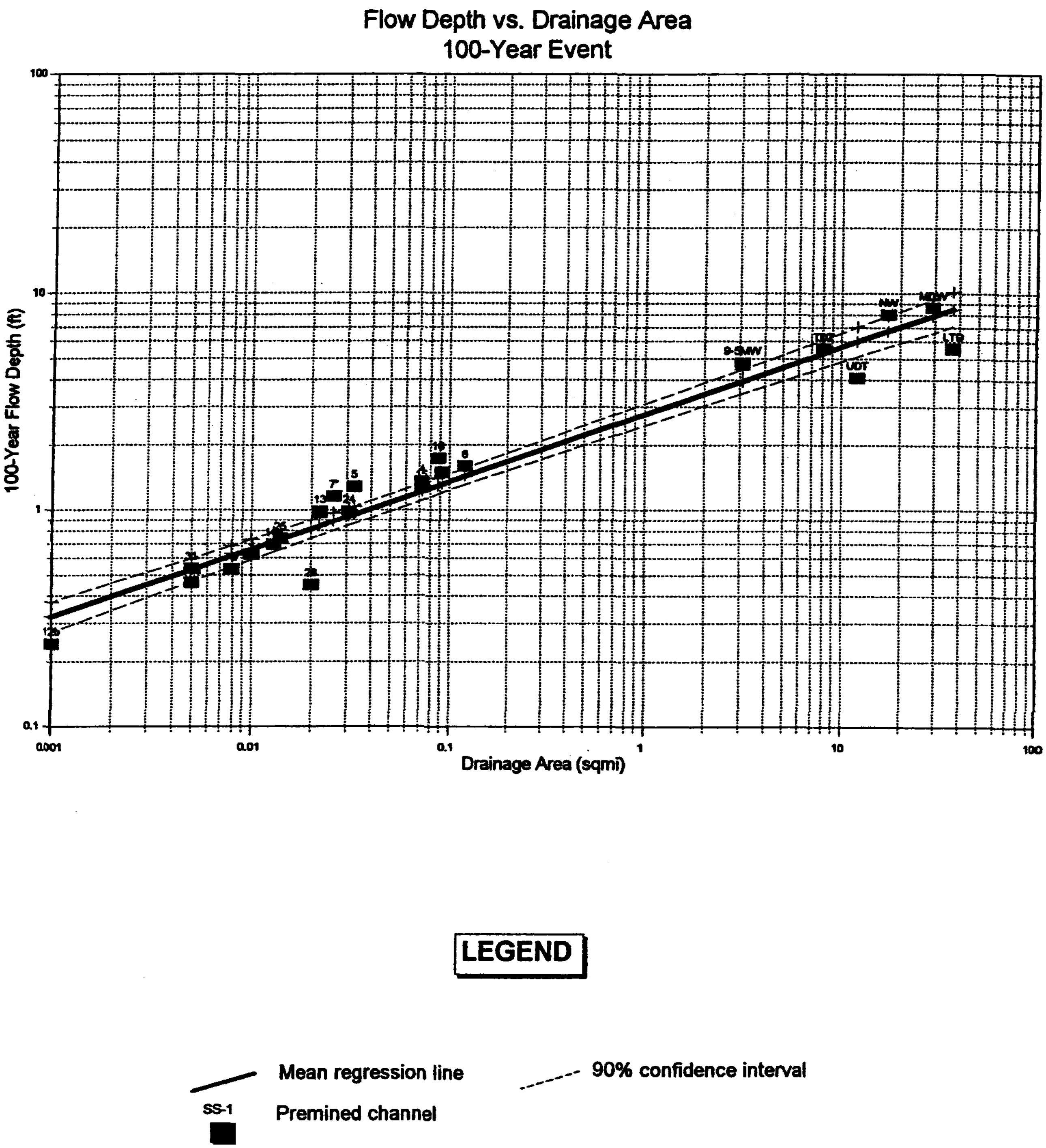
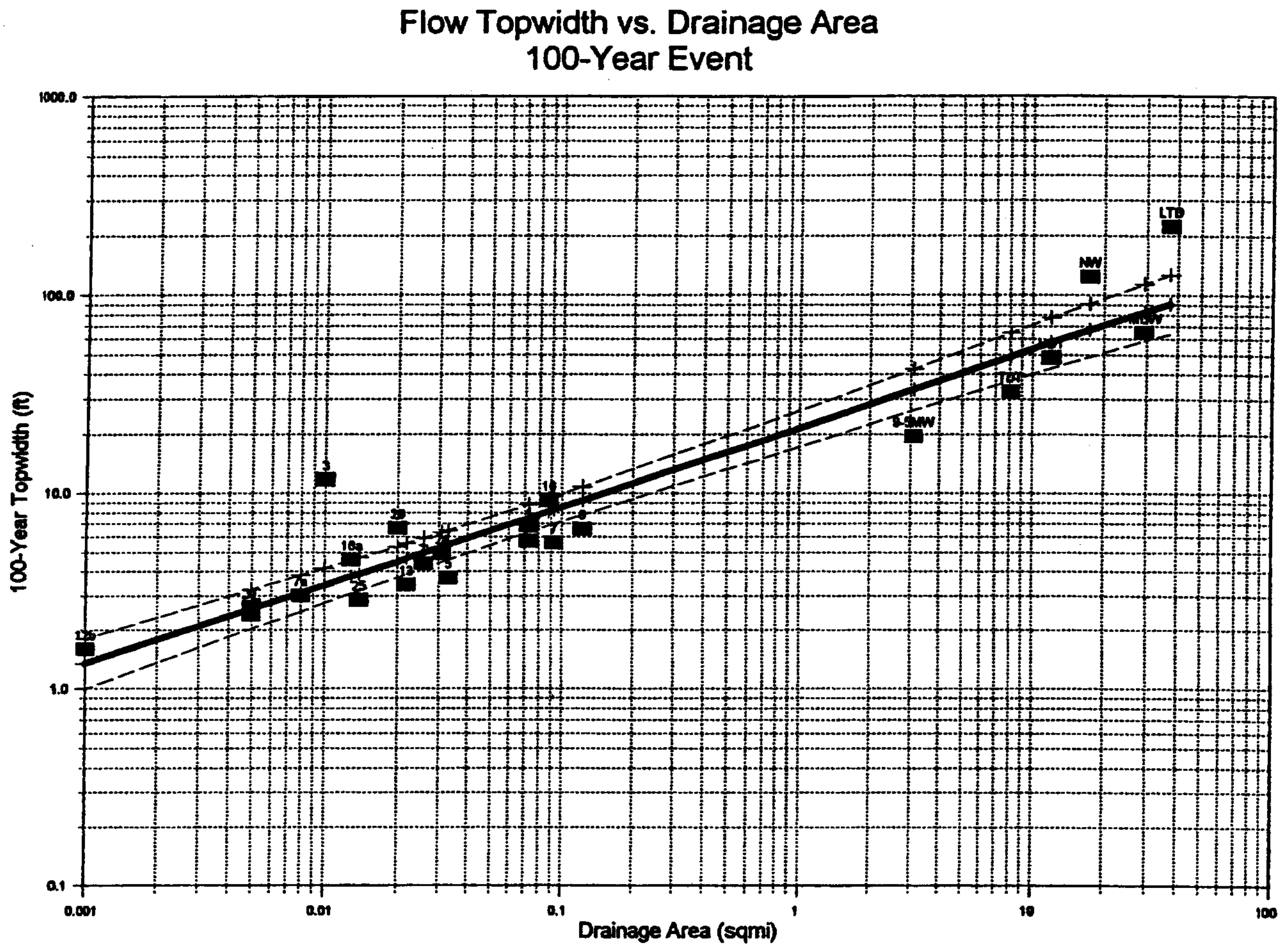


Figure A-4. Rainfall-runoff regression plot for 100-year channel design parameters, Rock Springs area.



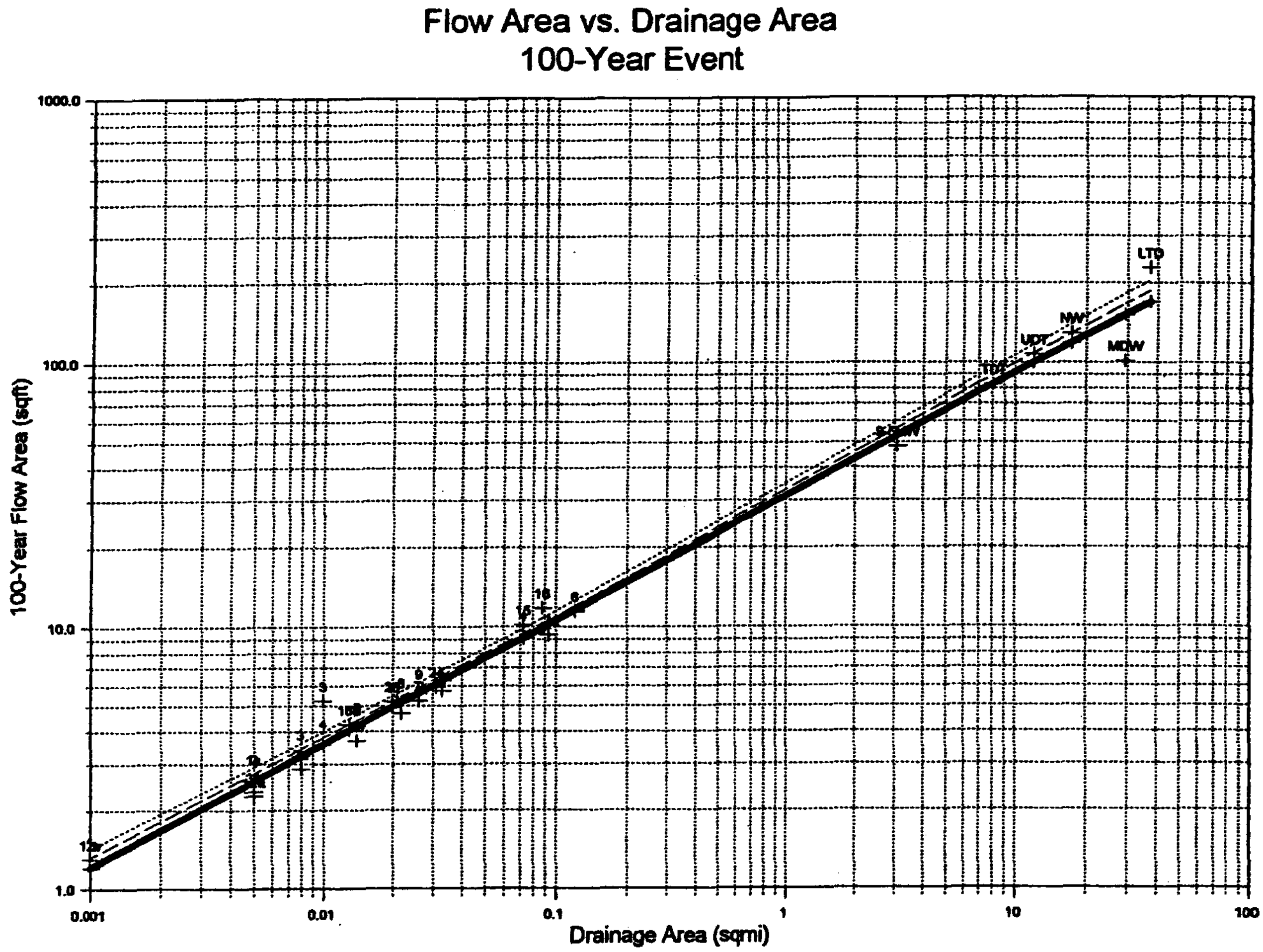
LEGEND

Mean regression line

90% confidence interval

SS-1 Premined channel

Figure A-5. Rainfall-runoff regression plot for 100-year channel design parameters, Rock Springs area.



LEGEND

Mean regression line

SS-1 Premined channel

90% confidence interval

99% confidence interval

Figure A-6. Regional analysis regression plot for 100-year channel design parameters, Rock Springs area.

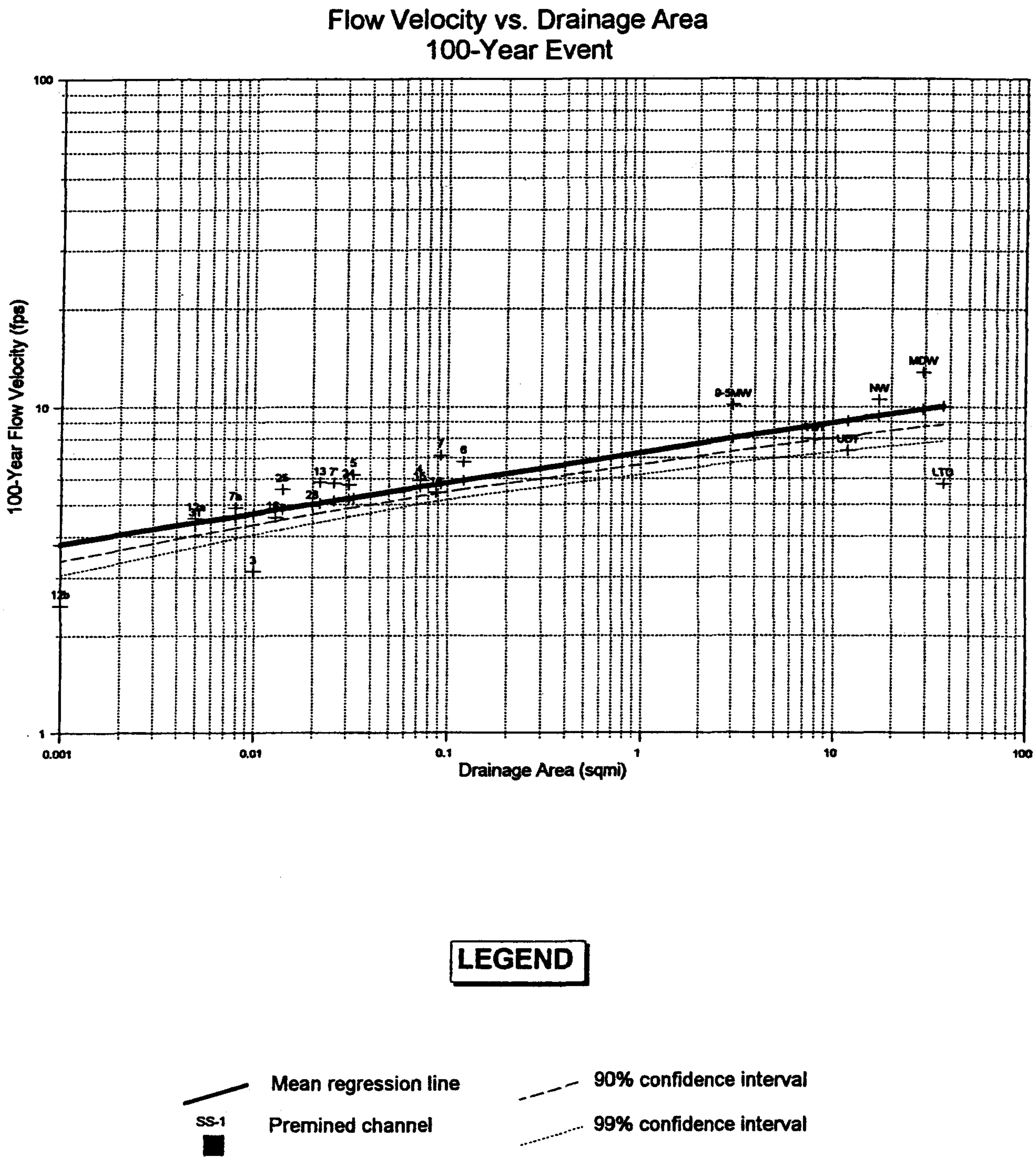


Figure A-7. Regional analysis regression plot for 100-year channel design parameters, Rock Springs area.

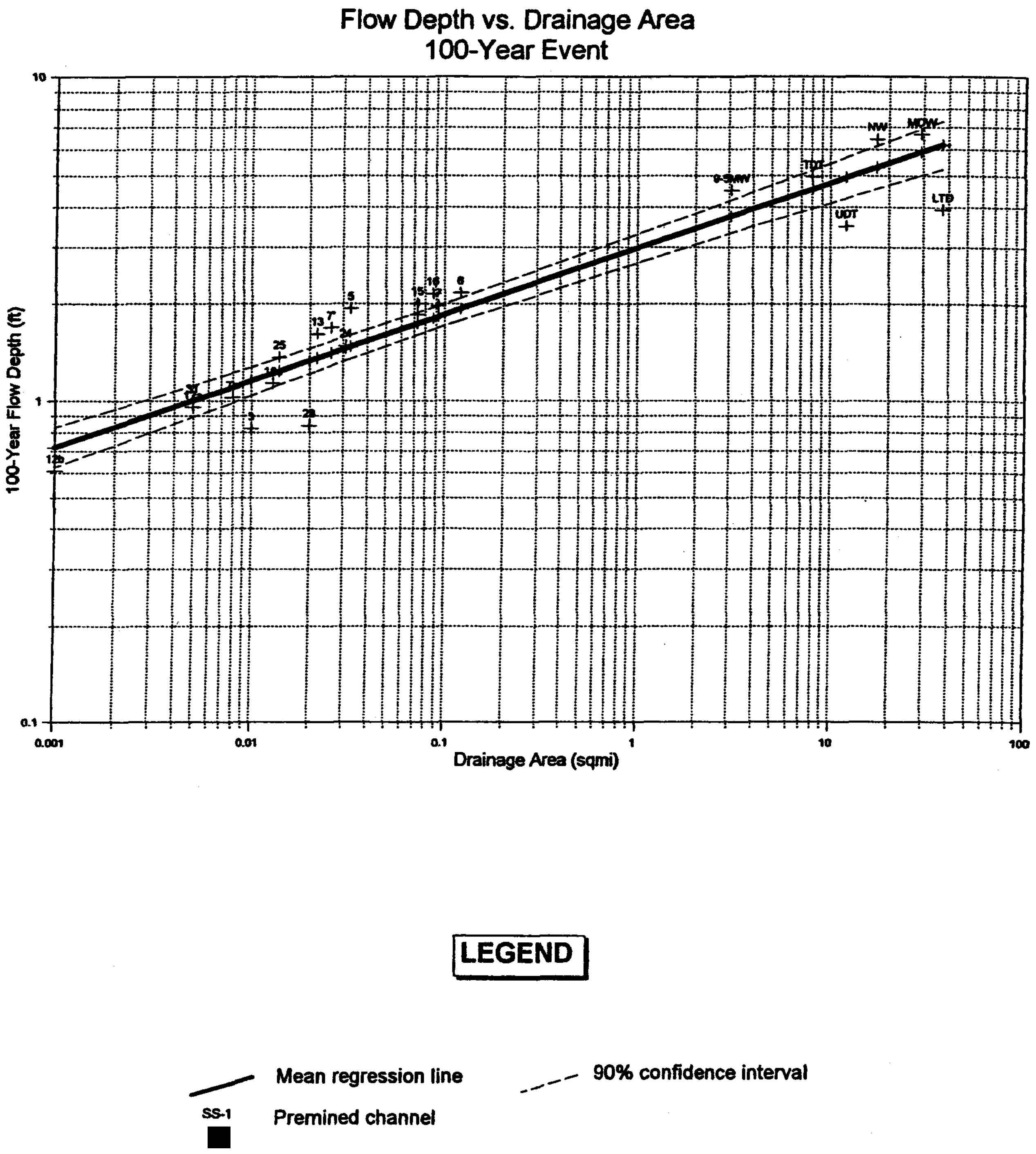


Figure A-8. Regional analysis regression plot for 100-year channel design parameters, Rock Springs area.

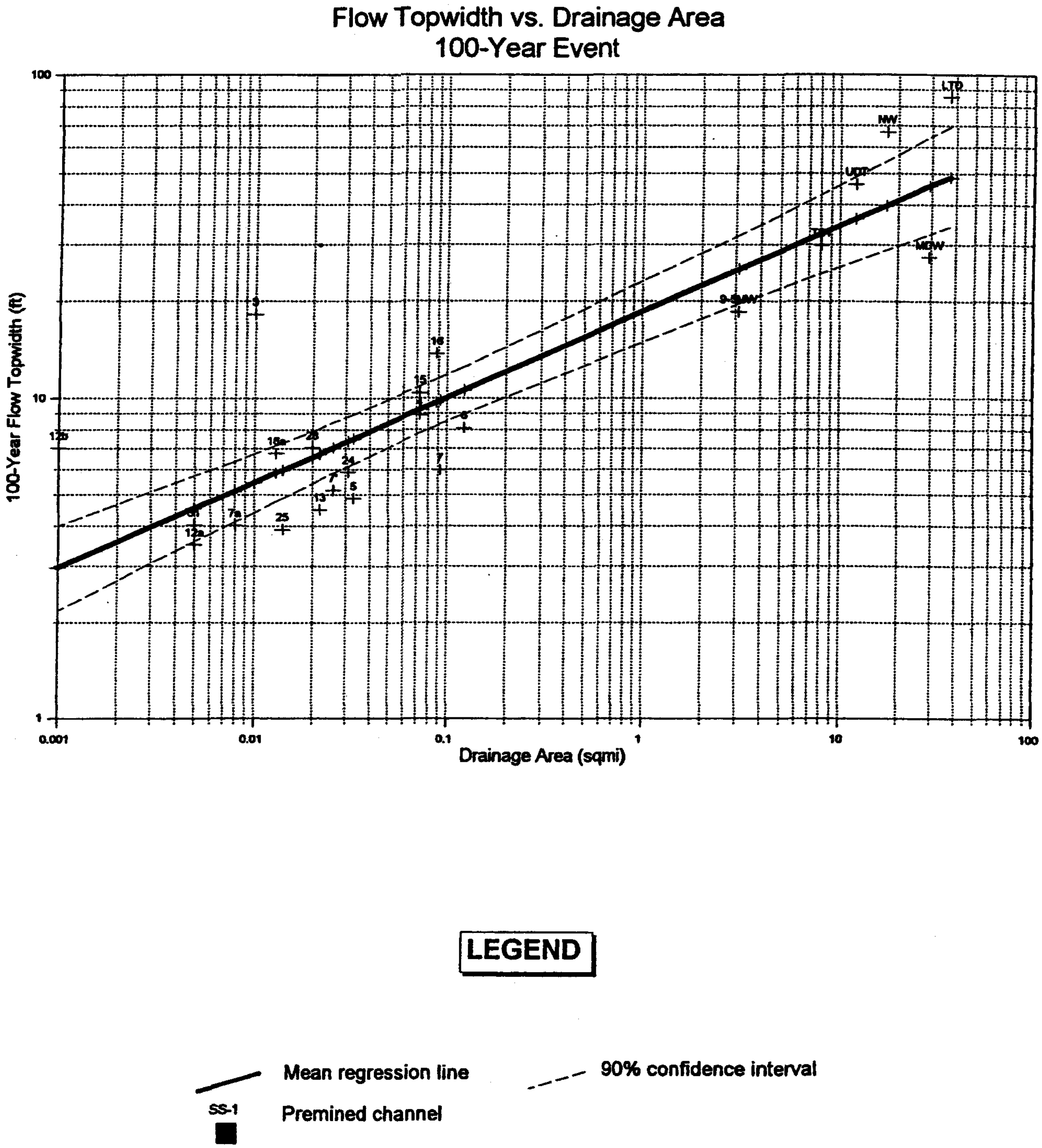


Figure A-9. Regional analysis regression plot for 100-year channel design parameters, Rock Springs area.

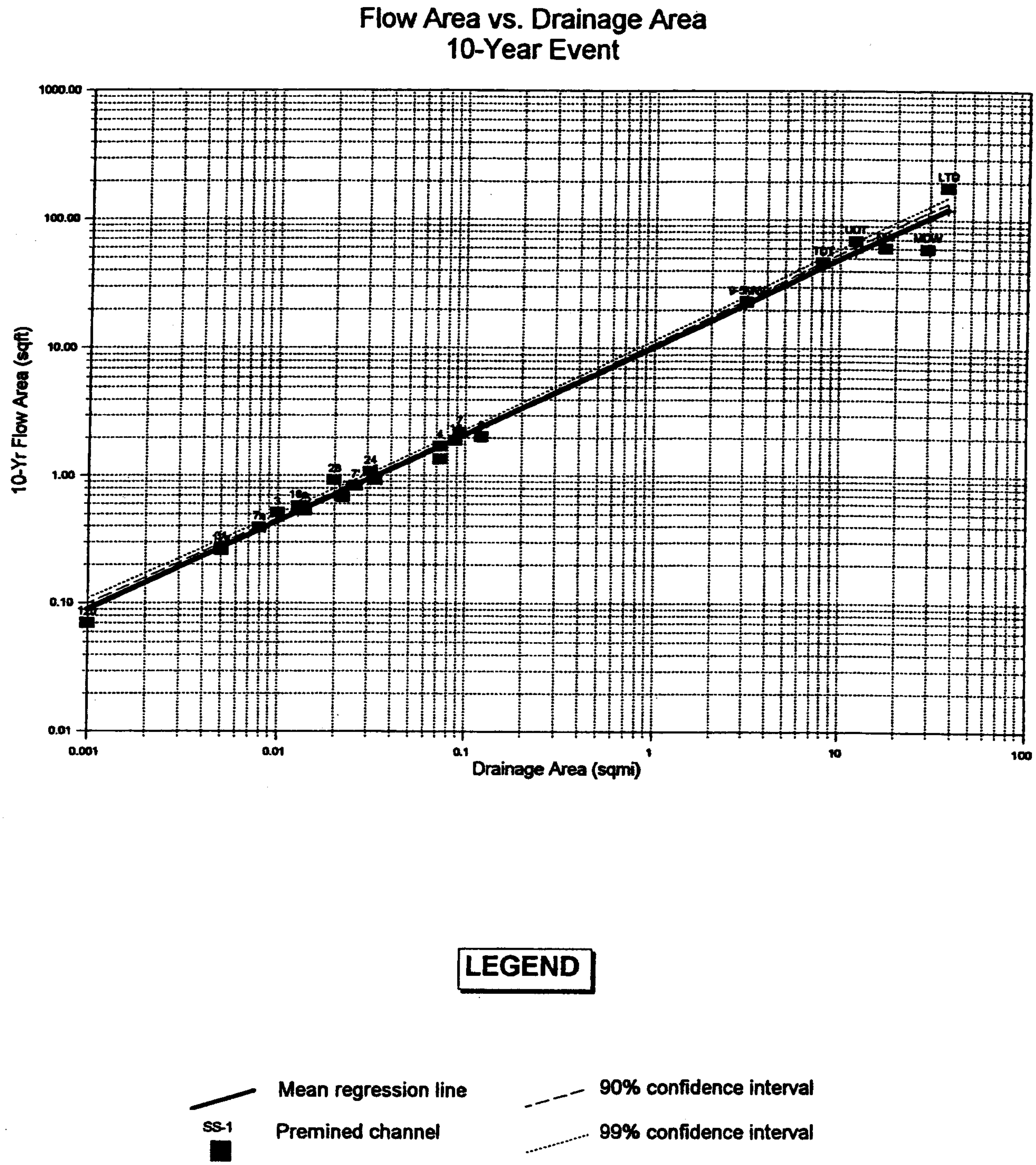


Figure A-10. Rainfall-runoff regression plot for 10-year channel design parameters, Rock Springs area.

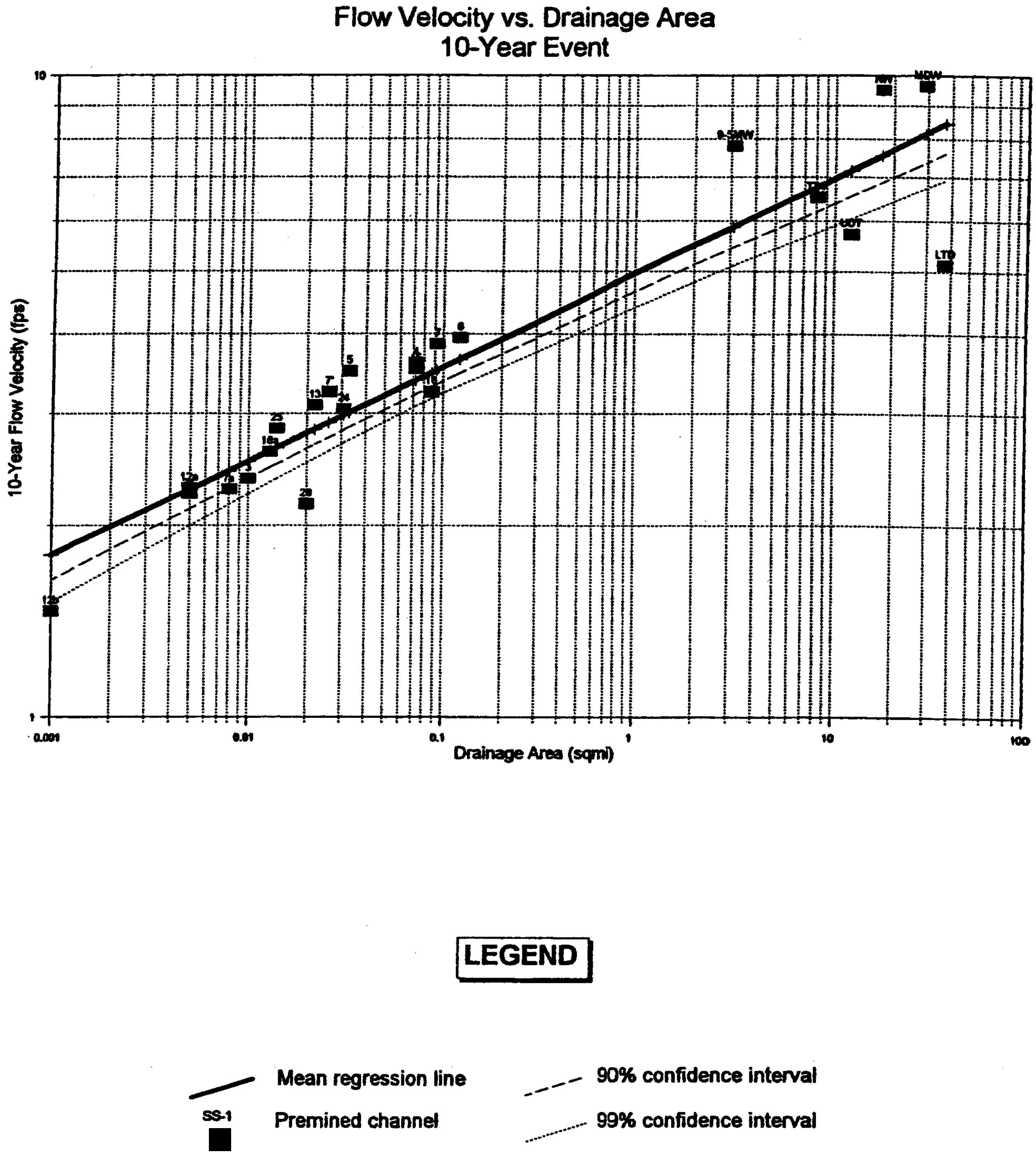


Figure A-11. Rainfall-runoff regression plot for 10-year channel design parameters, Rock Springs area.

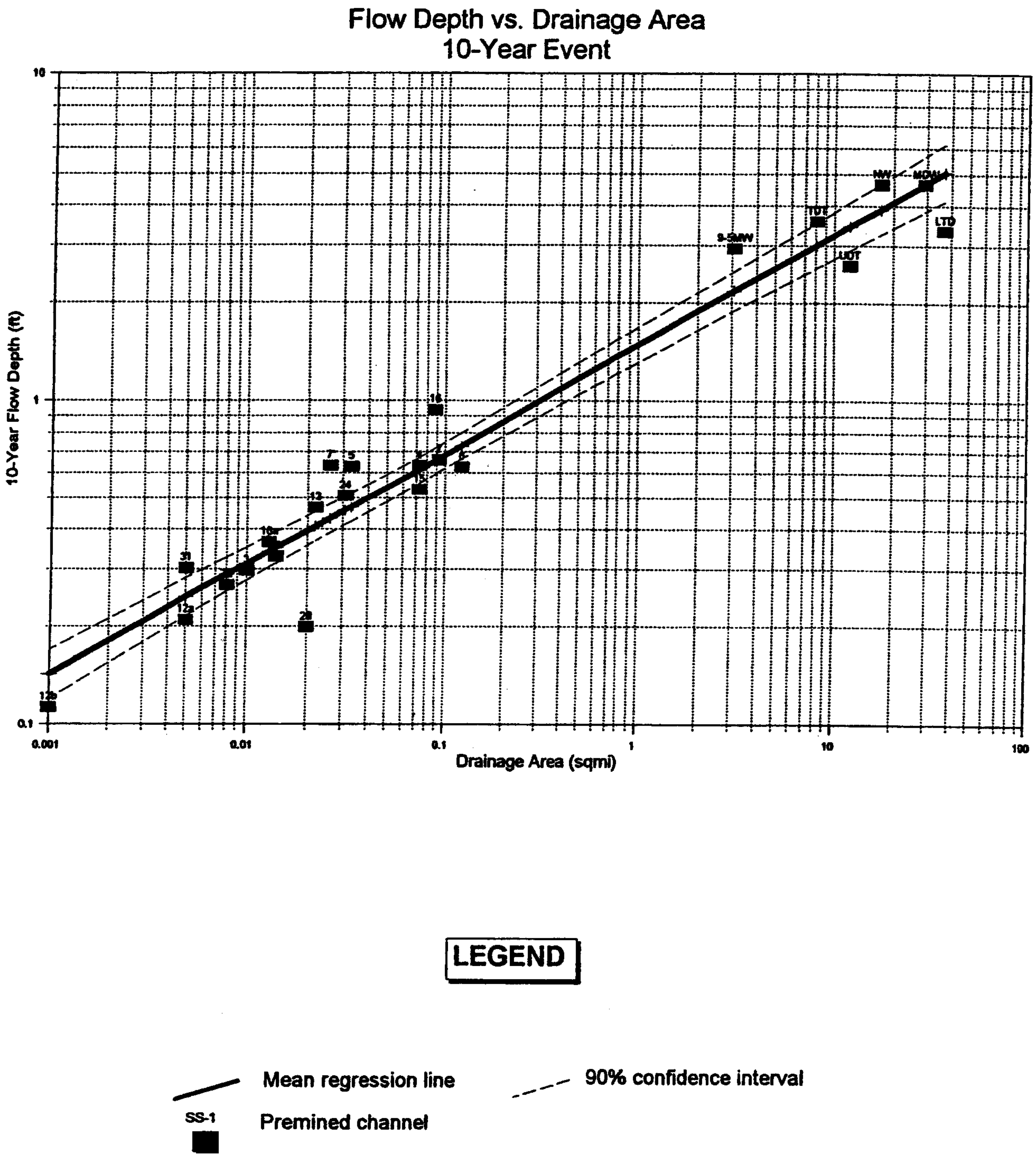


Figure A-12. Rainfall-runoff regression plot for 10-year channel design parameters, Rock Springs area.

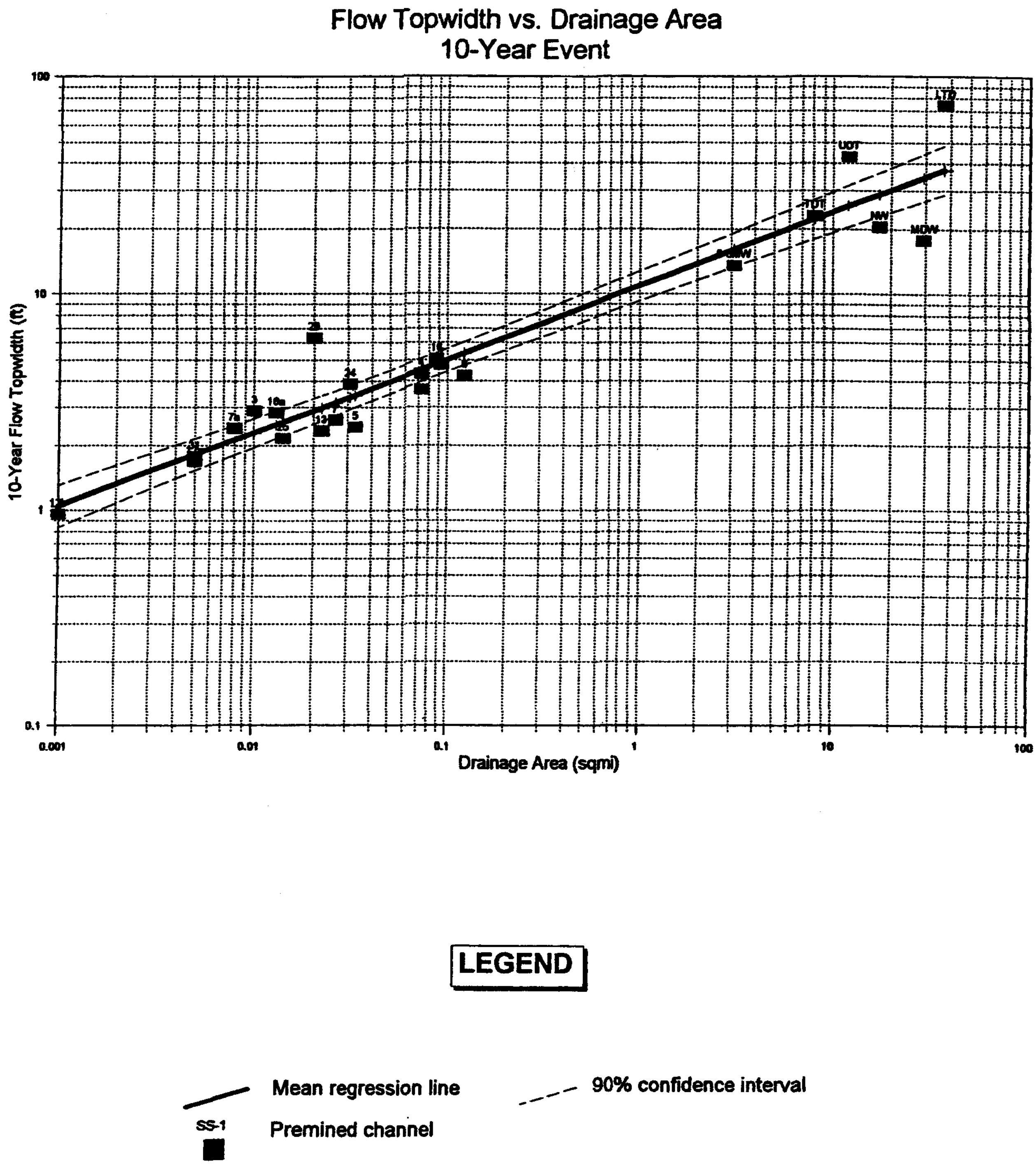
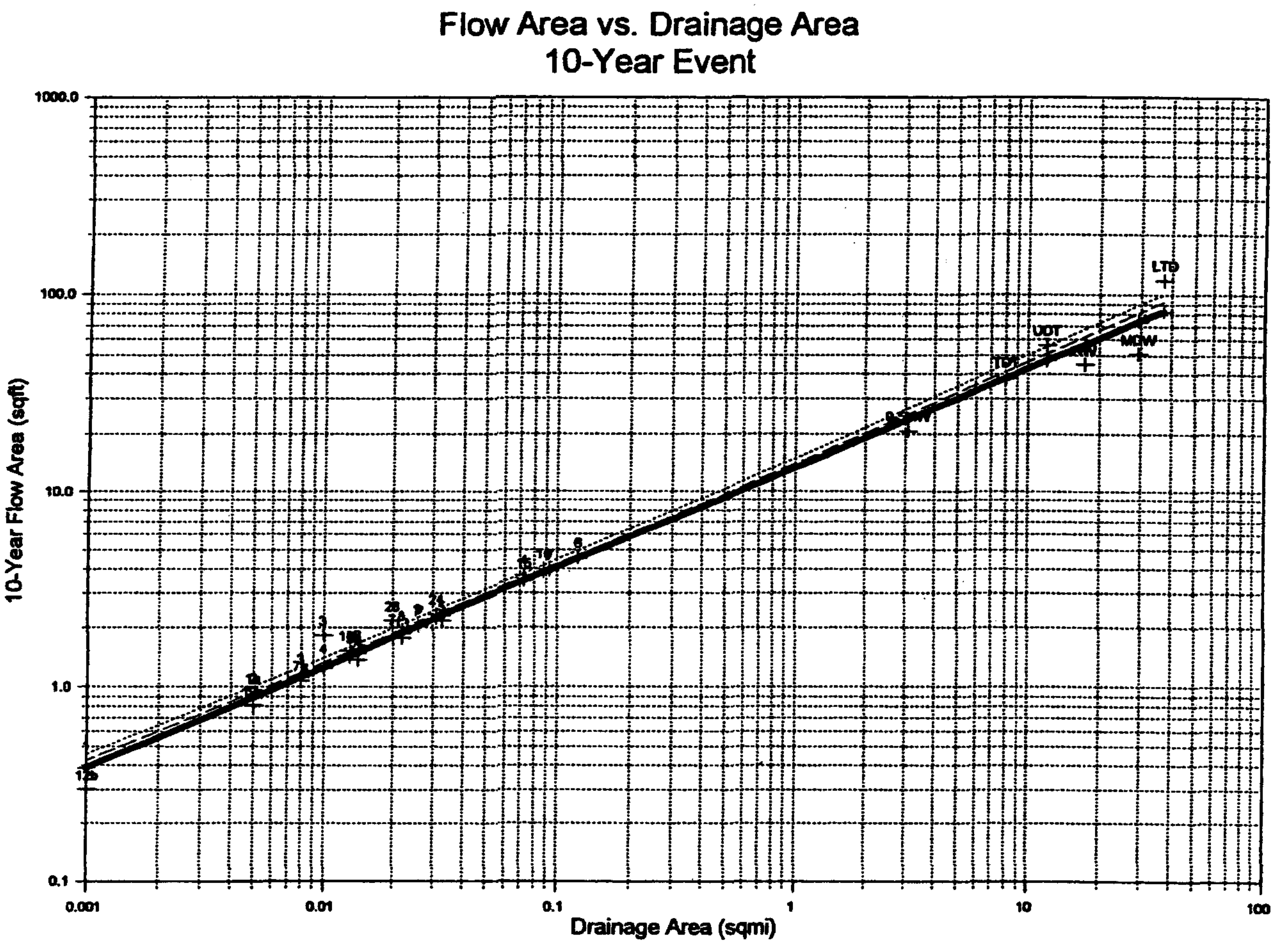


Figure A-13. Rainfall-runoff regression plot for 10-year channel design parameters, Rock Springs area.



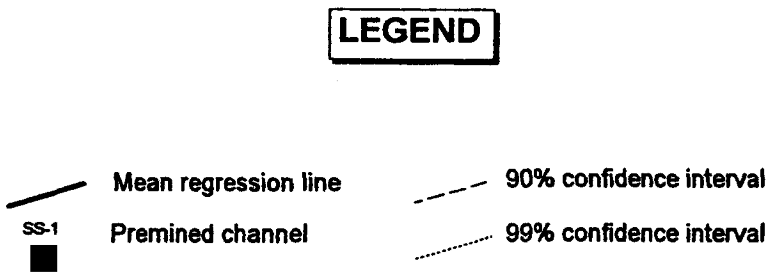


Figure A-14. Regional analysis regression plot for 10-year channel design parameters, Rock Springs area.

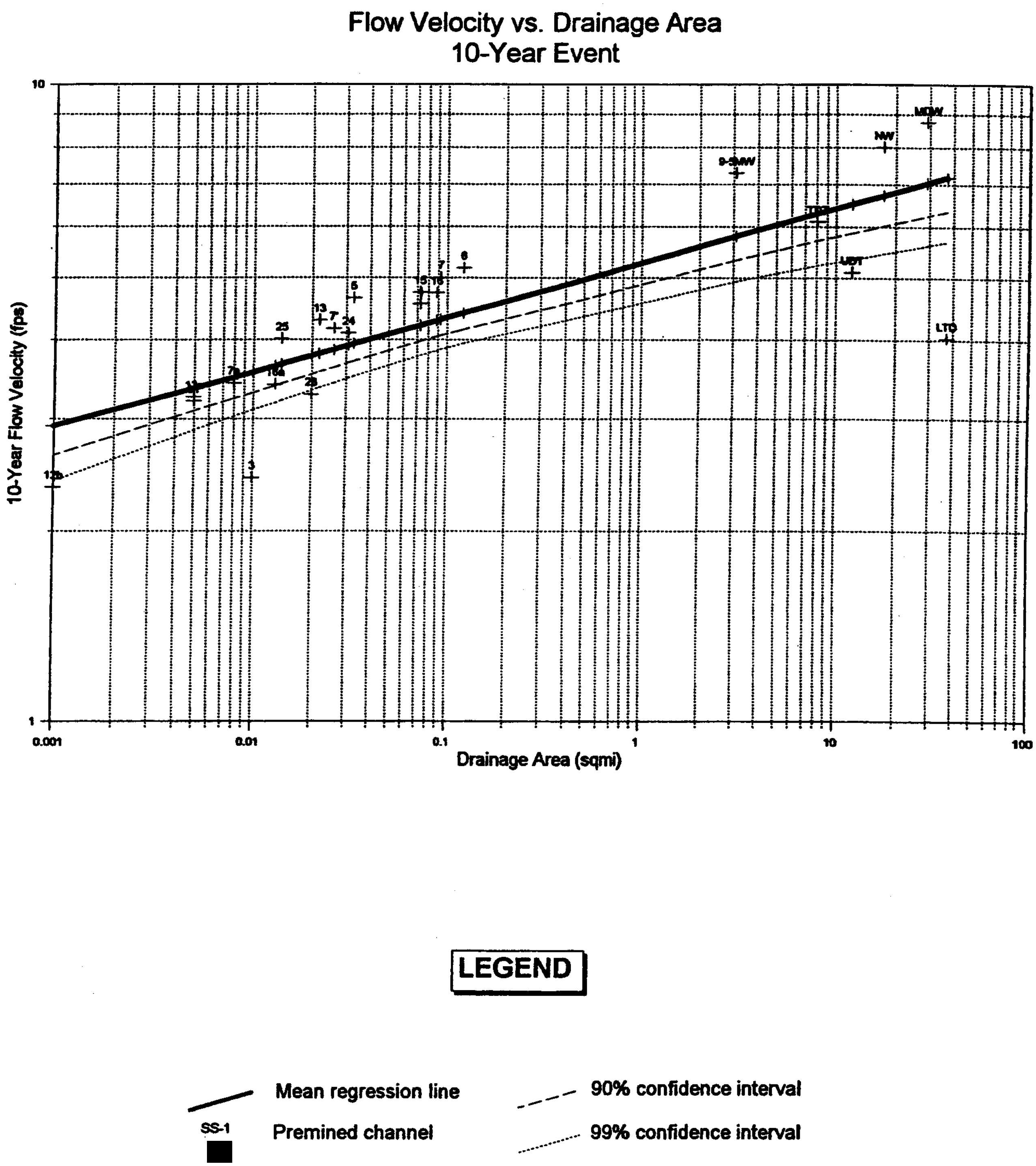


Figure A-15. Regional analysis regression plot for 10-year channel design parameters, Rock Springs area.

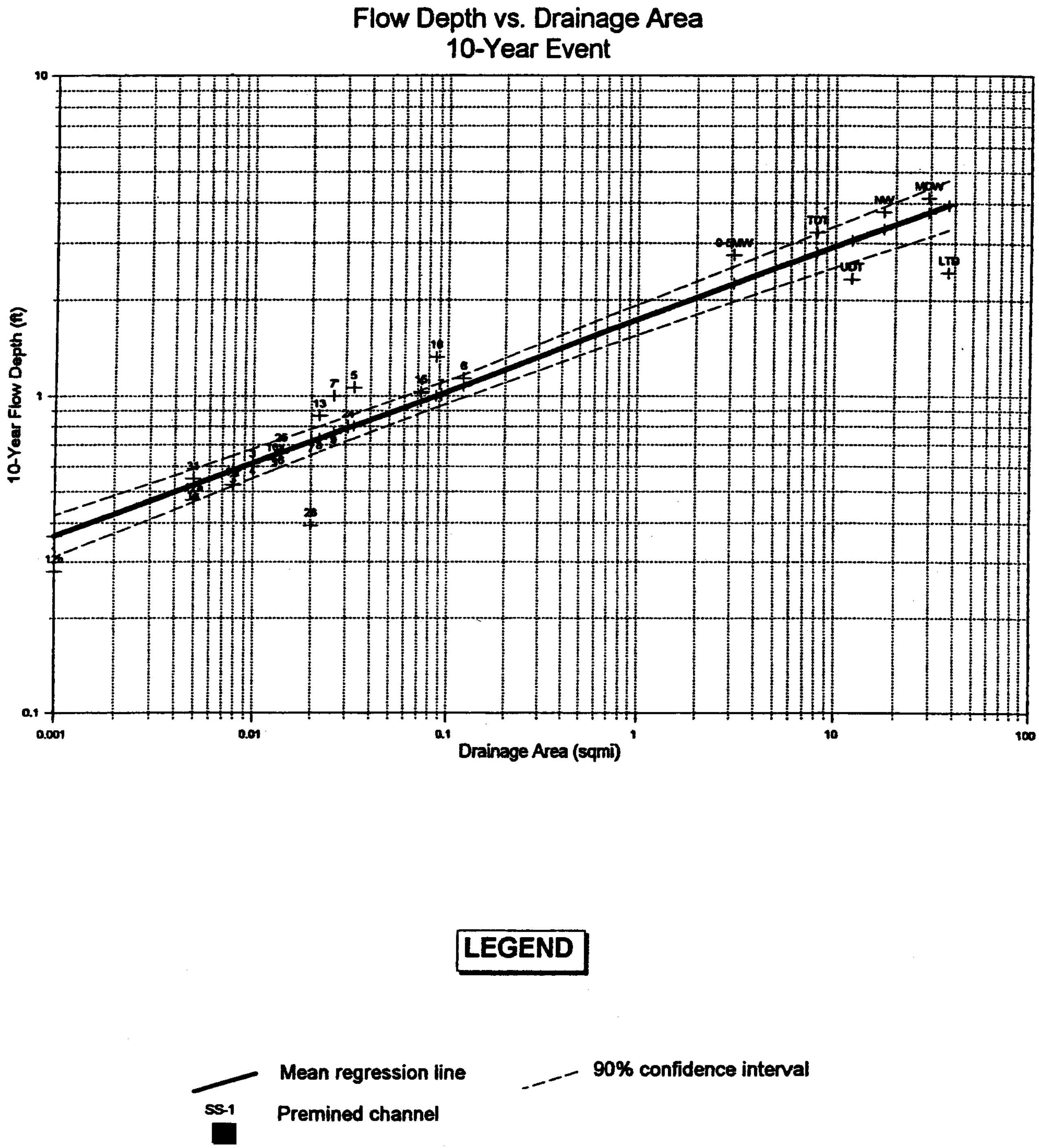


Figure A-16. Regional analysis regression plot for 10-year channel design parameters, Rock Springs area.

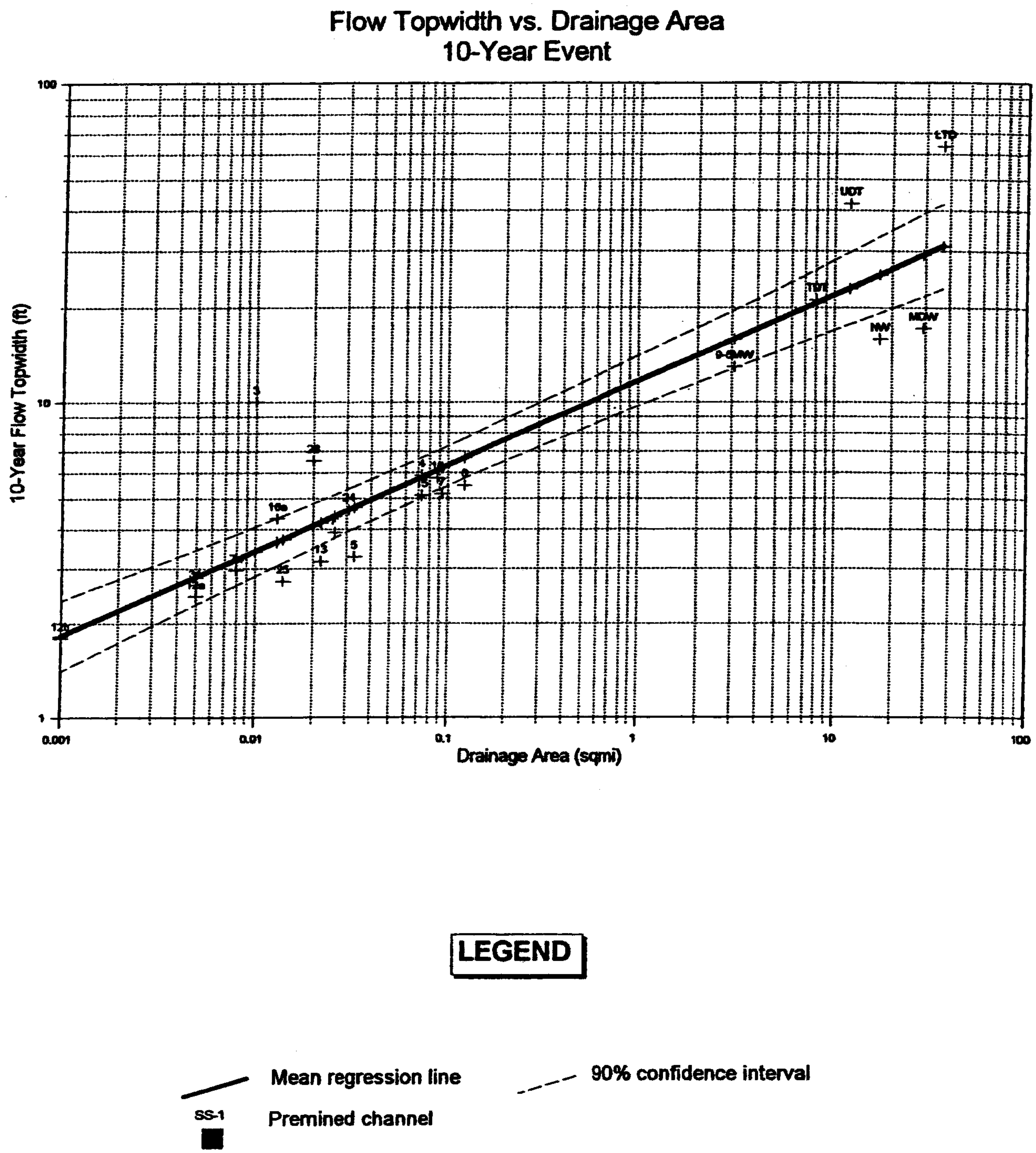


Figure A-17. Regional analysis regression plot for 10-year channel design parameters, Rock Springs area.

APPENDIX B

Hanna Area
Regression Results

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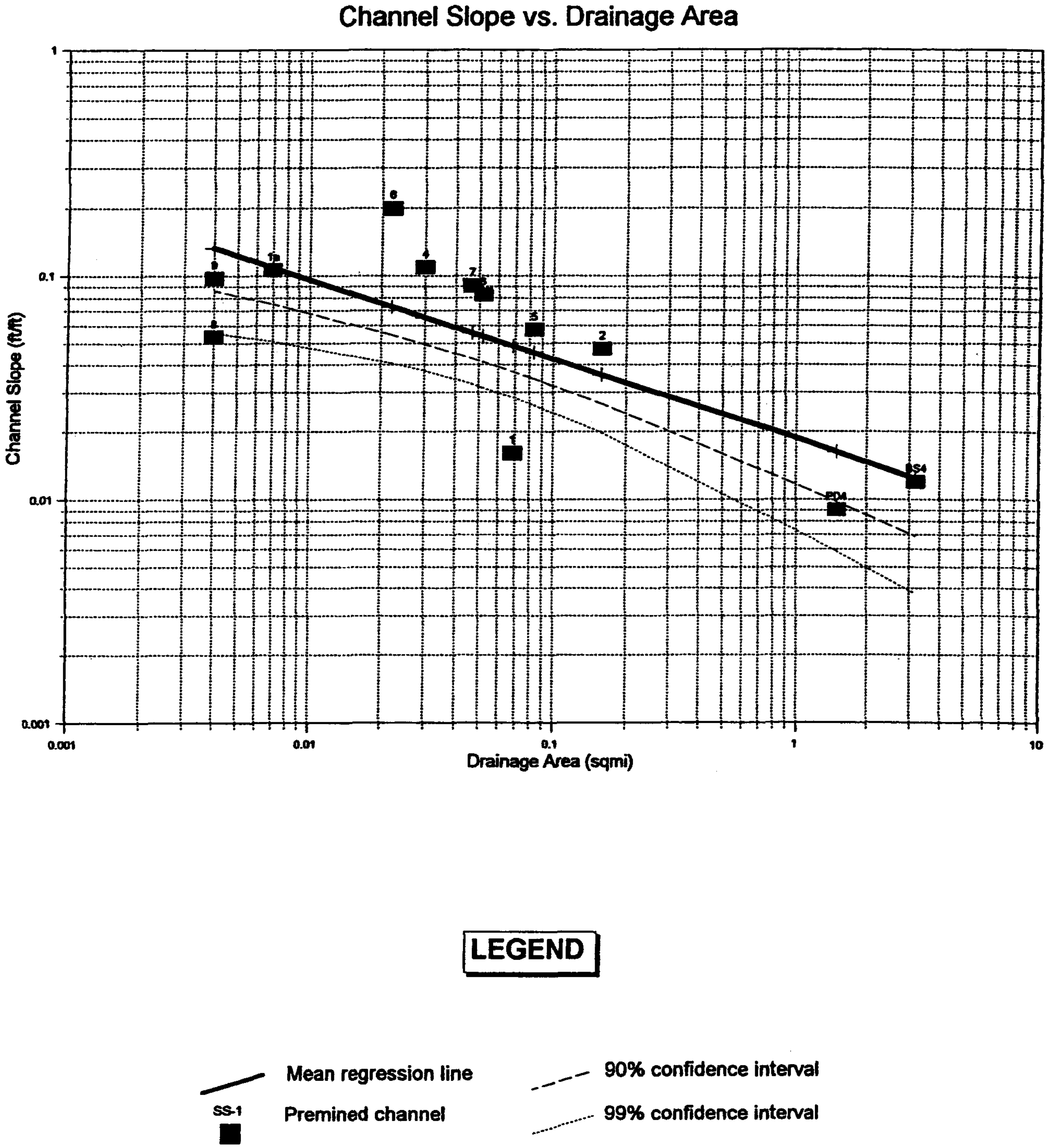
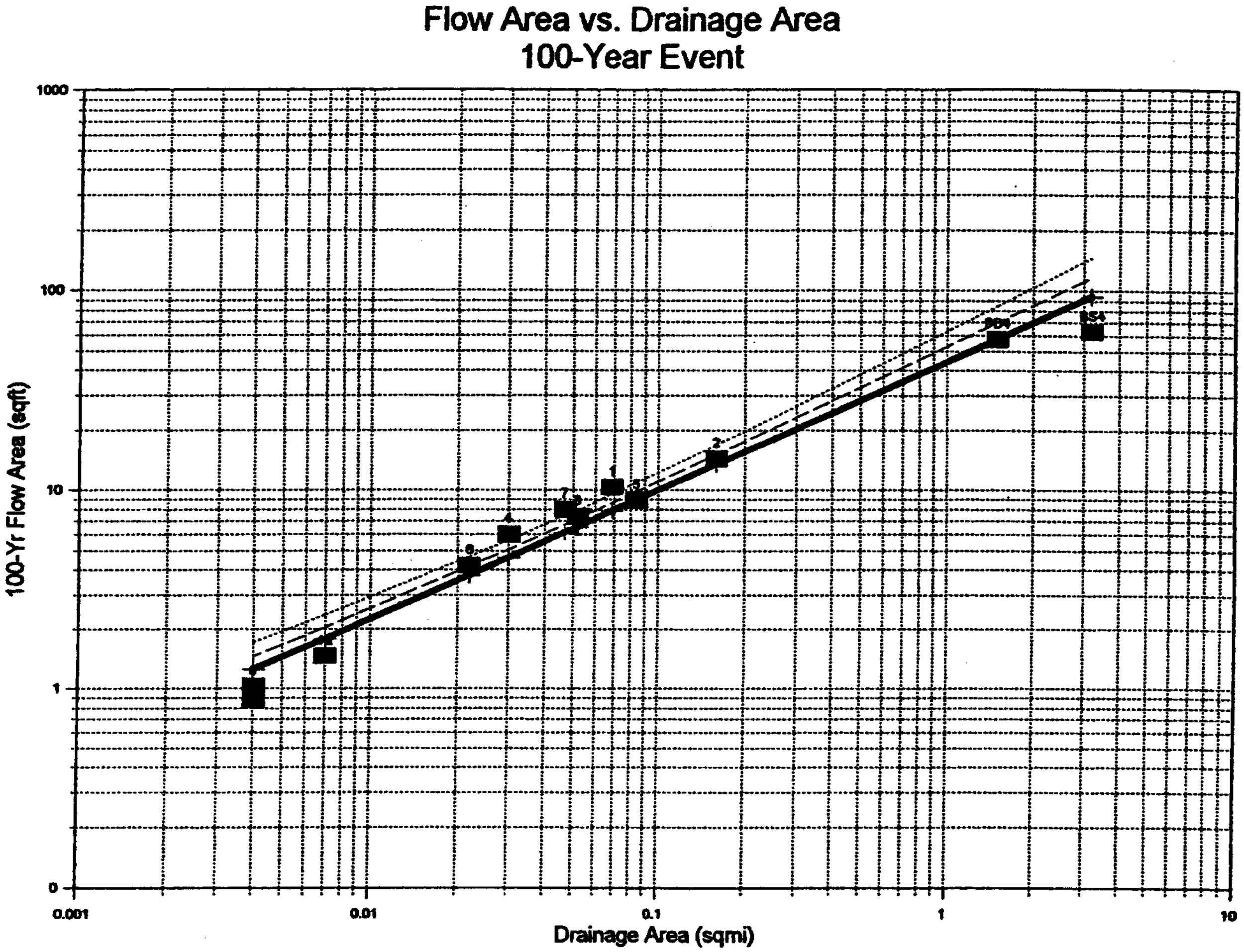


Figure B-1. Channel slope, Hanna area.



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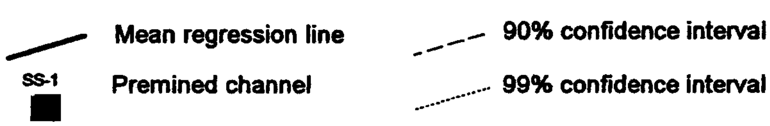


Figure B-2. Rainfall-runoff regression plot for 100-year channel design parameters, Hanna area.

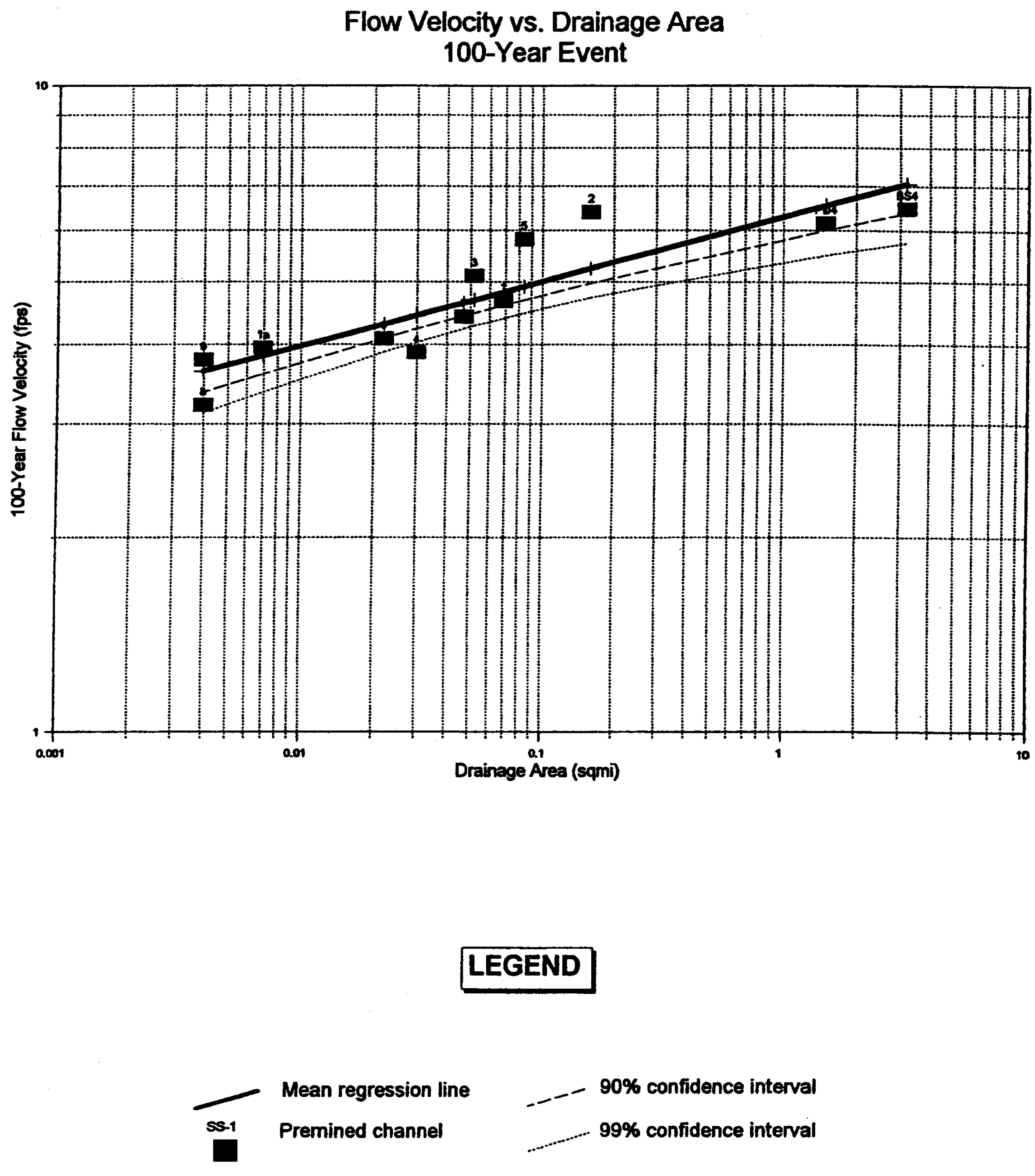


Figure B-3. Rainfall-runoff regression plot for 100-year channel design parameters, Hanna area.

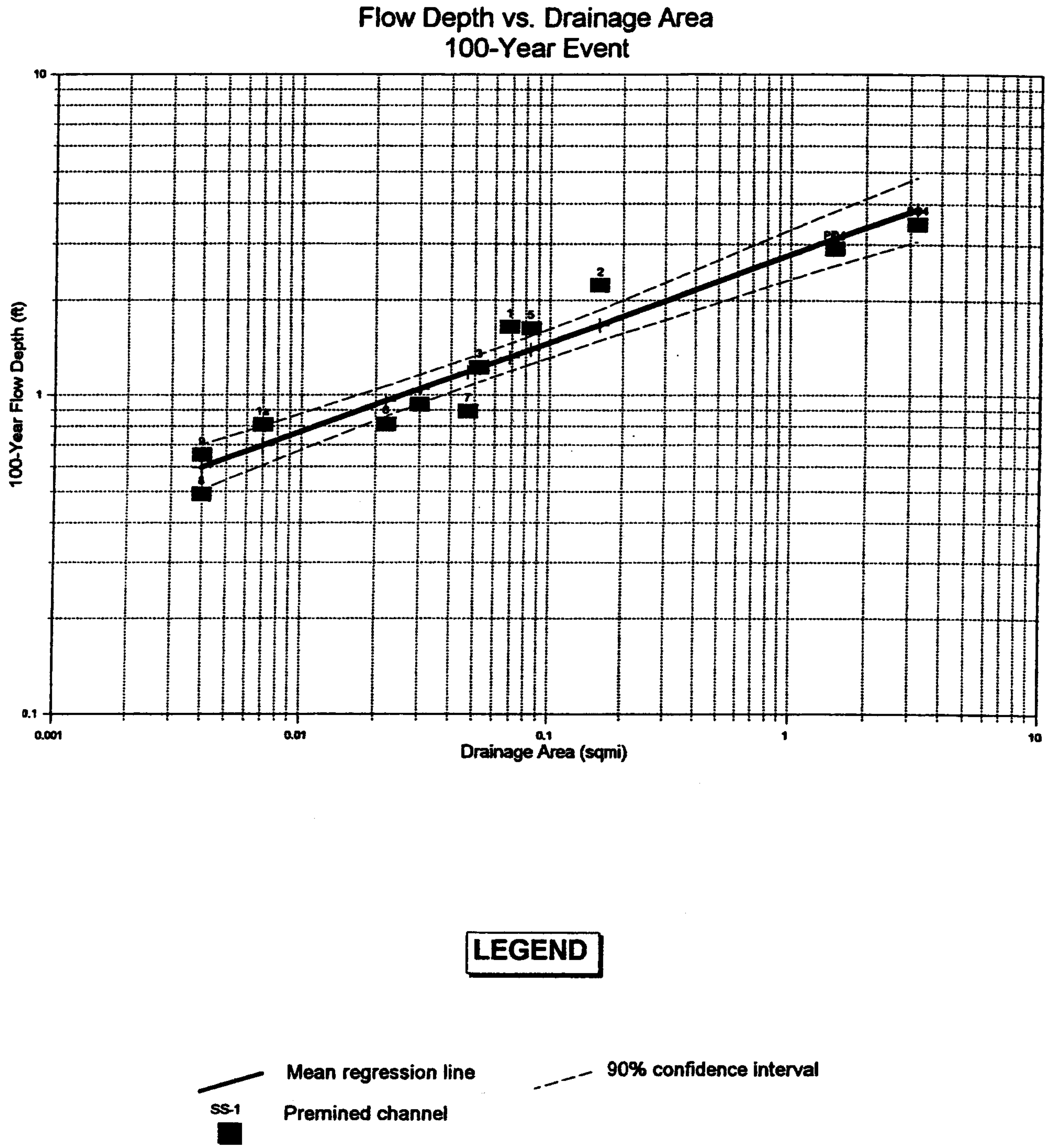
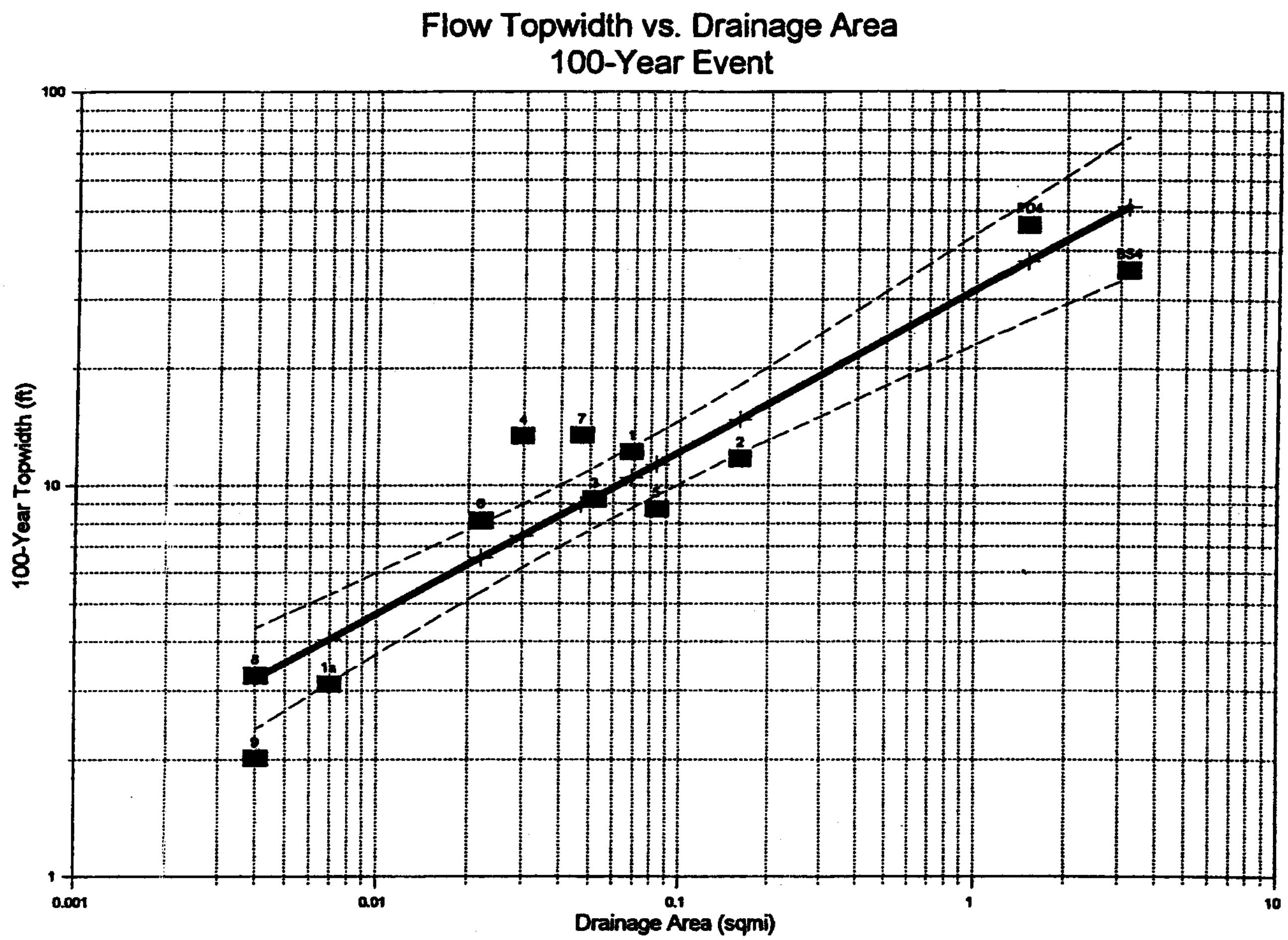


Figure B-4. Rainfall-runoff regression plot for 100-year channel design parameters, Hanna area.



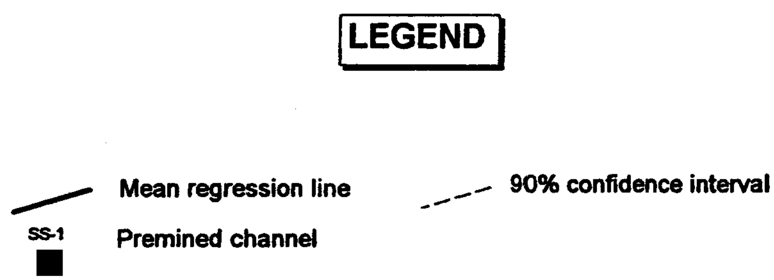


Figure B-5. Rainfall-runoff regression plot for 100-year channel design parameters, Hanna area.

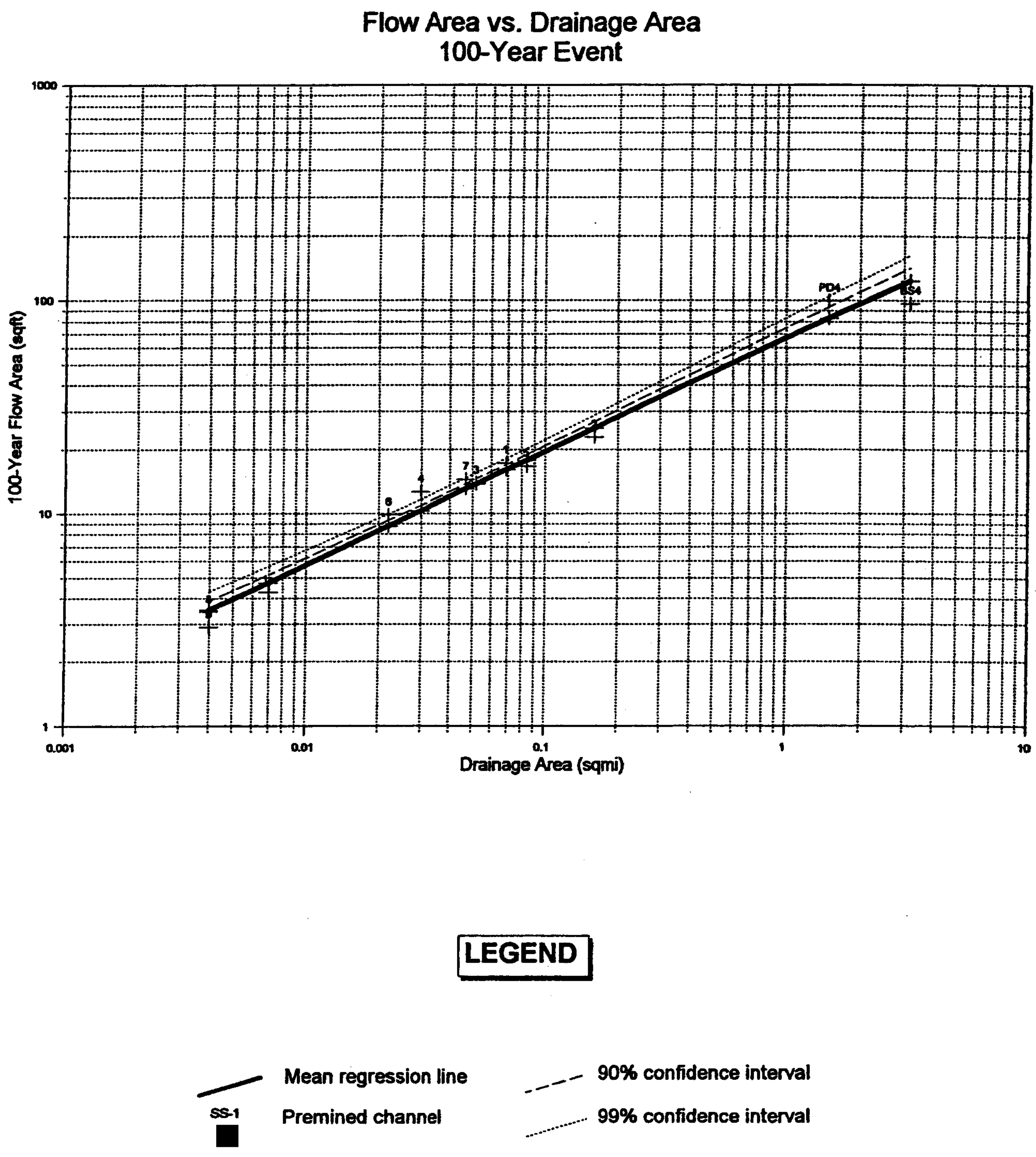


Figure B-6. Regional analysis regression plot for 100-year channel design parameters, Hanna area.

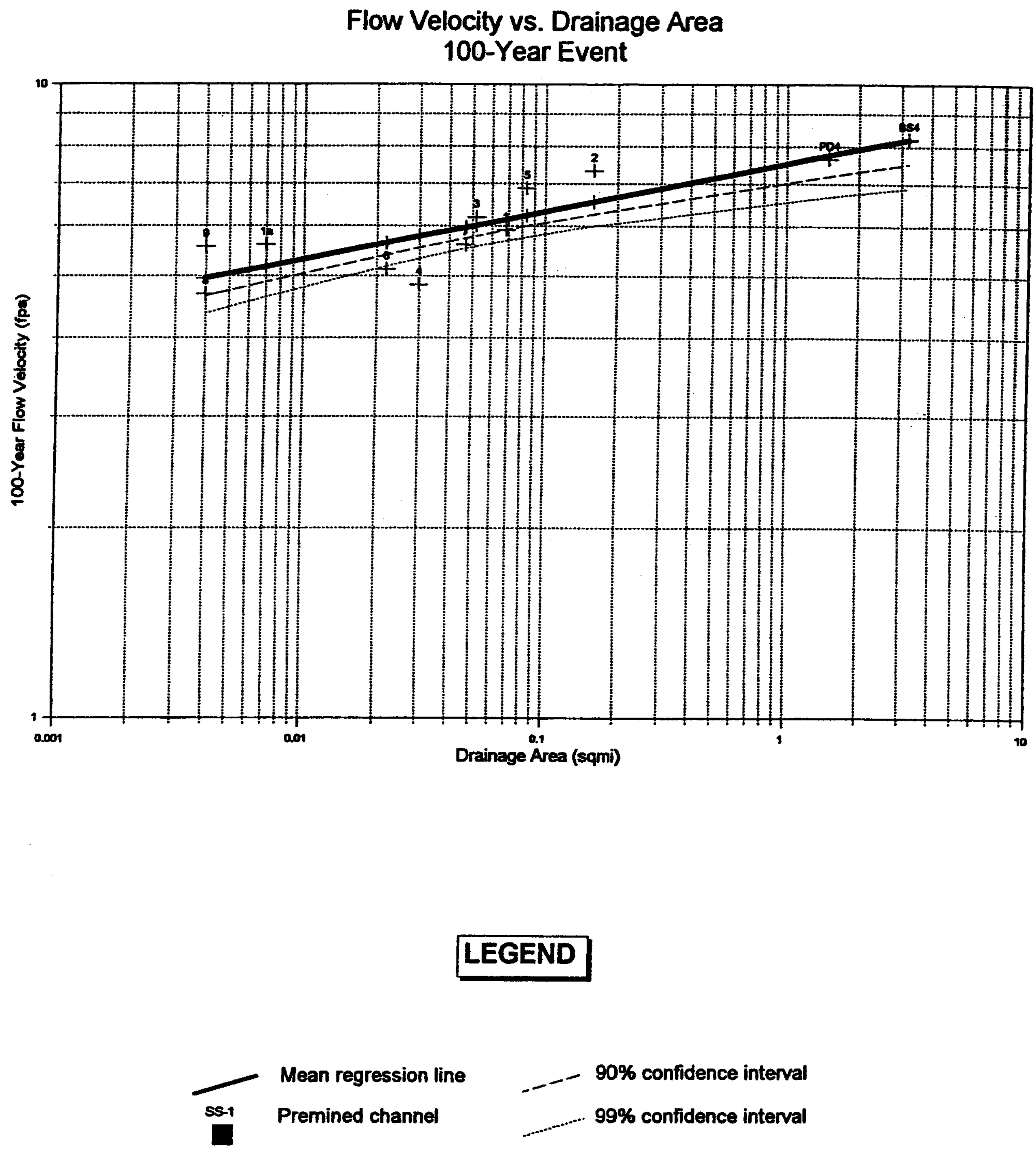
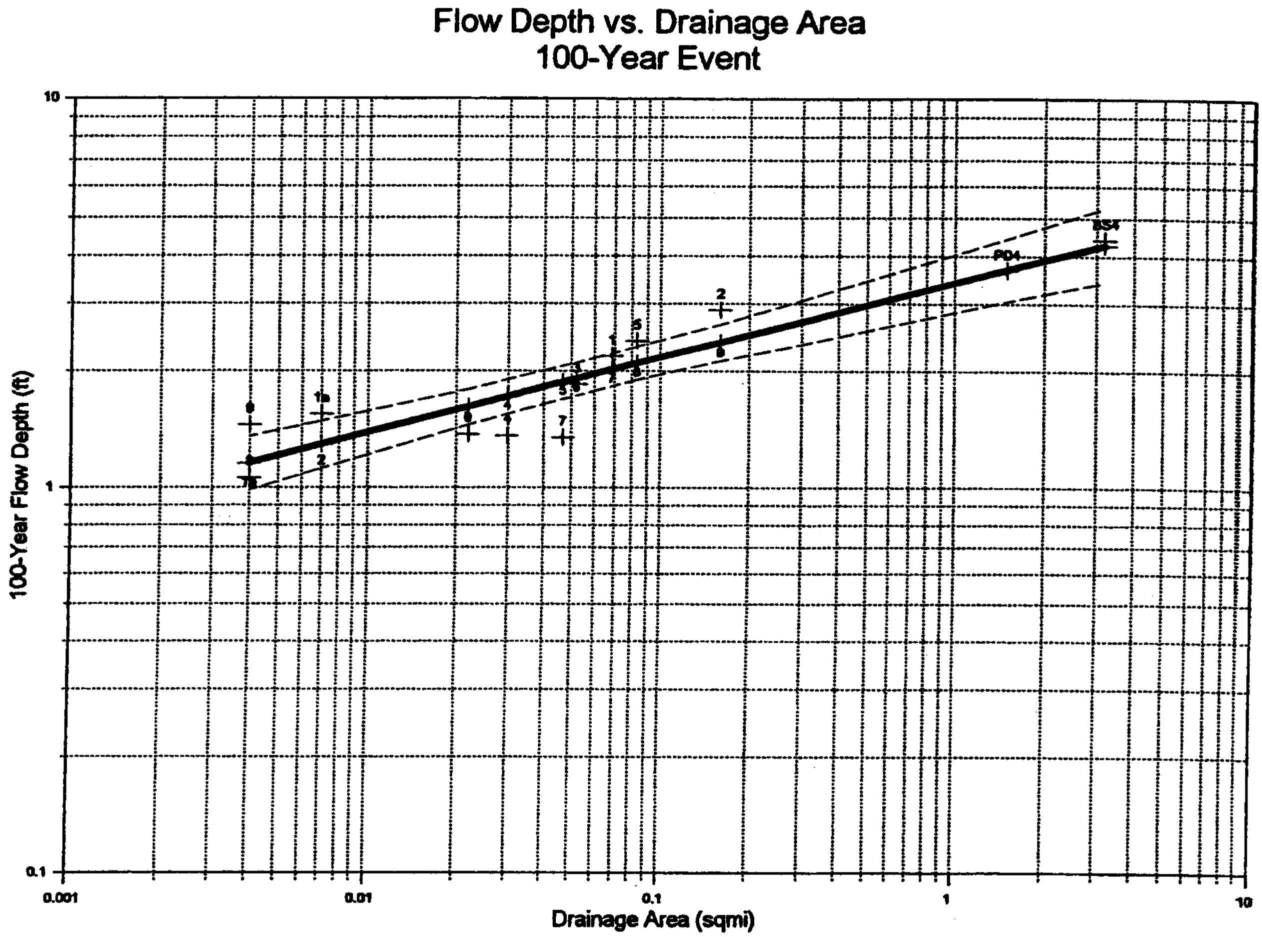


Figure B-7. Regional analysis regression plot for 100-year channel design parameters, Hanna area.



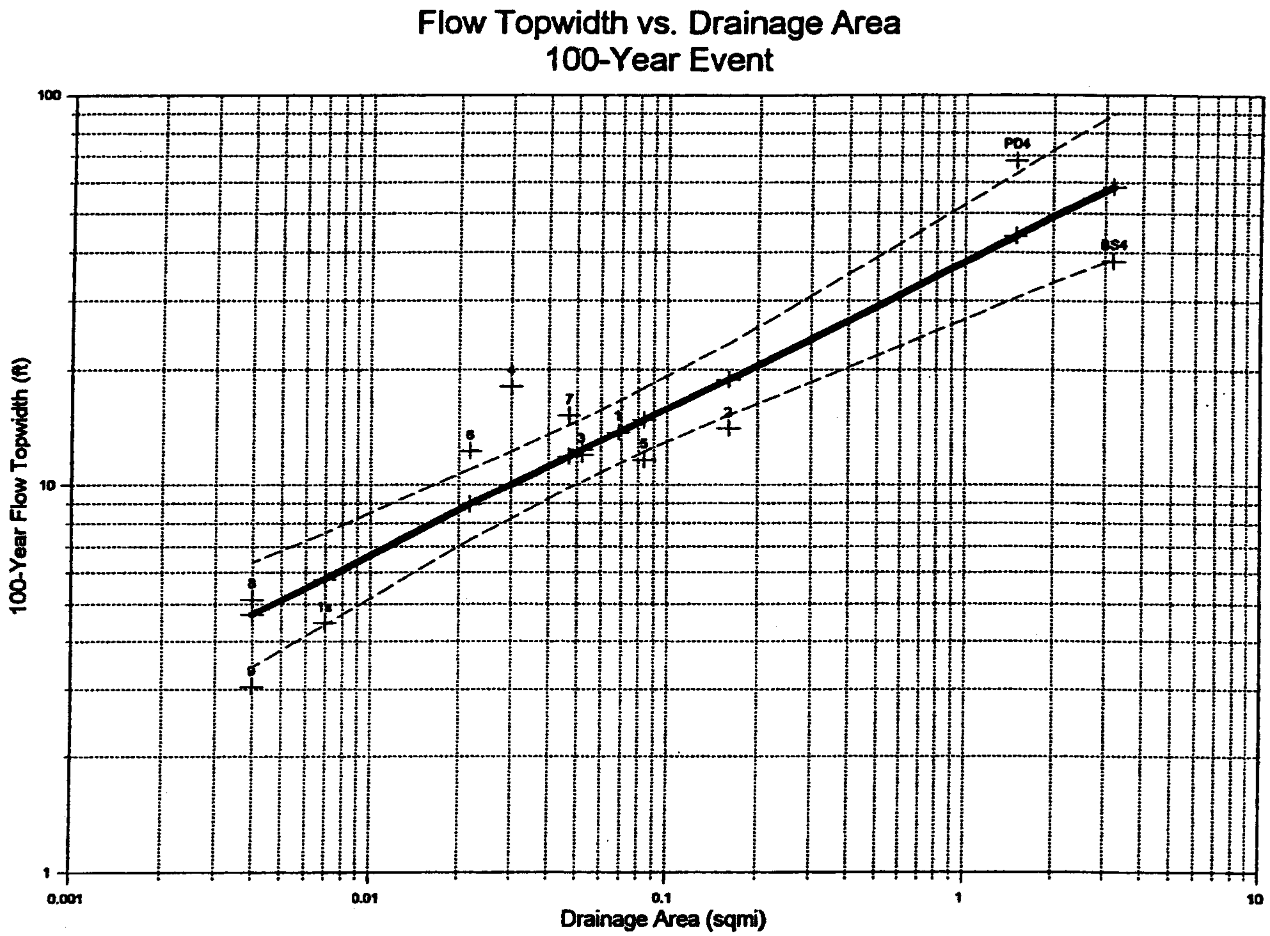
LEGEND

Mean regression line

90% confidence interval

SS-1 Premined channel

Figure B-8. Regional analysis regression plot for 100-year channel design parameters, Hanna area.



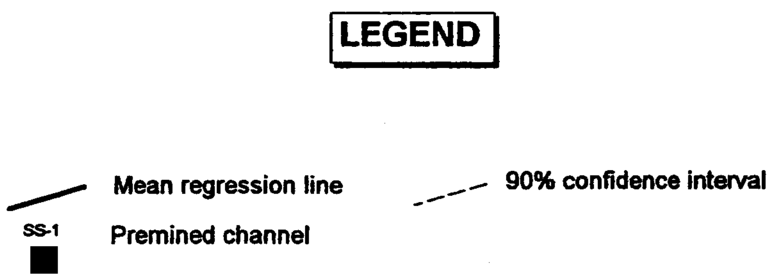


Figure B-9. Regional analysis regression plot for 100-year channel design parameters, Hanna area.

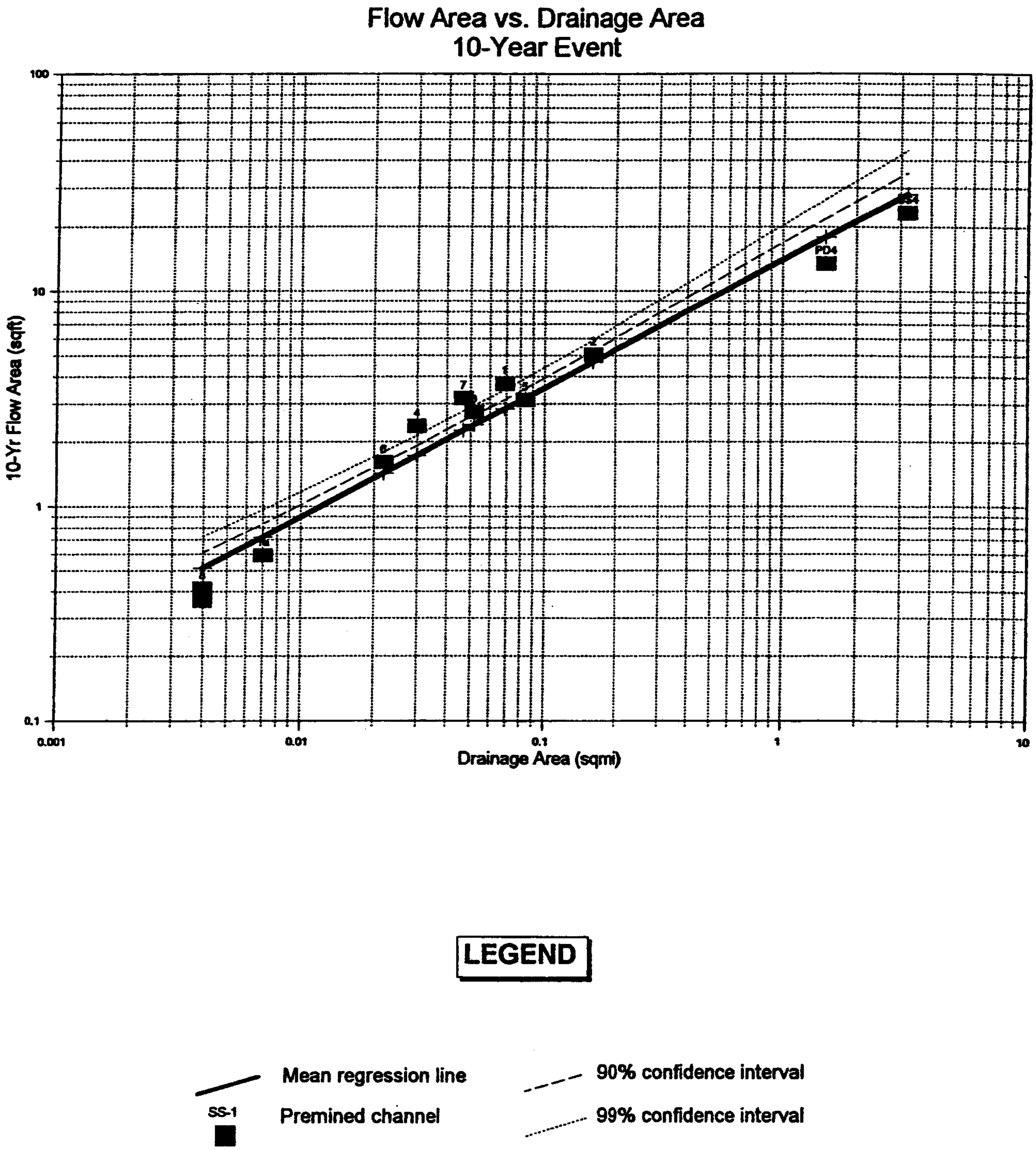


Figure B-10. Rainfall-runoff regression plot for 10-year channel design parameters, Hanna area.

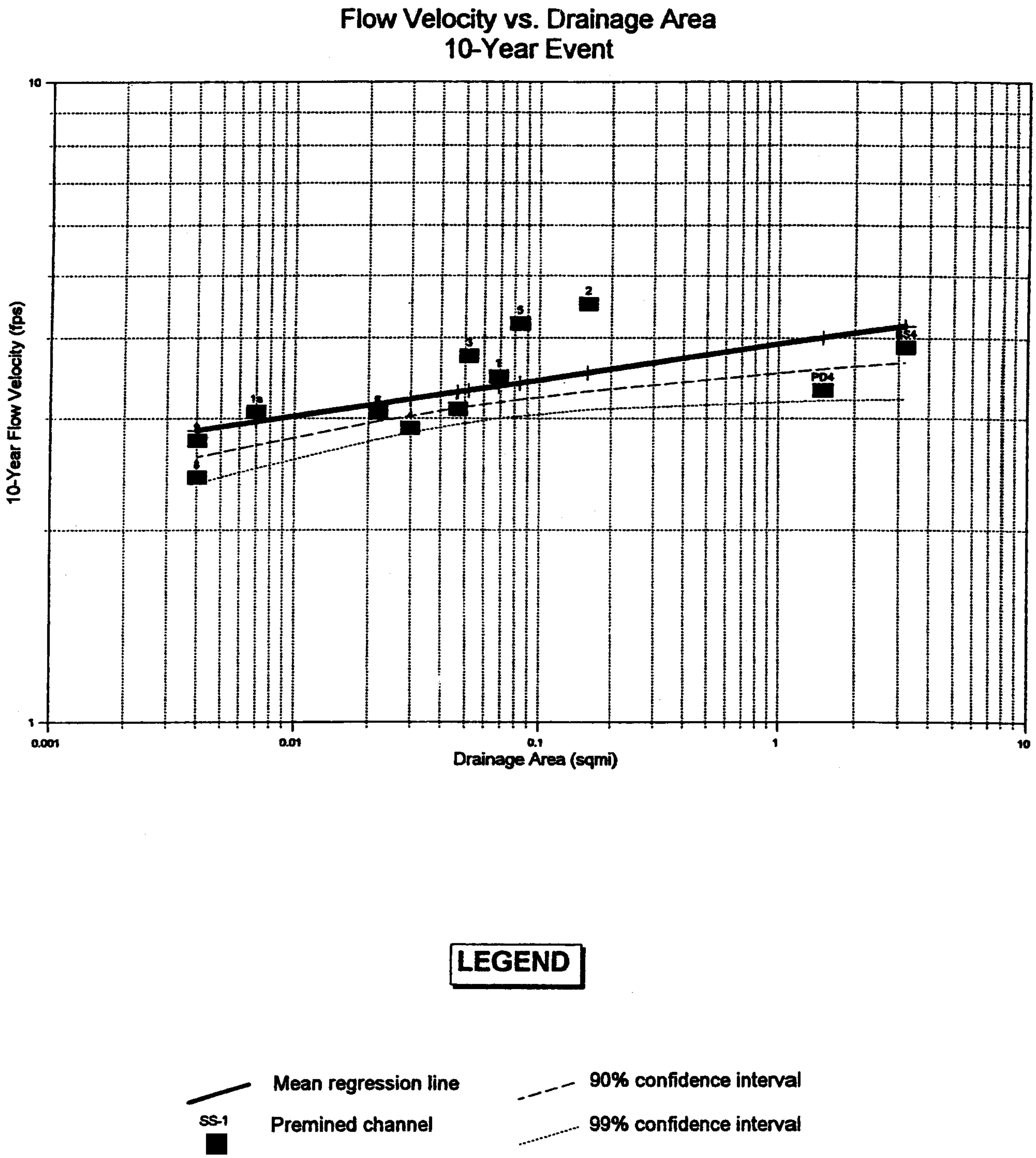
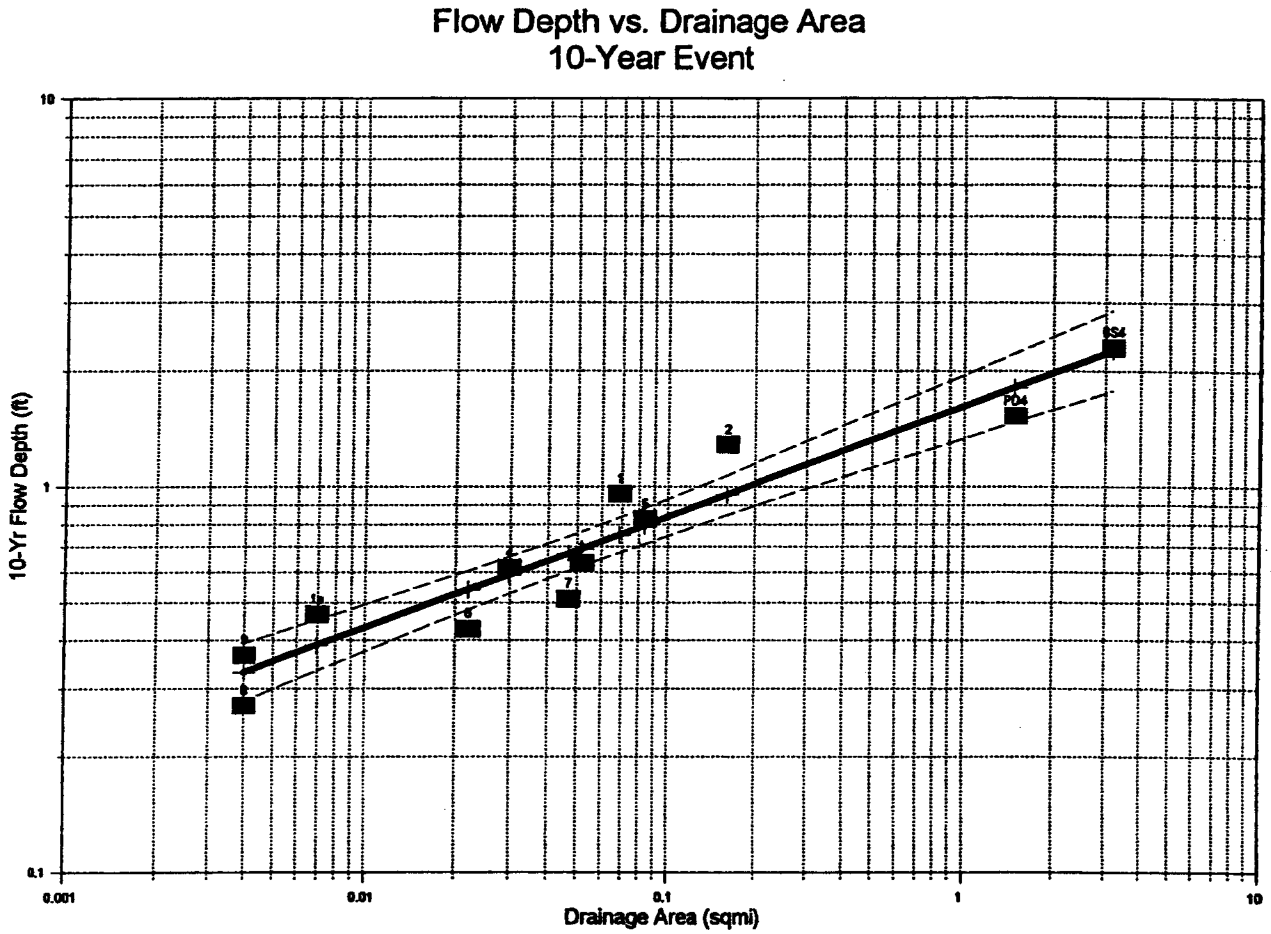


Figure B-11. Rainfall-runoff regression plot for 10-year channel design parameters, Hanna area.



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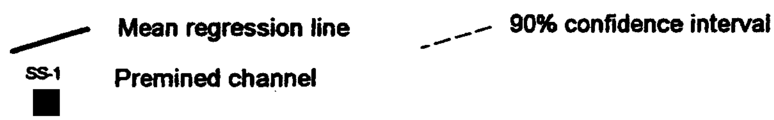
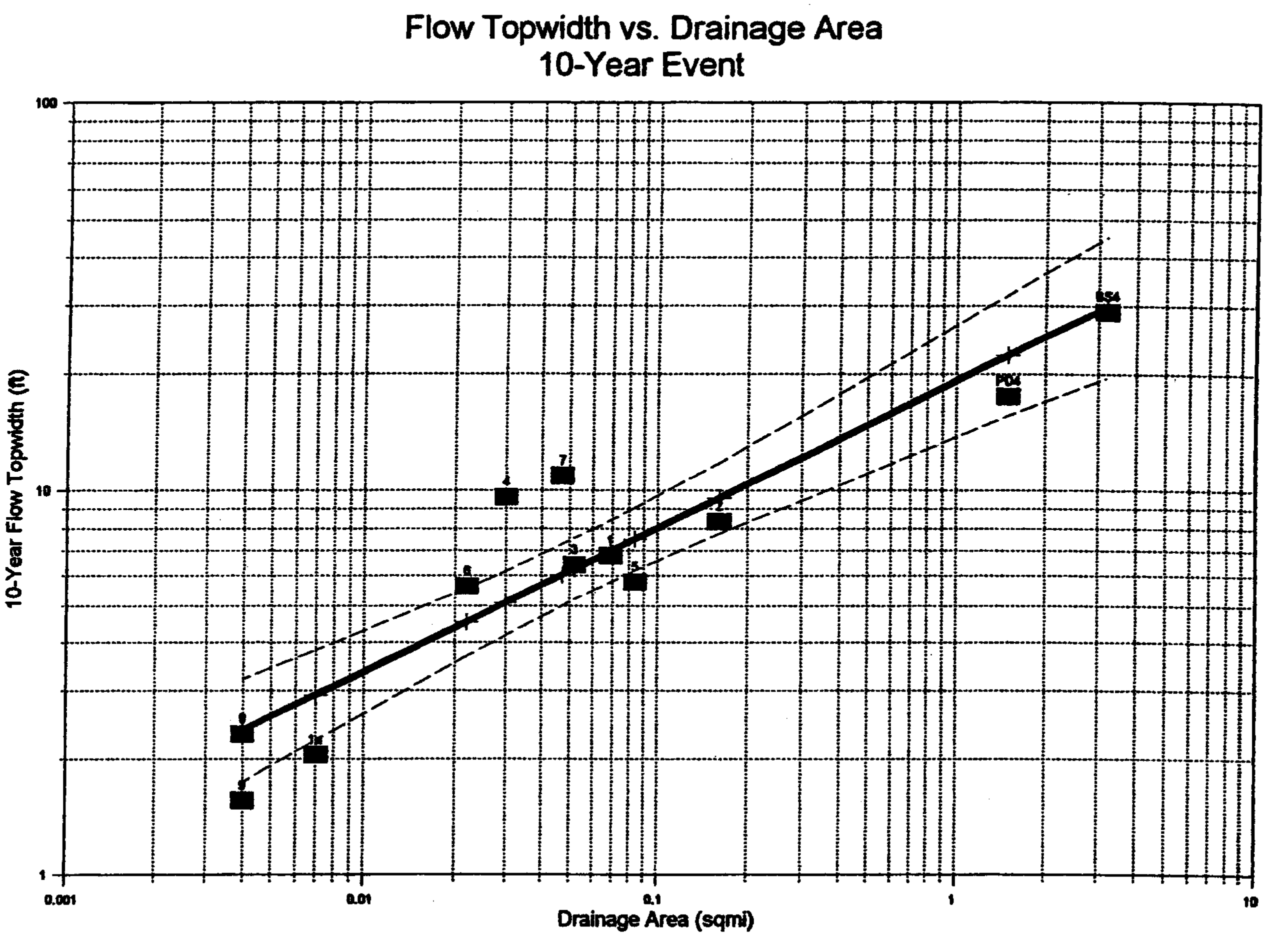


Figure B-12. Rainfall-runoff regression plot for 10-year channel design parameters, Hanna area.



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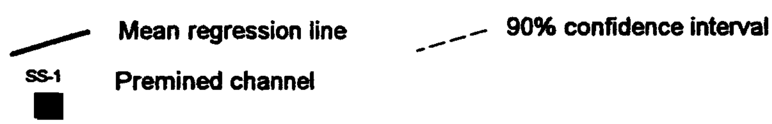

Figure B-13. Rainfall-runoff regression plot for 10-year channel design parameters, Hanna area.

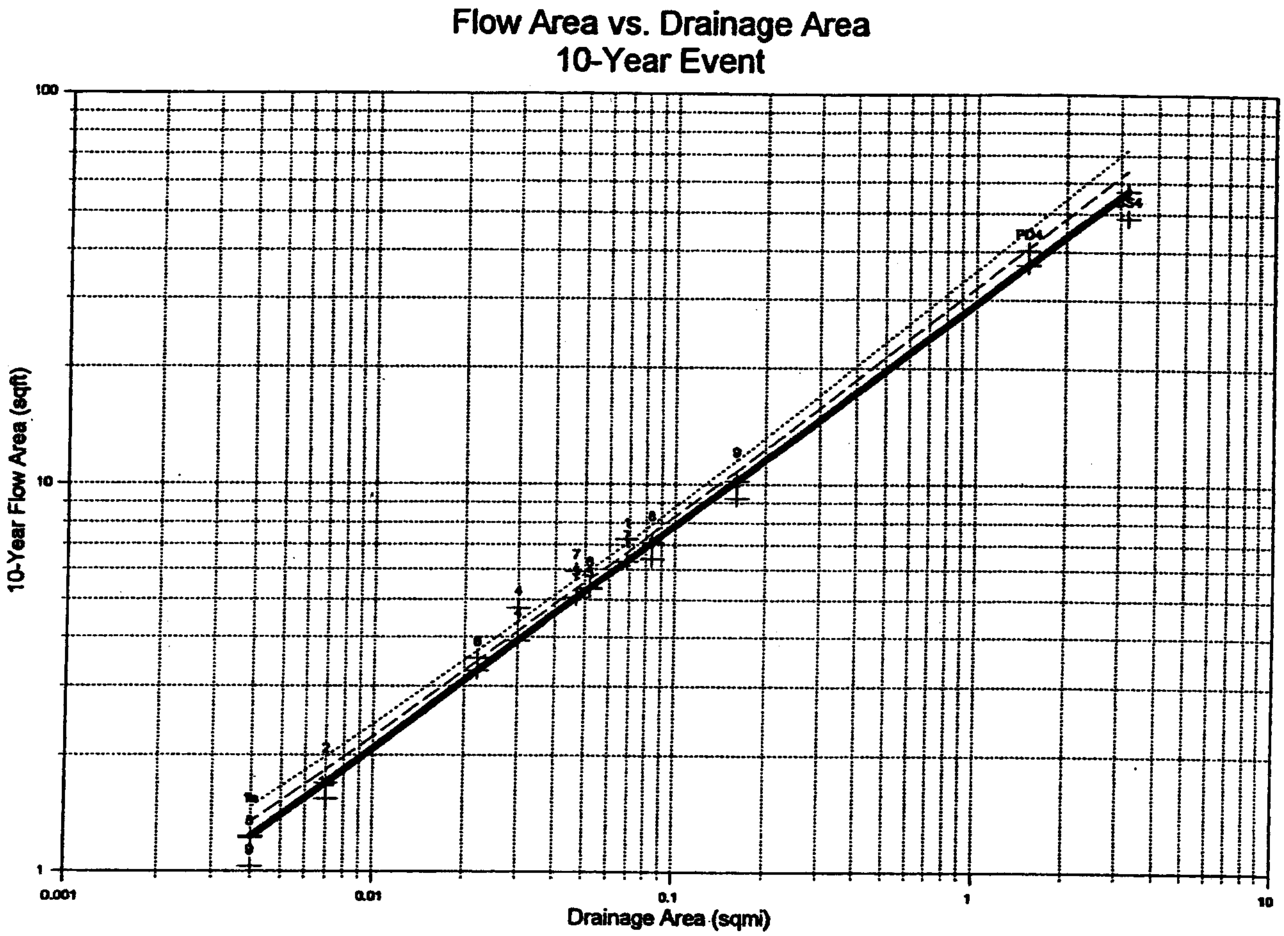

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Figure B-14. Regional analysis regression plot for 10-year channel design parameters, Hanna area.

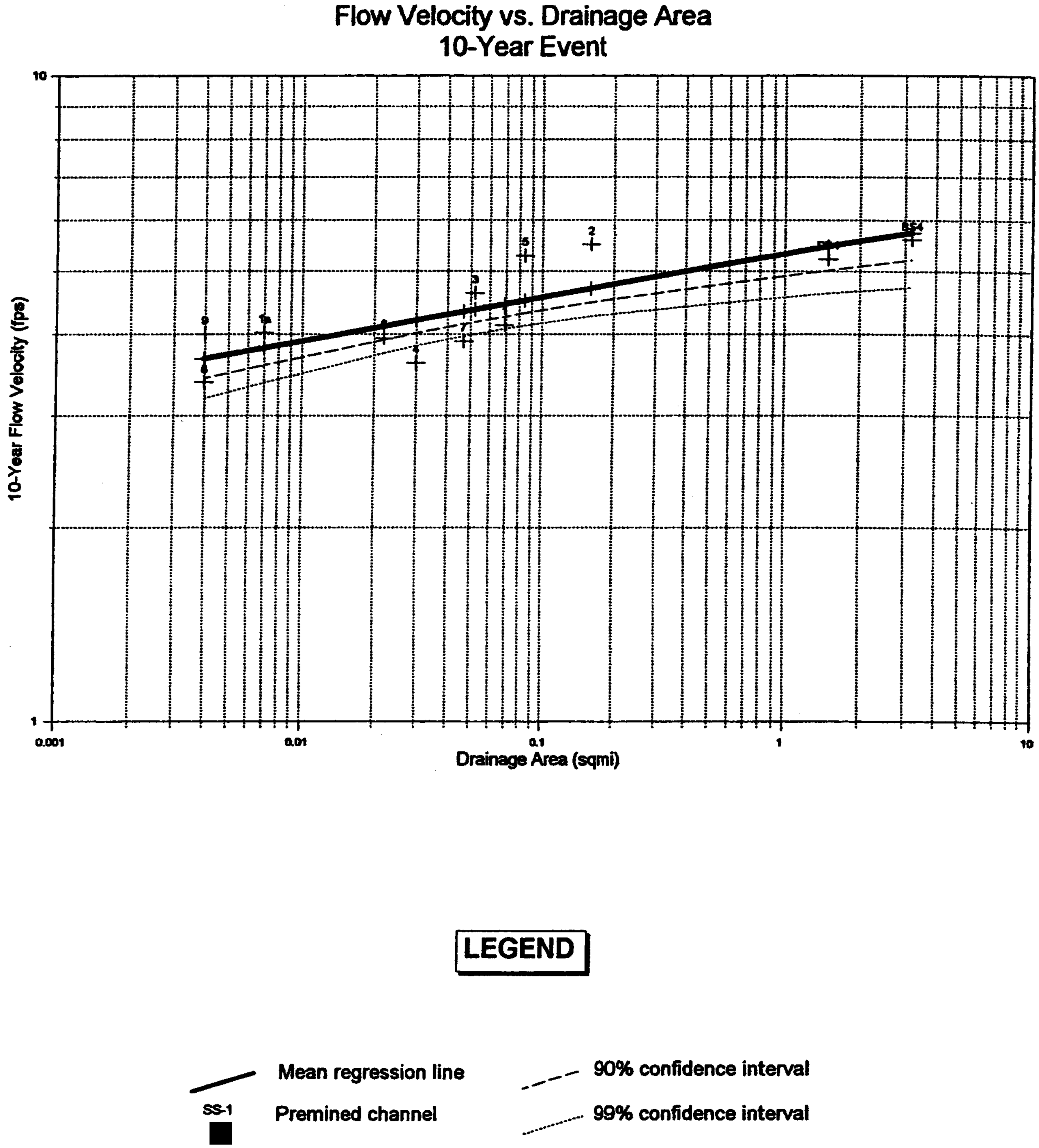

Figure B-15. Regional analysis regression plot for 10-year channel design parameters, Hanna area.

APPENDIX C

Powder River Basin Regression Results

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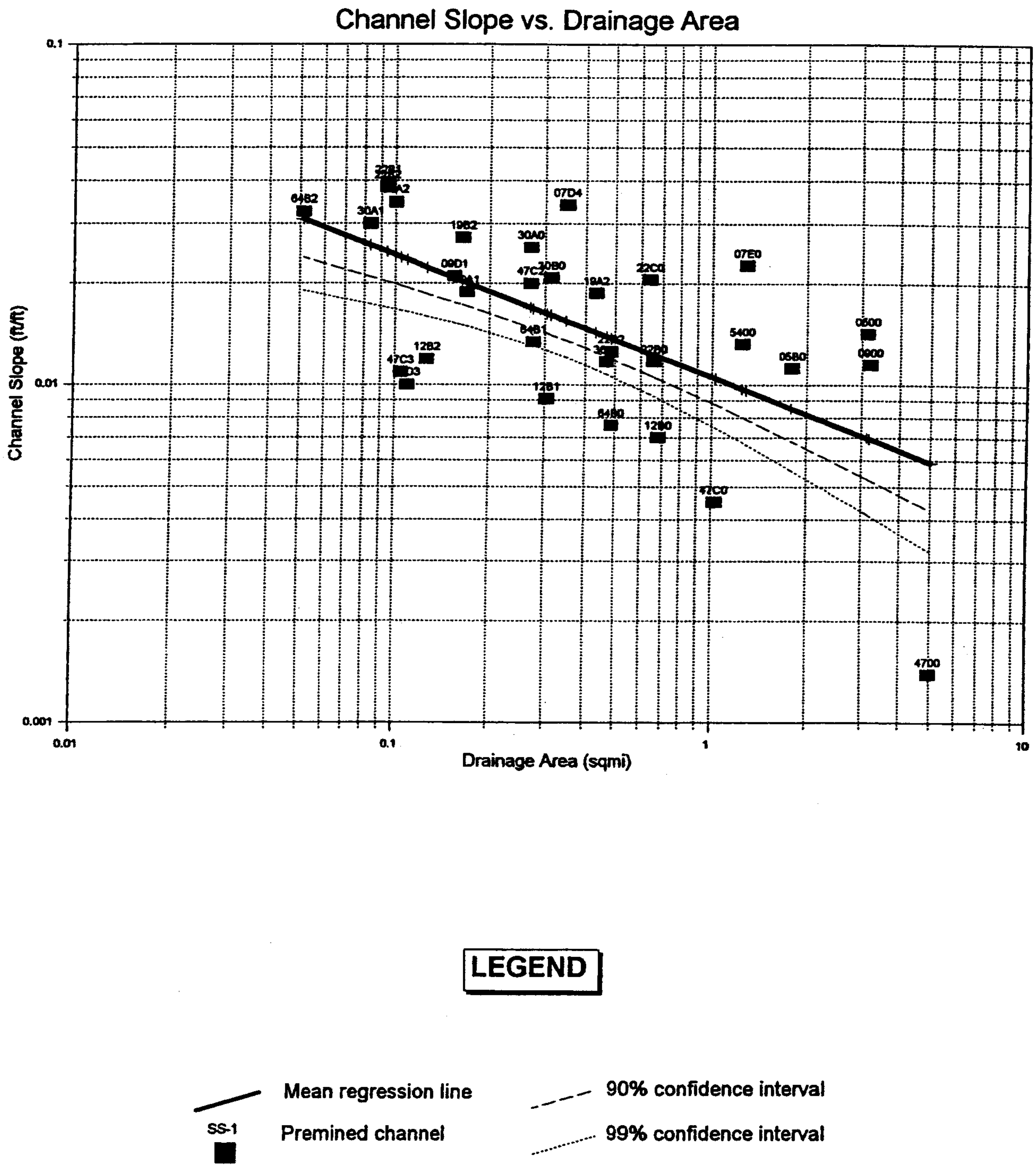


Figure C-1. Channel slope, Powder River area.

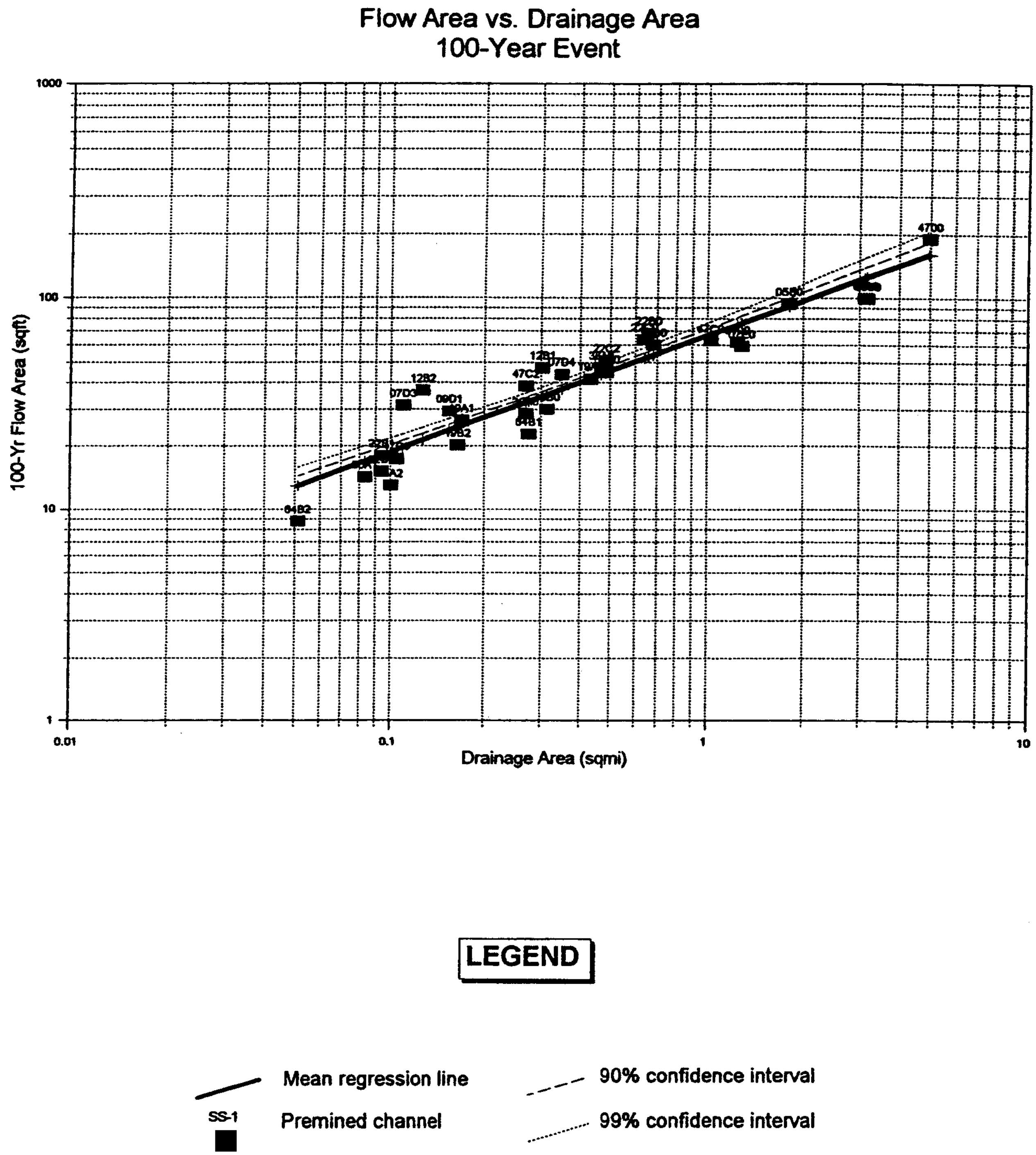


Figure C-2. Rainfall-runoff regression plot for 100-year channel design parameters, Powder River area.

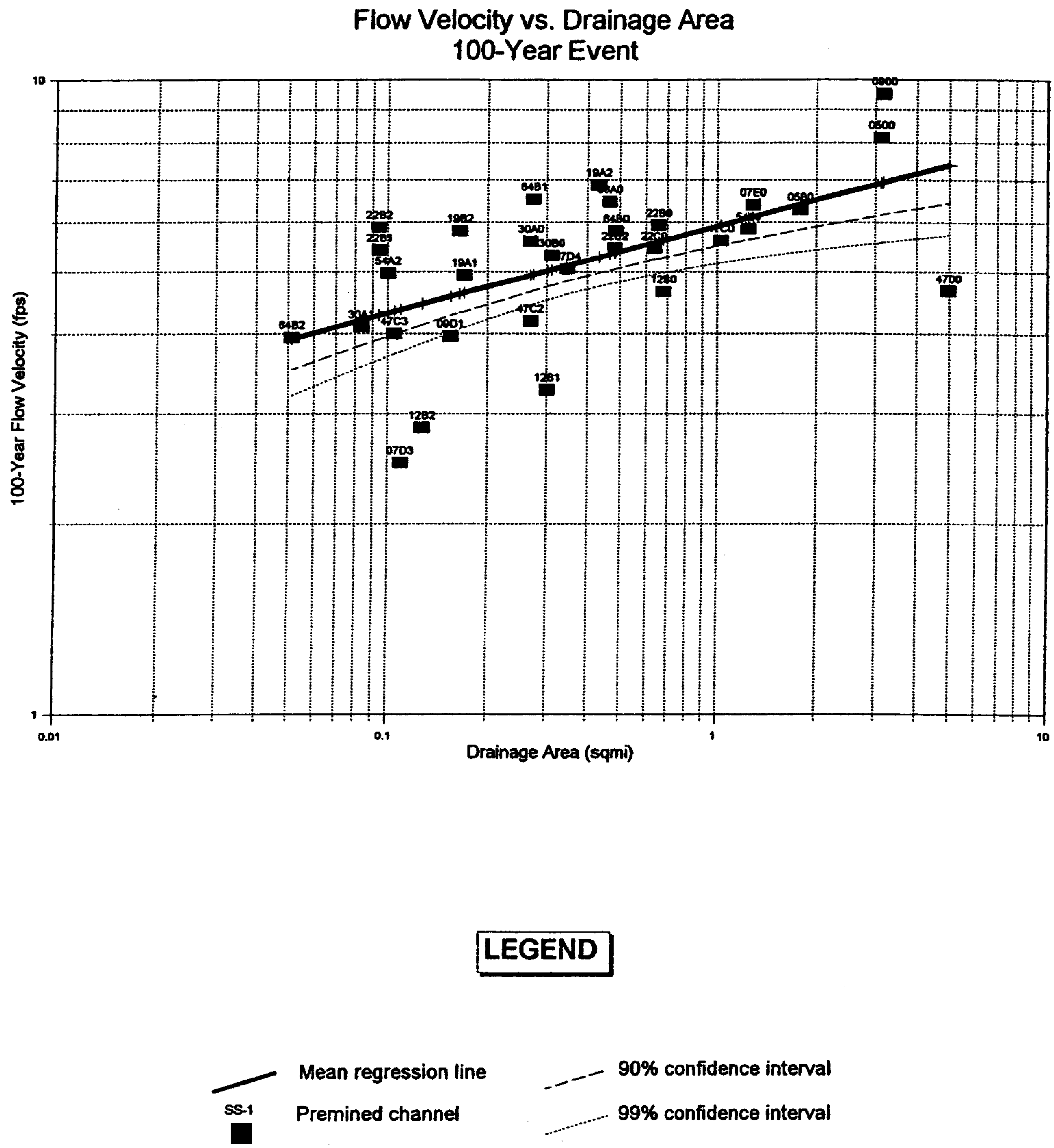
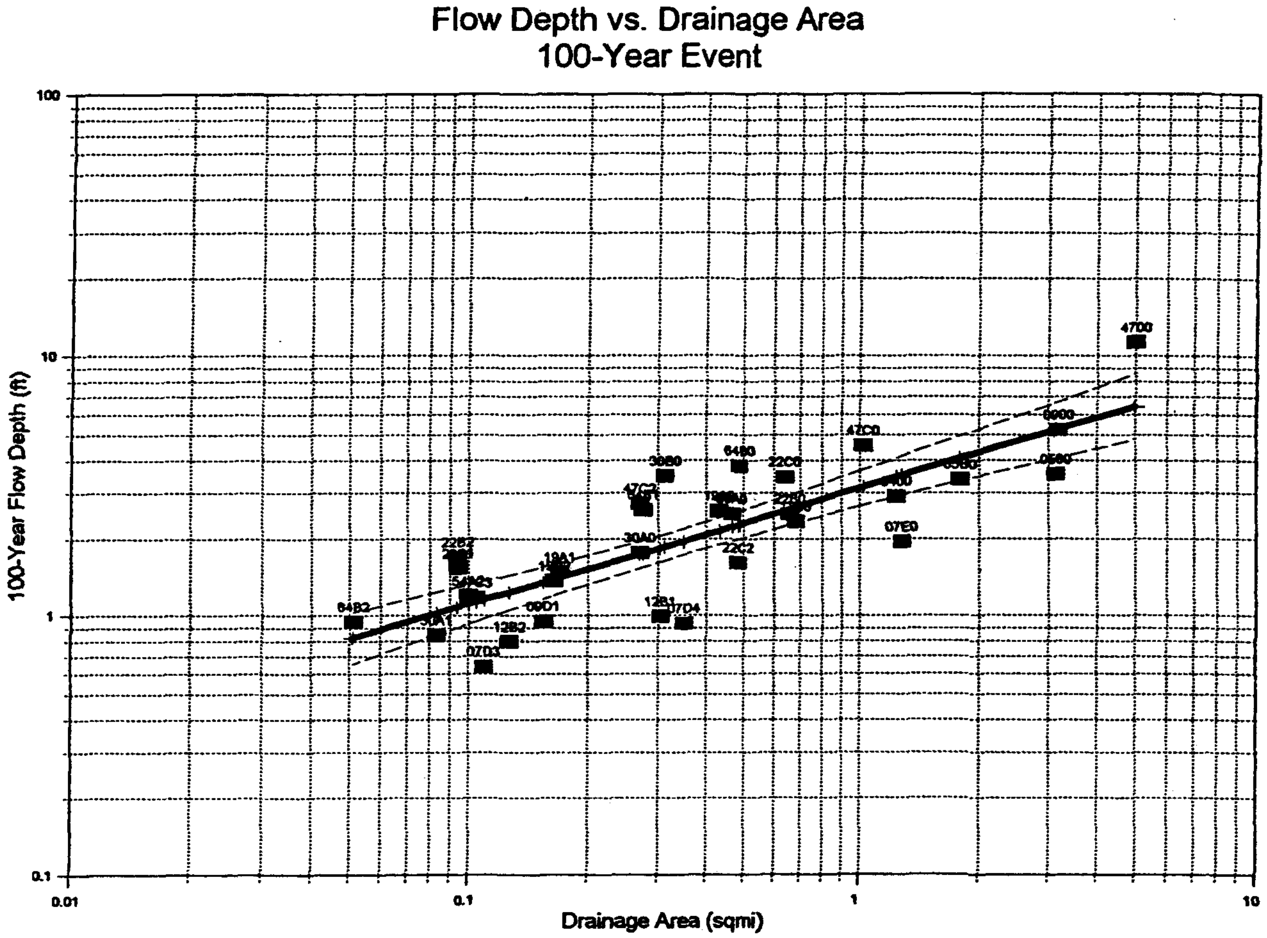


Figure C-3. Rainfall-runoff regression plot for 100-year channel design parameters, Powder River area.



LEGEND

Mean regression line

90% confidence interval

SS-1 Premined channel

Figure C-4. Rainfall-runoff regression plot for 100-year channel design parameters, Powder River area.

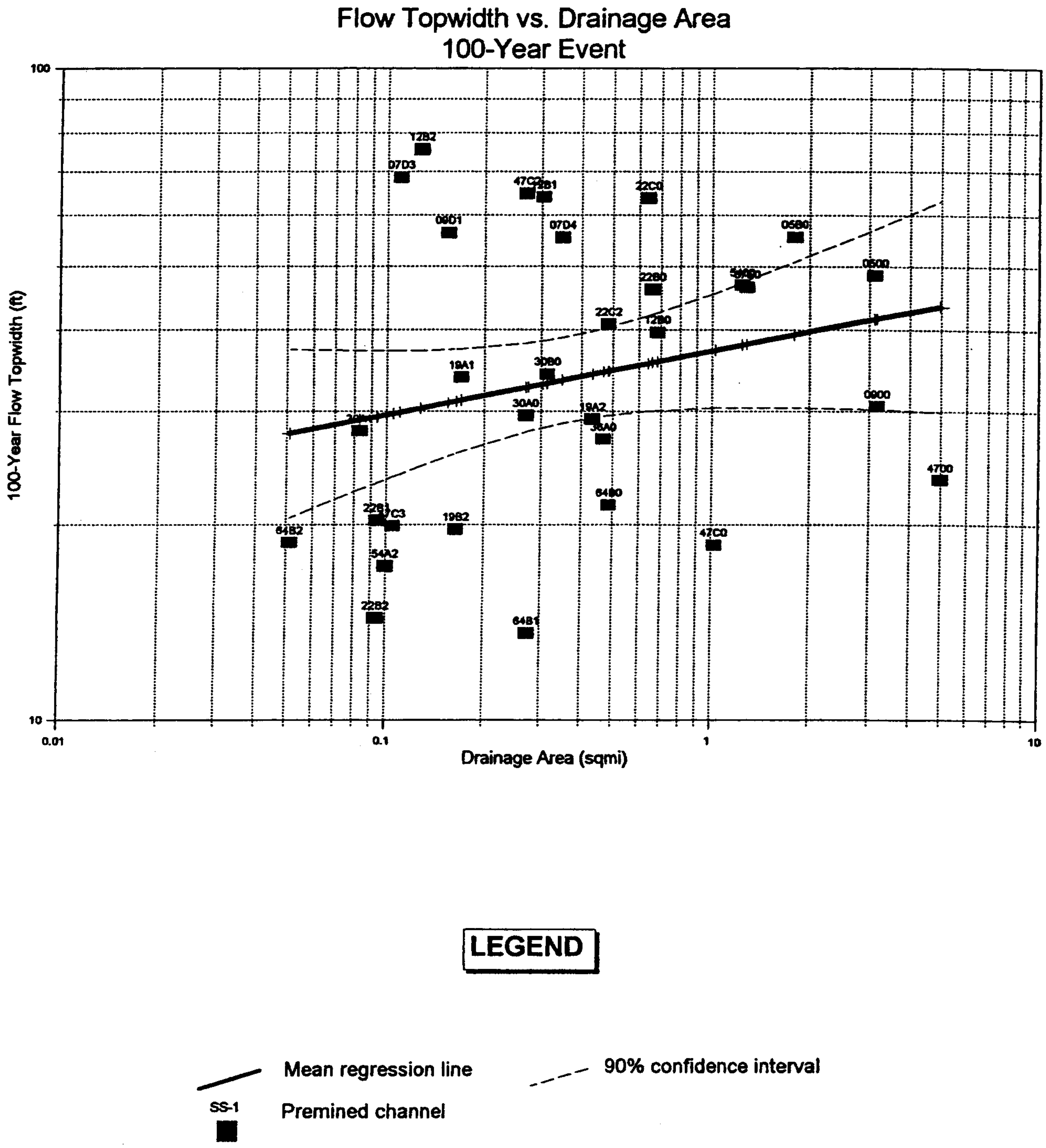


Figure C-5. Rainfall-runoff regression plot for 100-year channel design parameters, Powder River area.

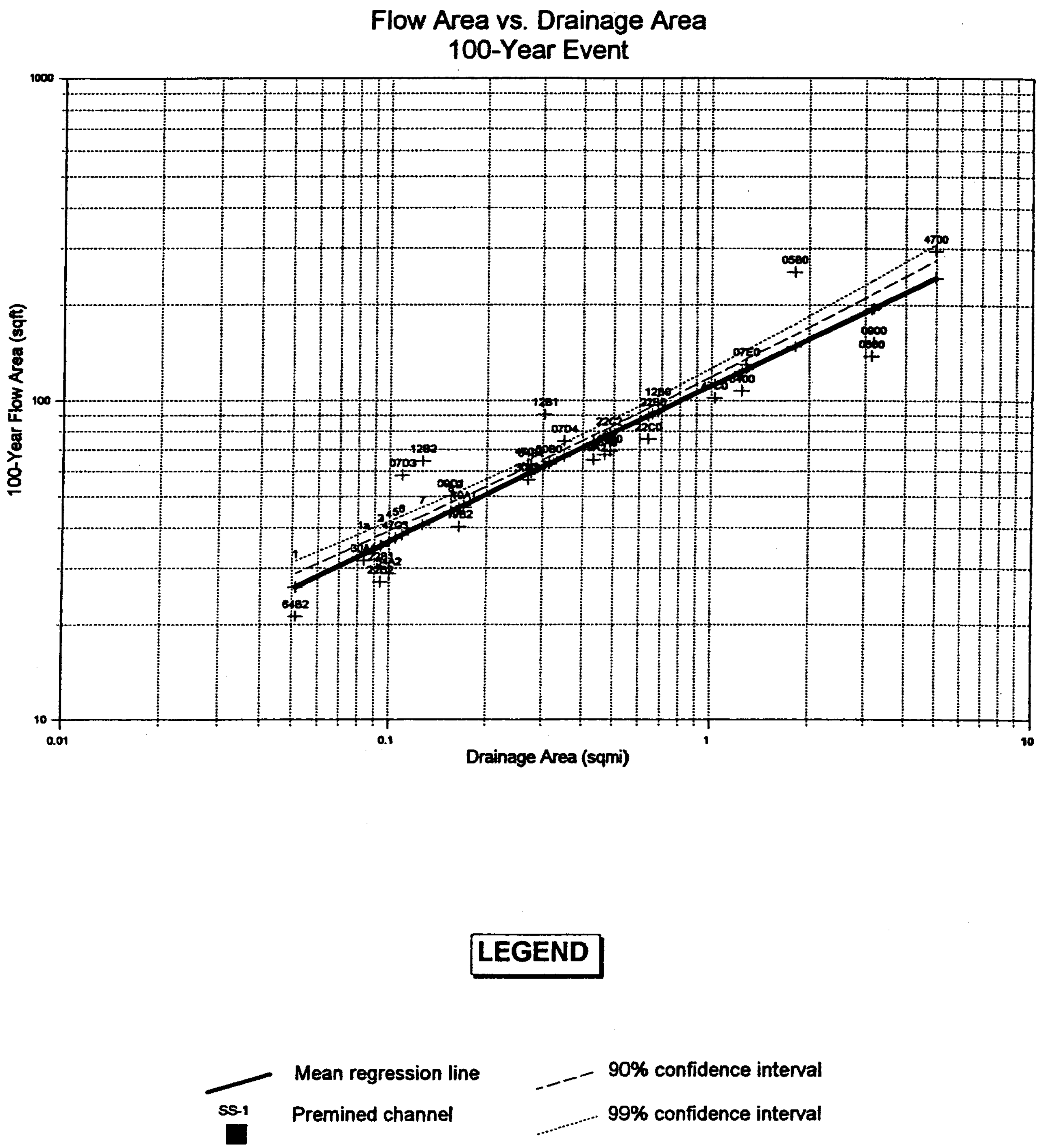


Figure C-6. Regional analysis regression plot for 100-year channel design parameters, Powder River area.

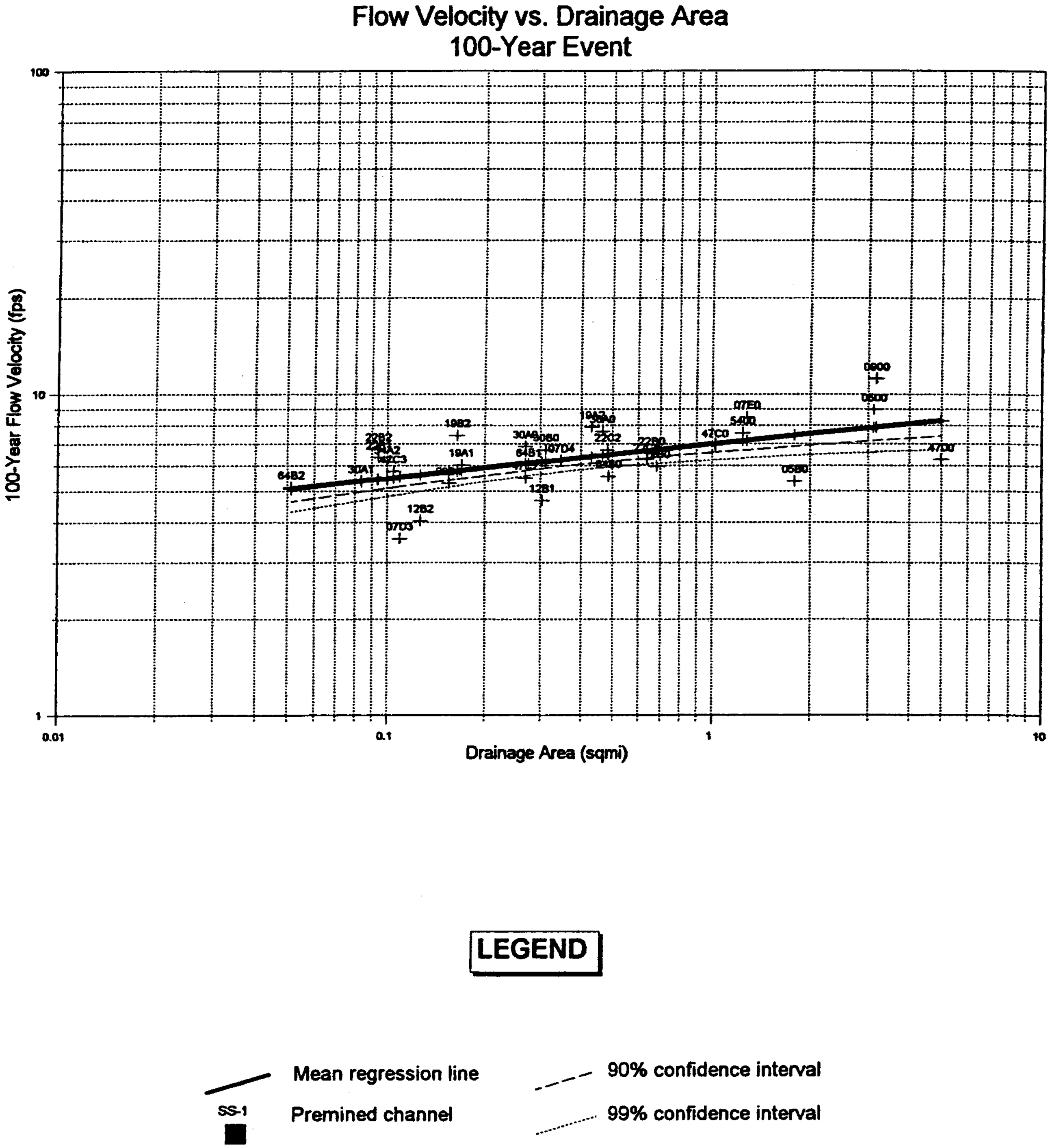


Figure C-7. Regional analysis regression plot for 100-year channel design parameters, Powder River area.

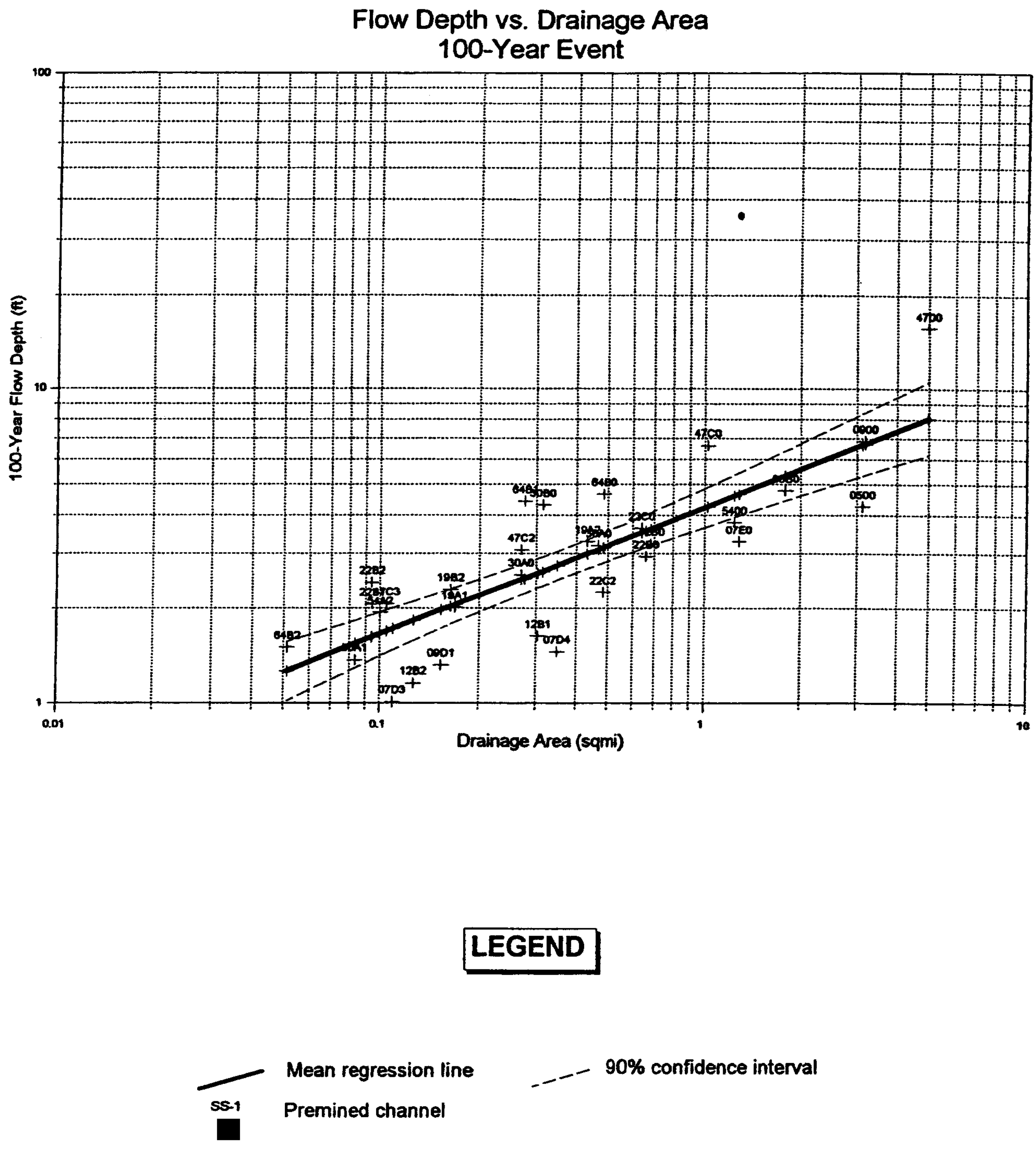
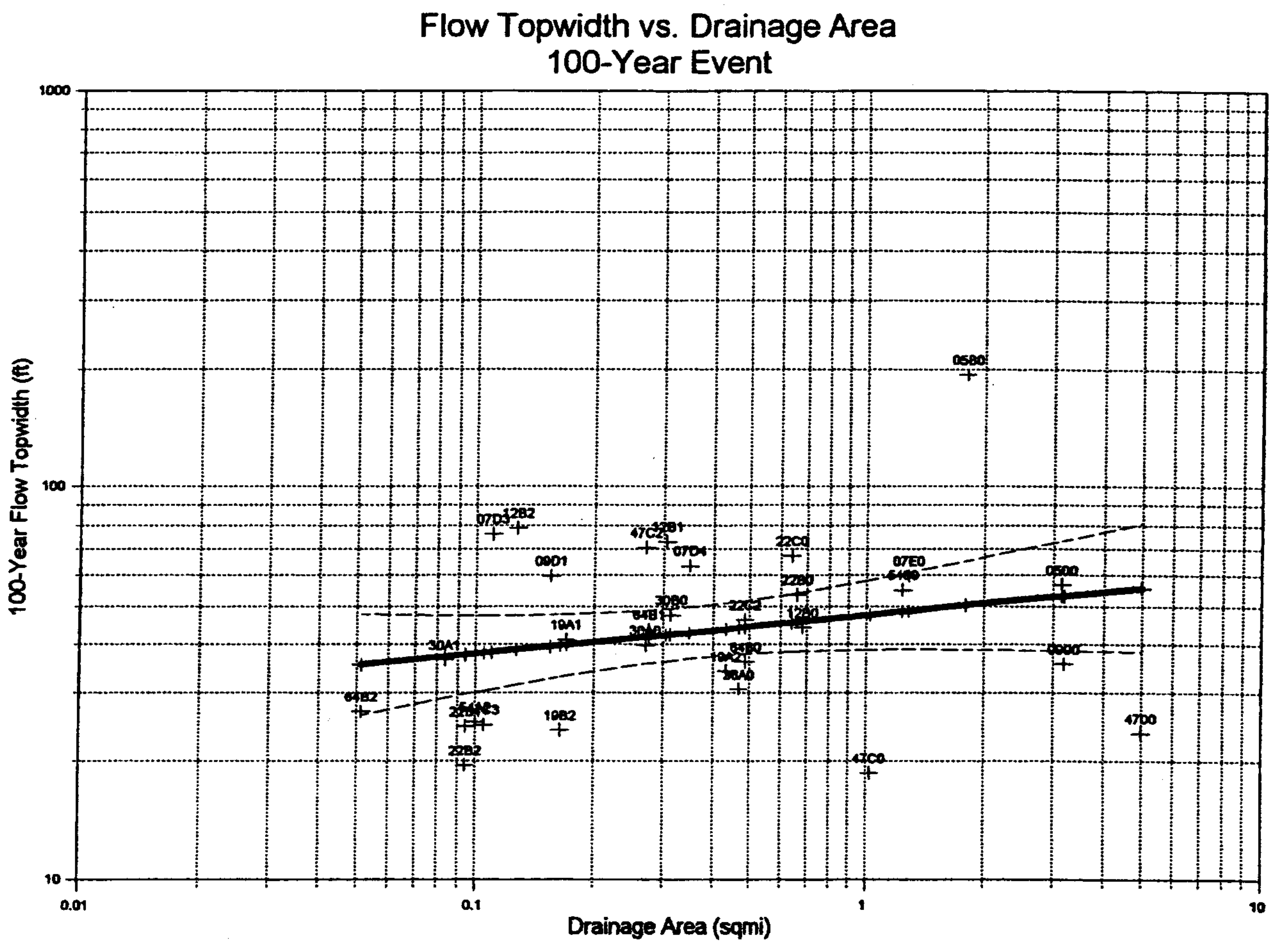


Figure C-8. Regional analysis regression plot for 100-year channel design parameters, Powder River area.



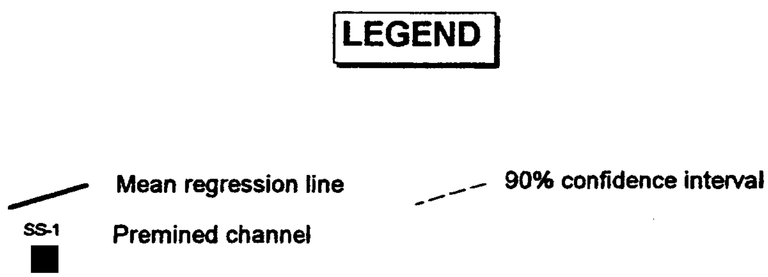


Figure C-9. Regional analysis regression plot for 100-year channel design parameters, Powder River area.

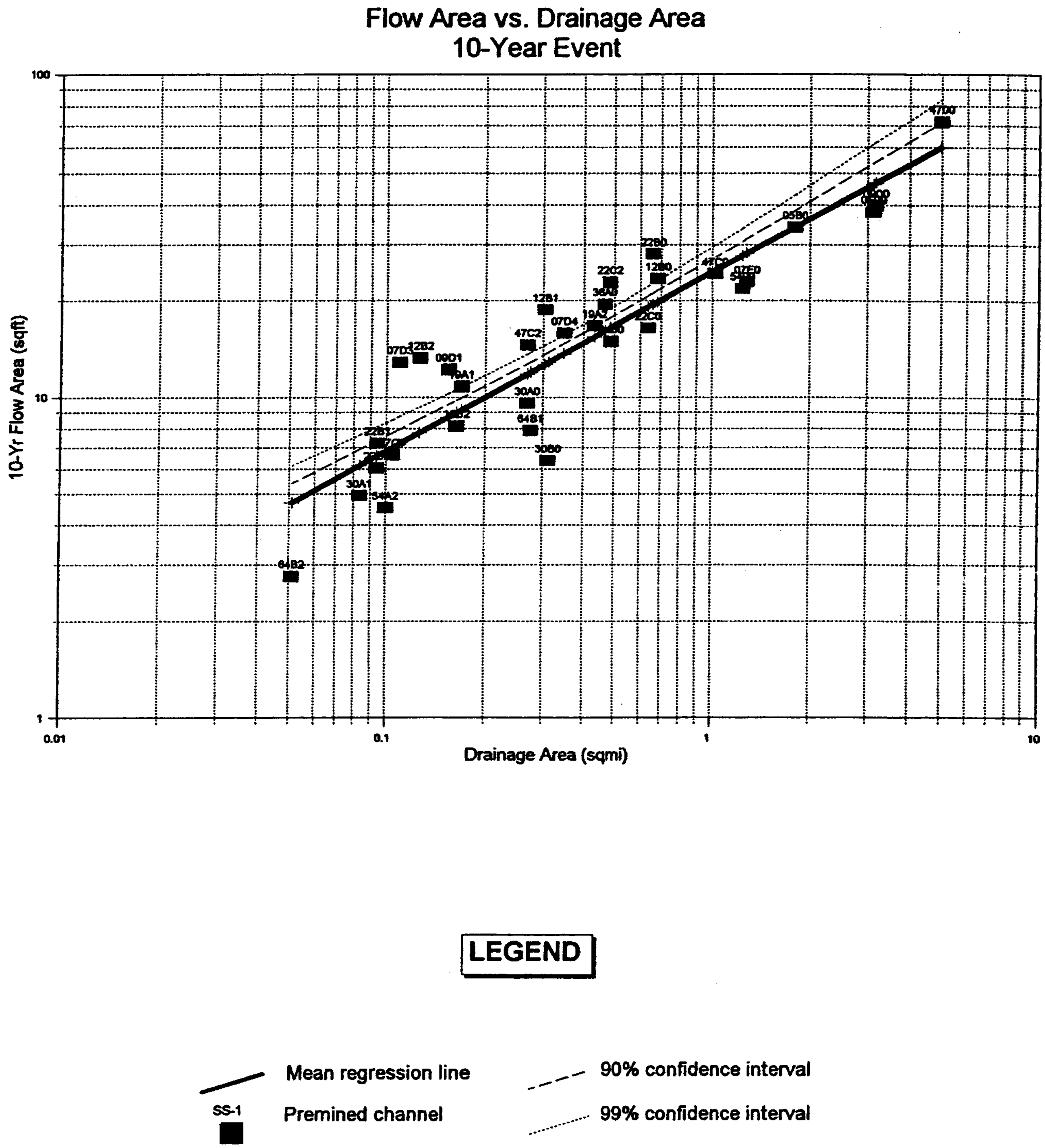


Figure C-10. Rainfall-runoff regression plot for 10-year channel design parameters, Powder River area.

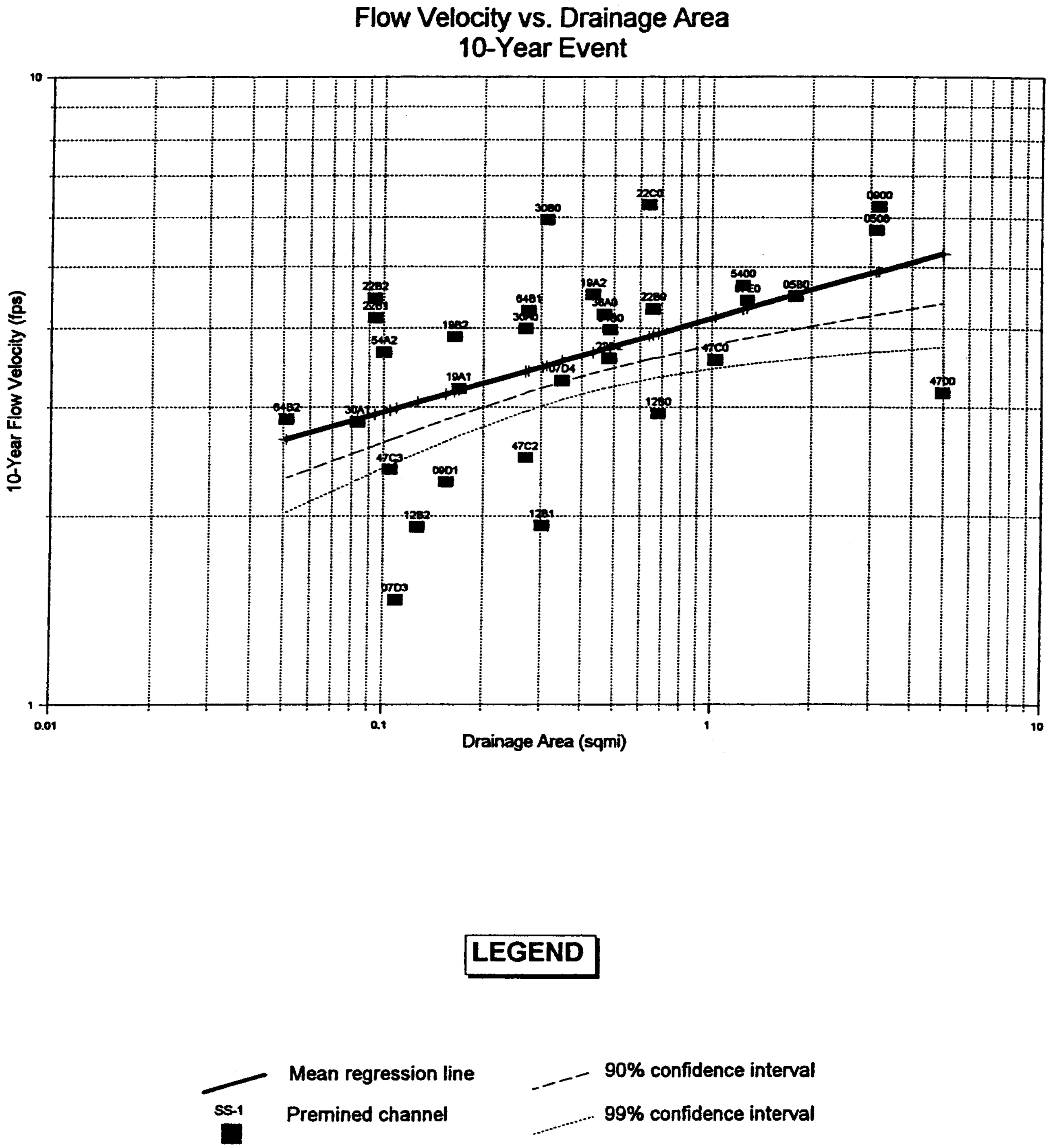


Figure C-11. Rainfall-runoff regression plot for 10-year channel design parameters, Powder River area.

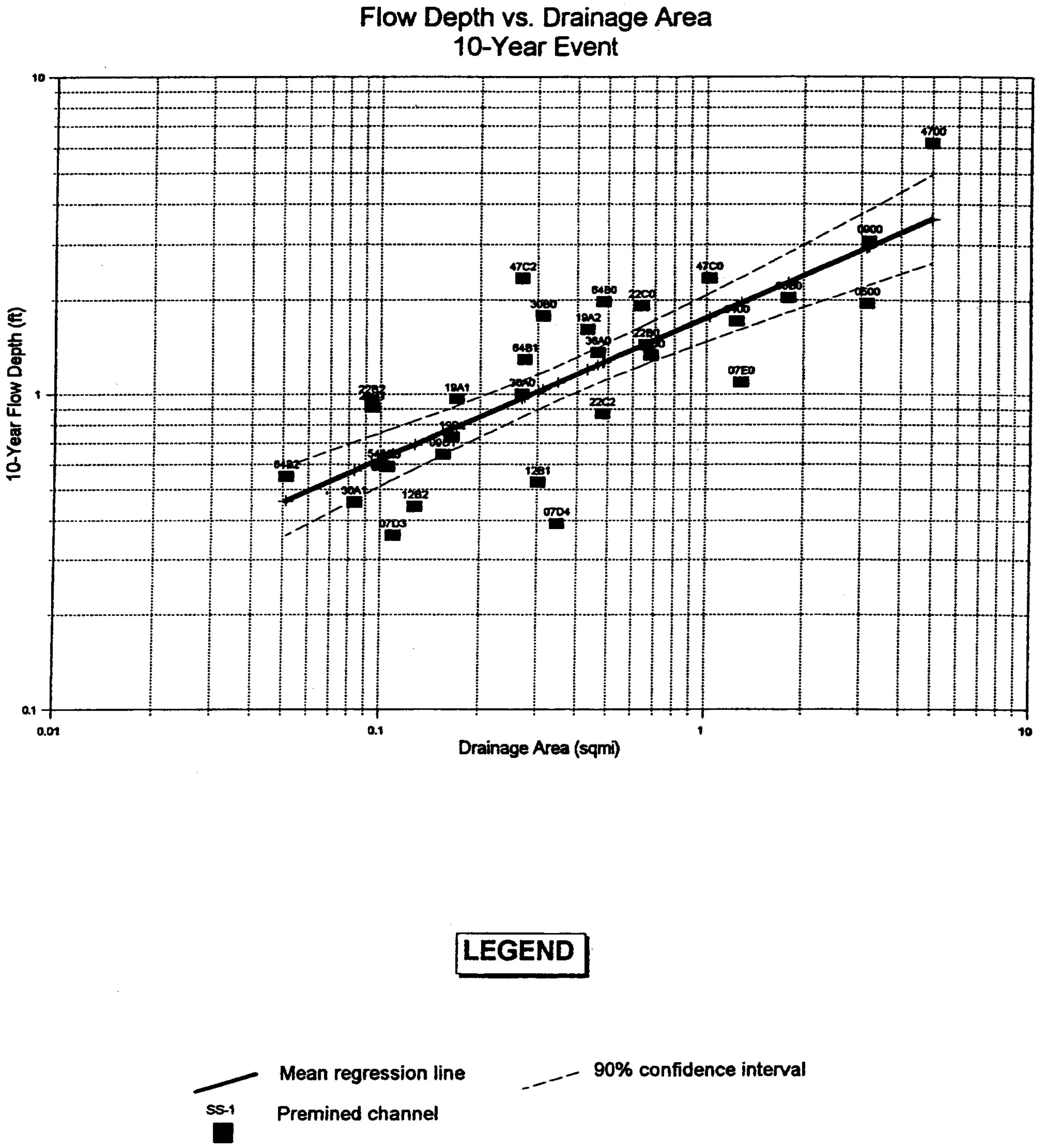


Figure C-12. Rainfall-runoff regression plot for 10-year channel design parameters, Powder River area.

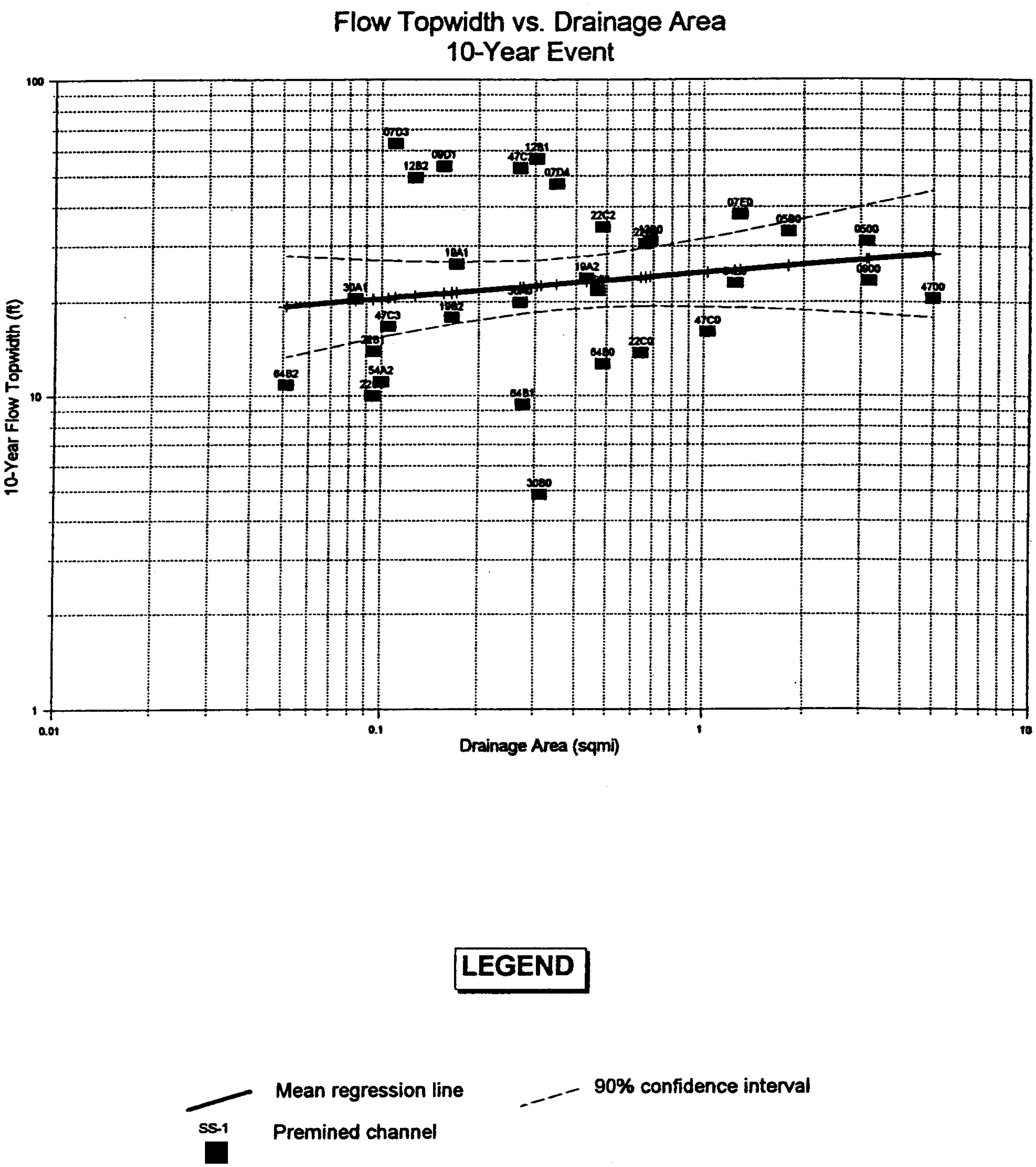


Figure C-13. Rainfall-runoff regression plot for 10-year channel design parameters, Powder River area.

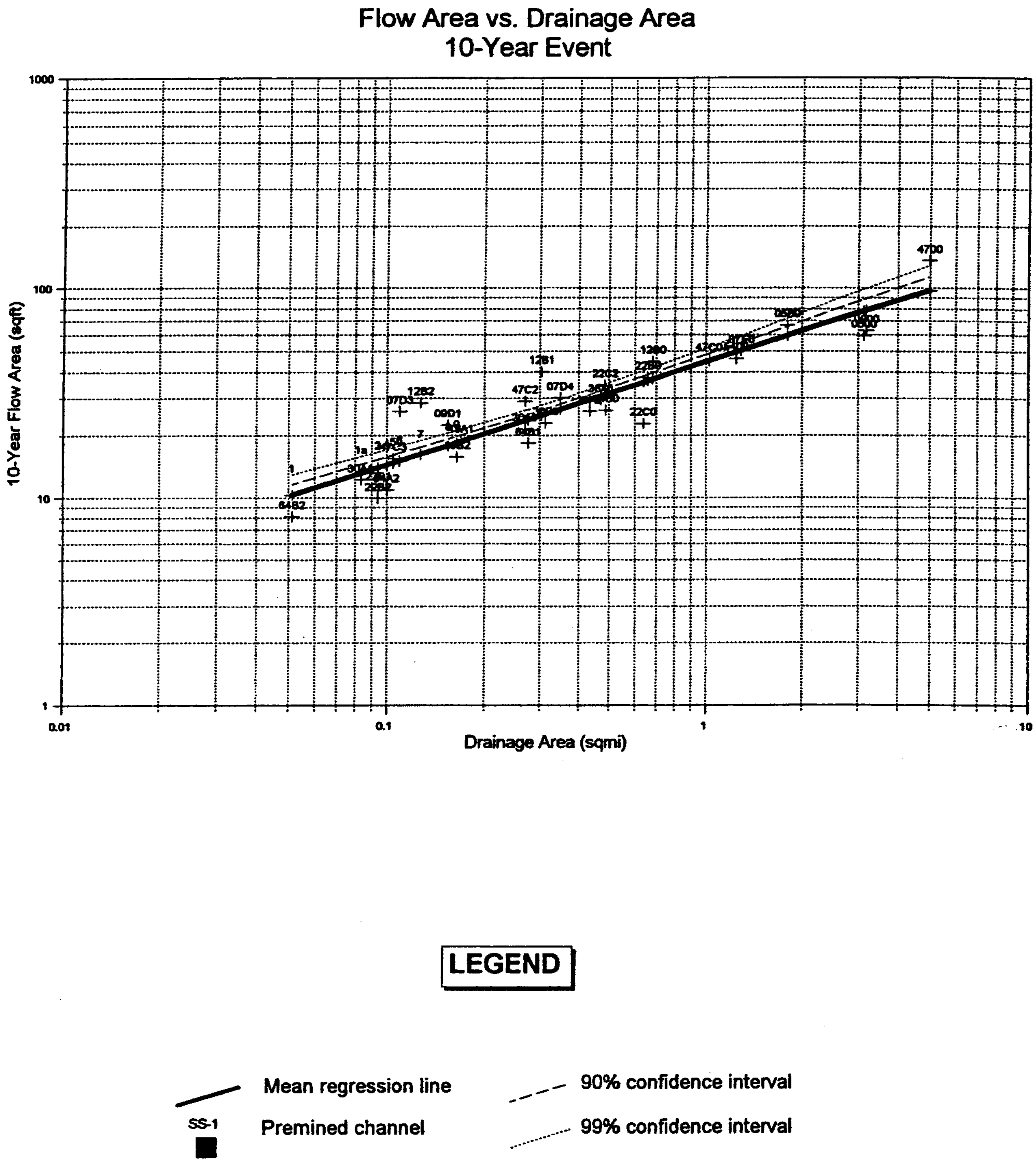


Figure C-14. Regional analysis regression plot for 10-year channel design parameters, Powder River area.

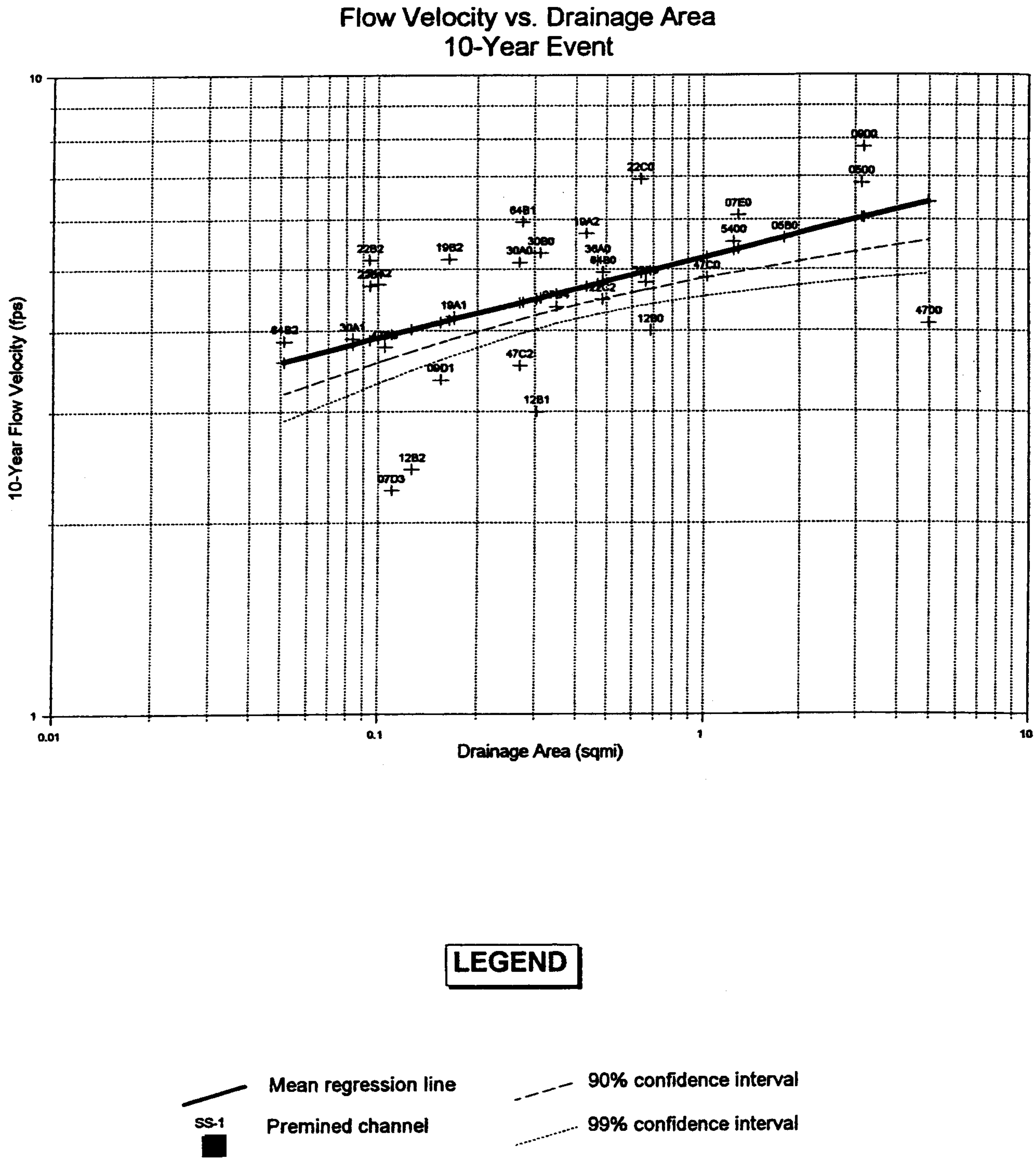


Figure C-15. Regional analysis regression plot for 10-year channel design parameters, Powder River area.

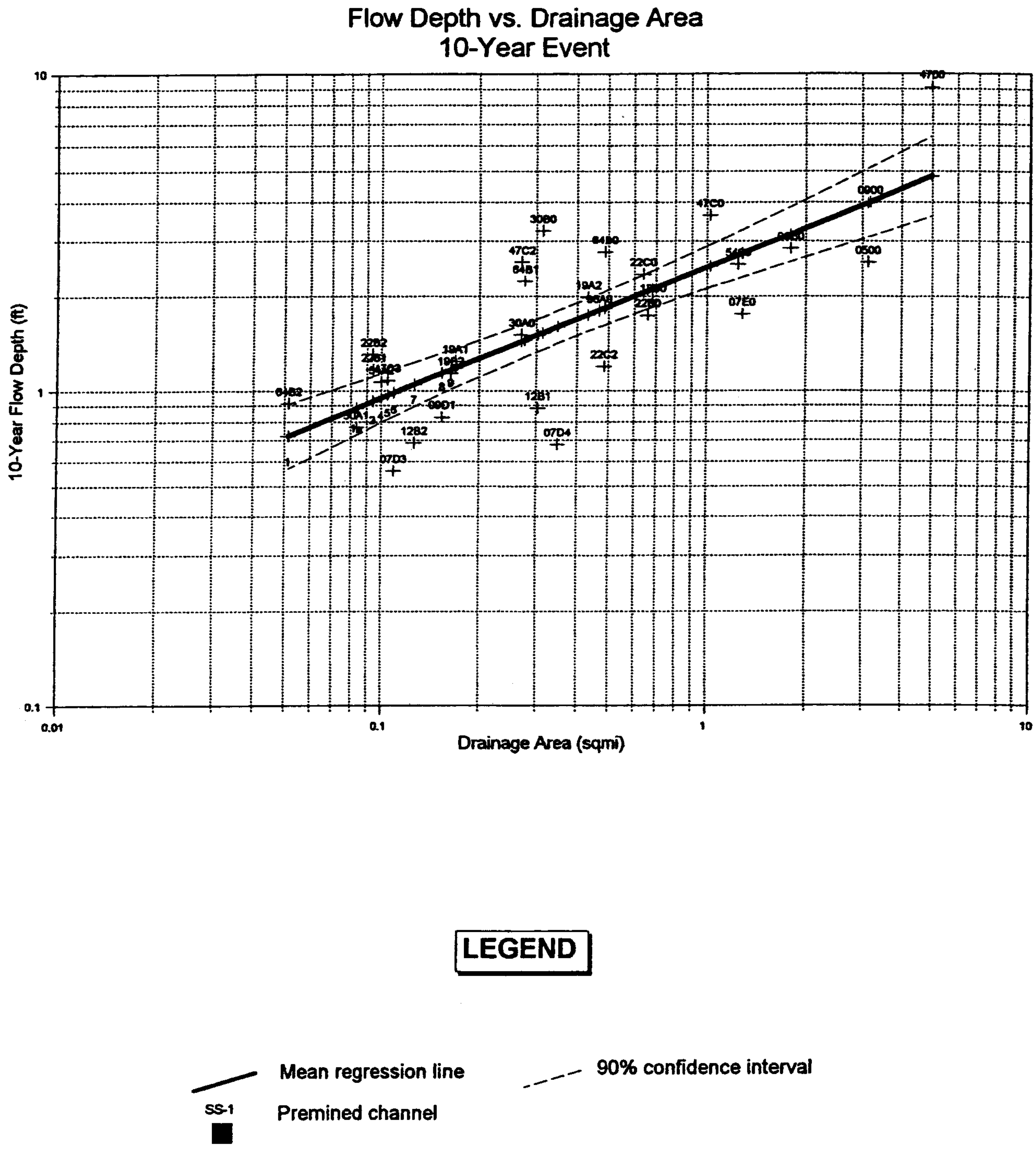
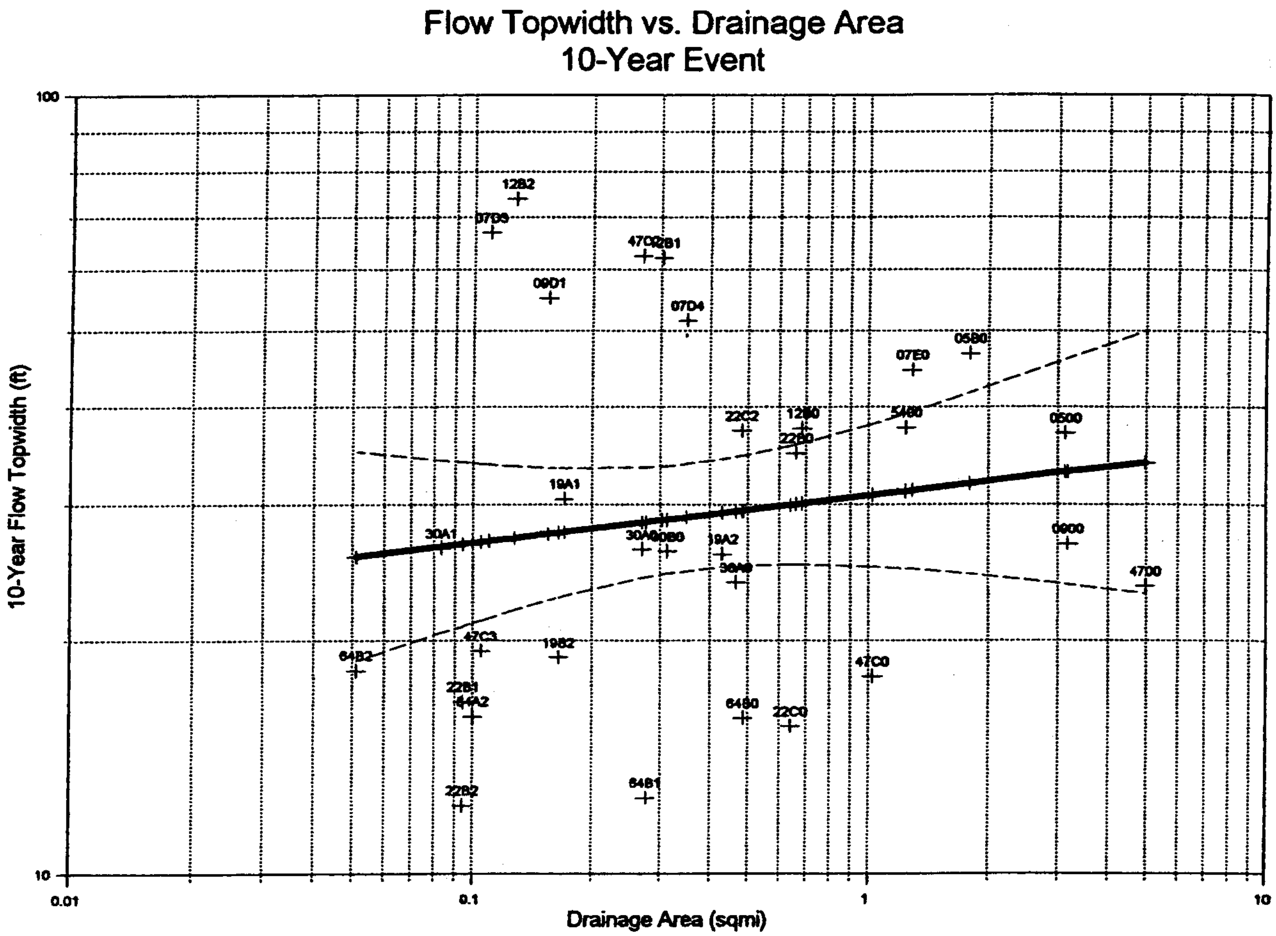


Figure C-16. Regional analysis regression plot for 10-year channel design parameters, Powder River area.



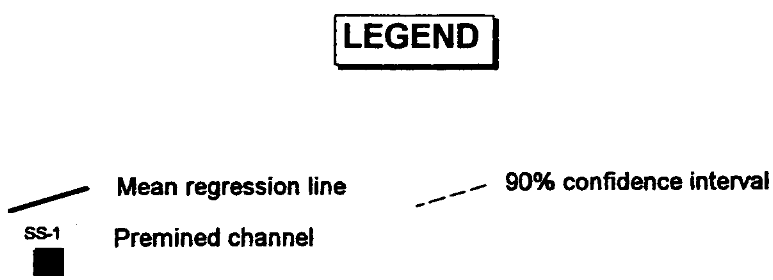


Figure C-17. Regional analysis regression plot for 10-year channel design parameters, Powder River area.

APPENDIX D

Glenrock Area
Regression Results

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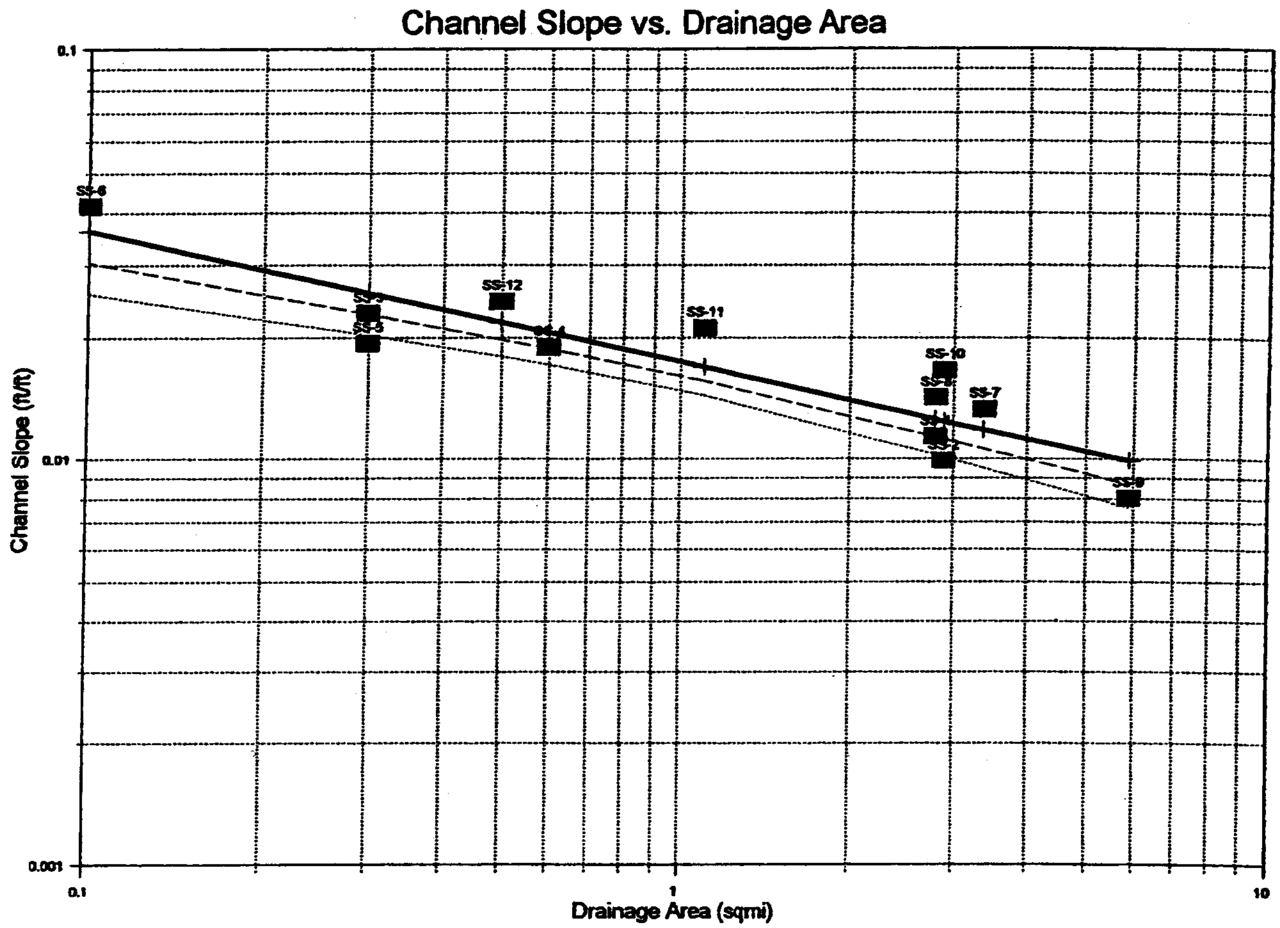


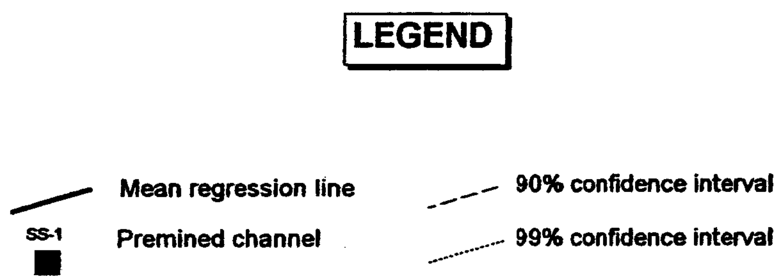


Figure D-1. Channel slope, Glenrock area.

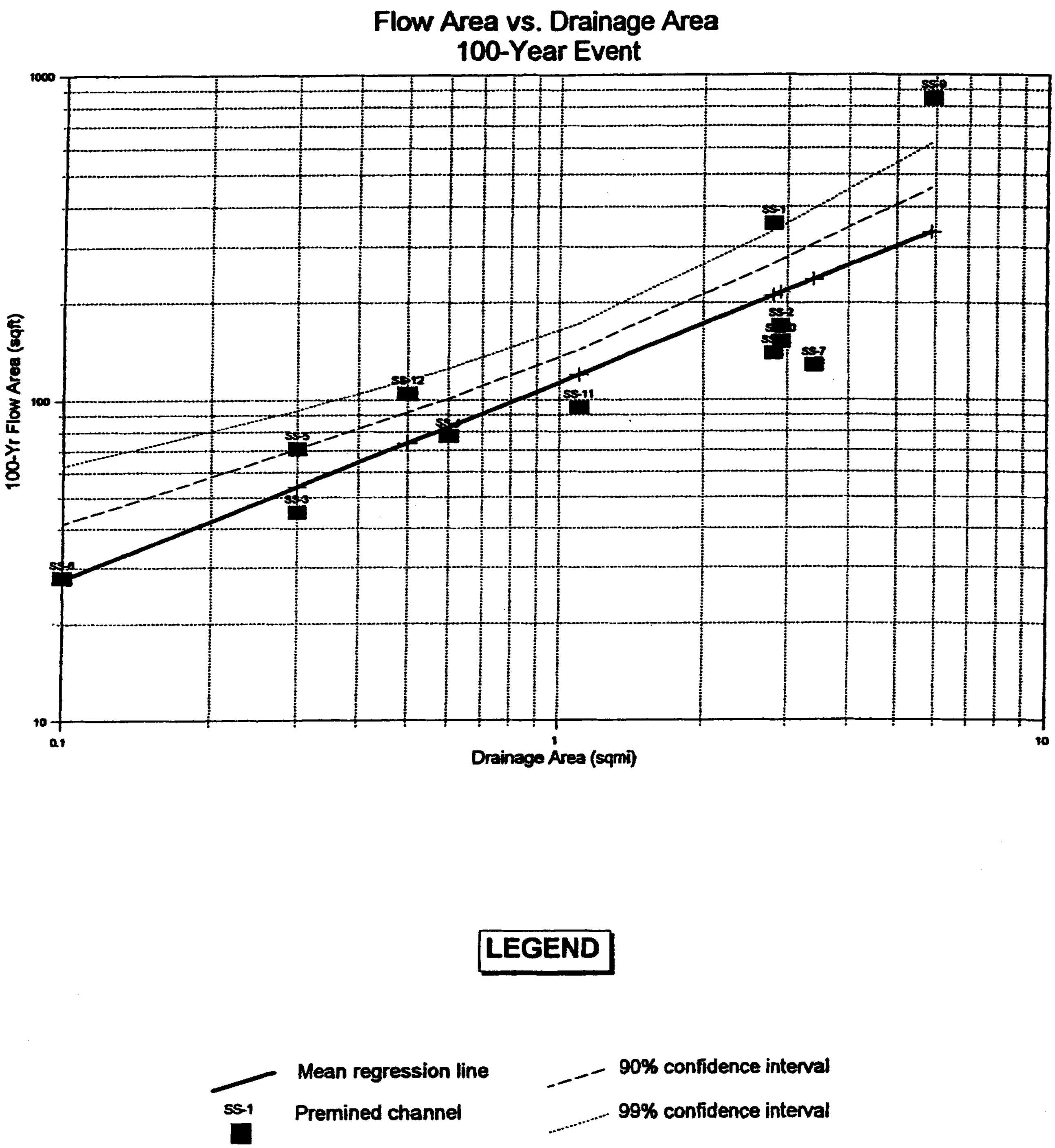


Figure D-2. Rainfall-runoff regression plot for 100-year channel design parameters, Glenrock area.

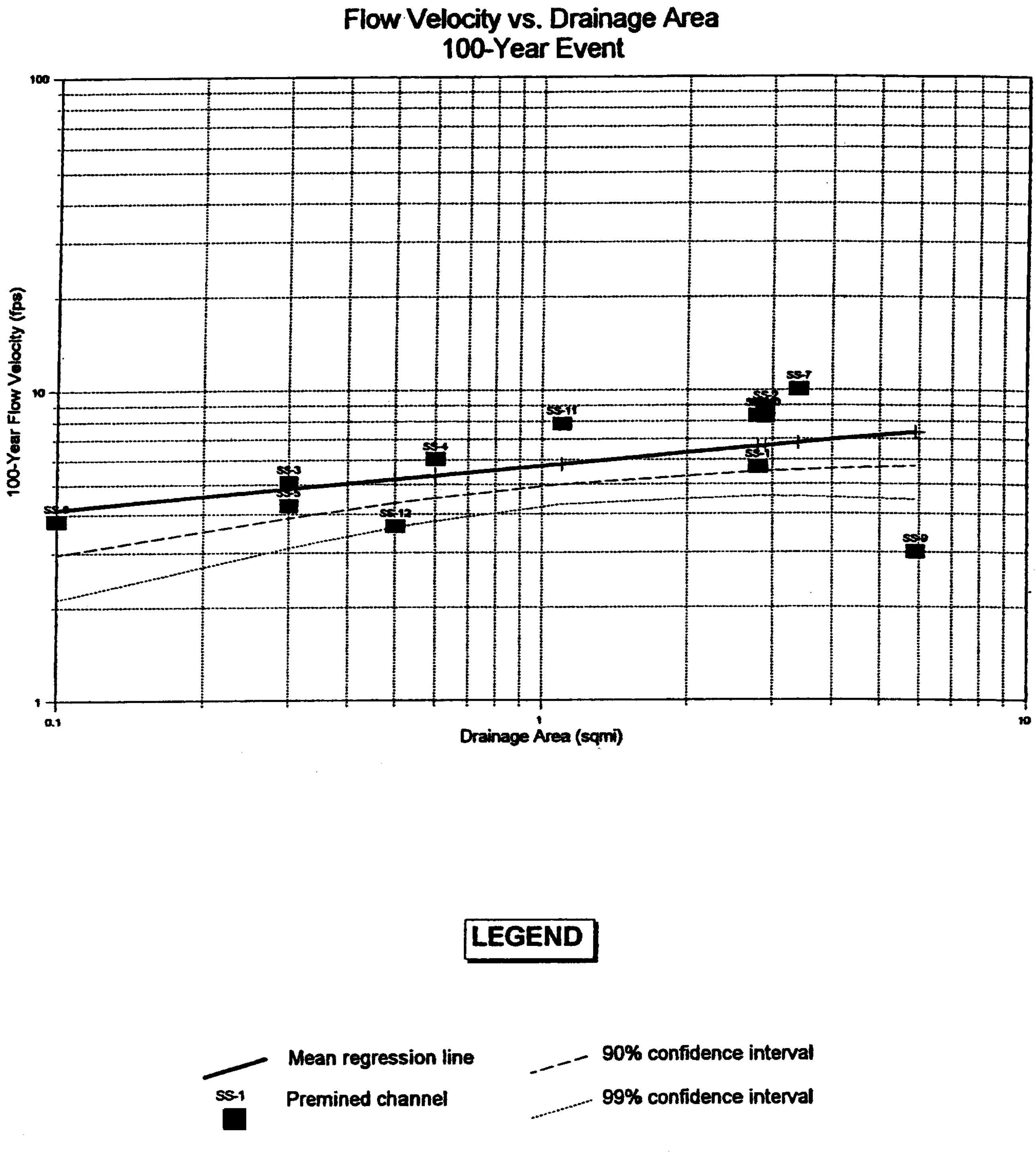


Figure D-3. Rainfall-runoff regression plot for 100-year channel design parameters, Glenrock area.

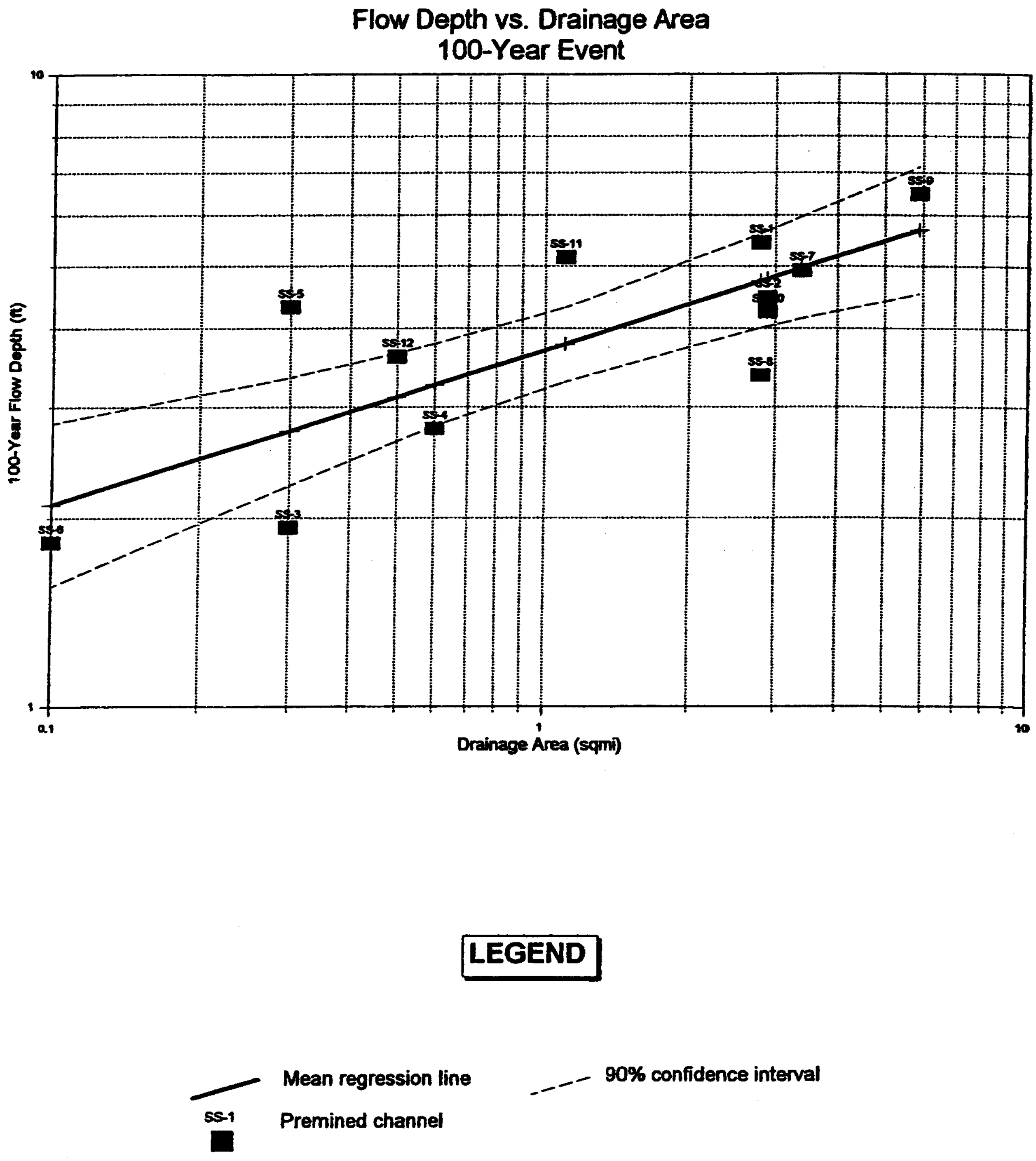


Figure D-4. Rainfall-runoff regression plot for 100-year channel design parameters, Glenrock area.

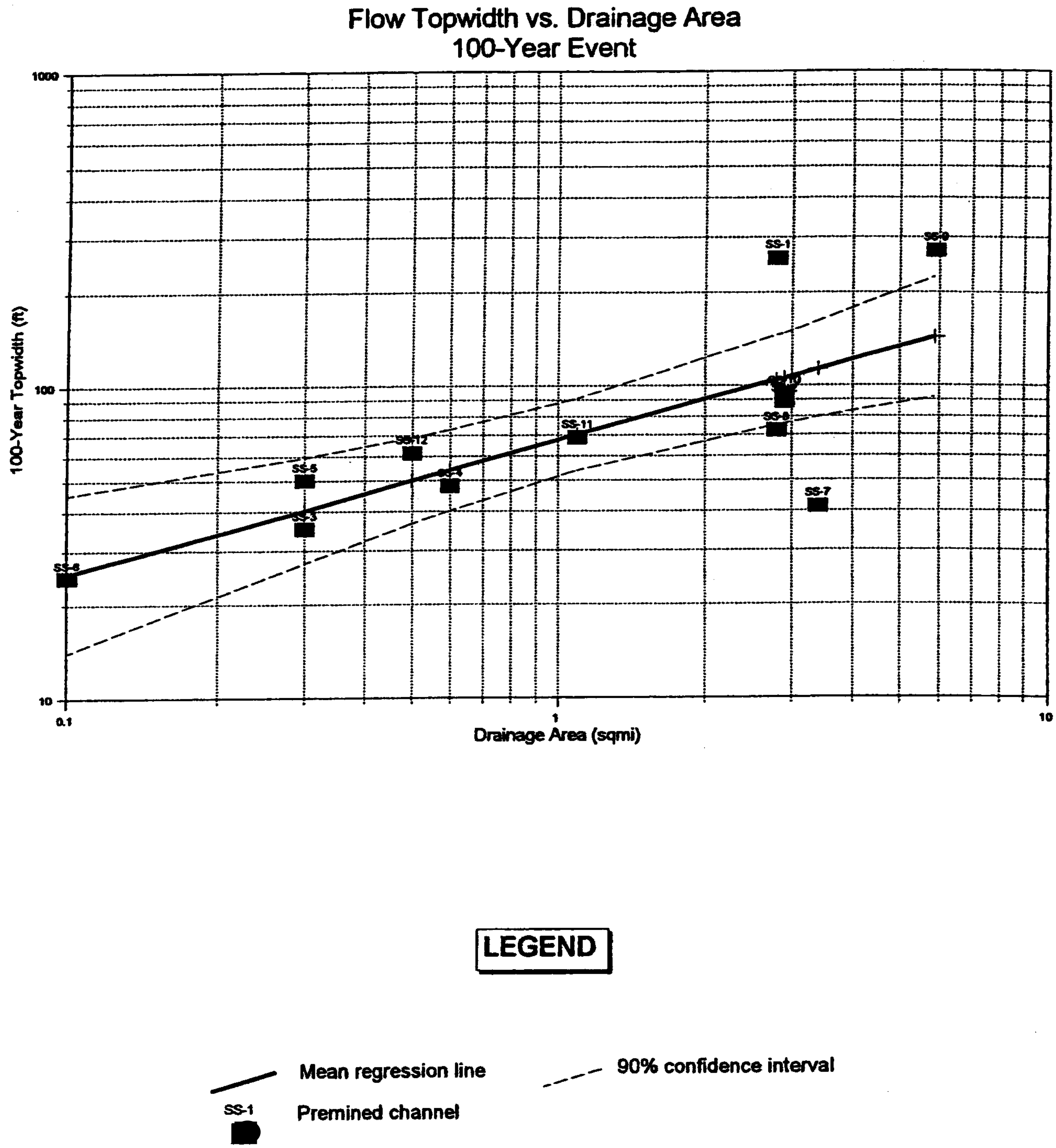
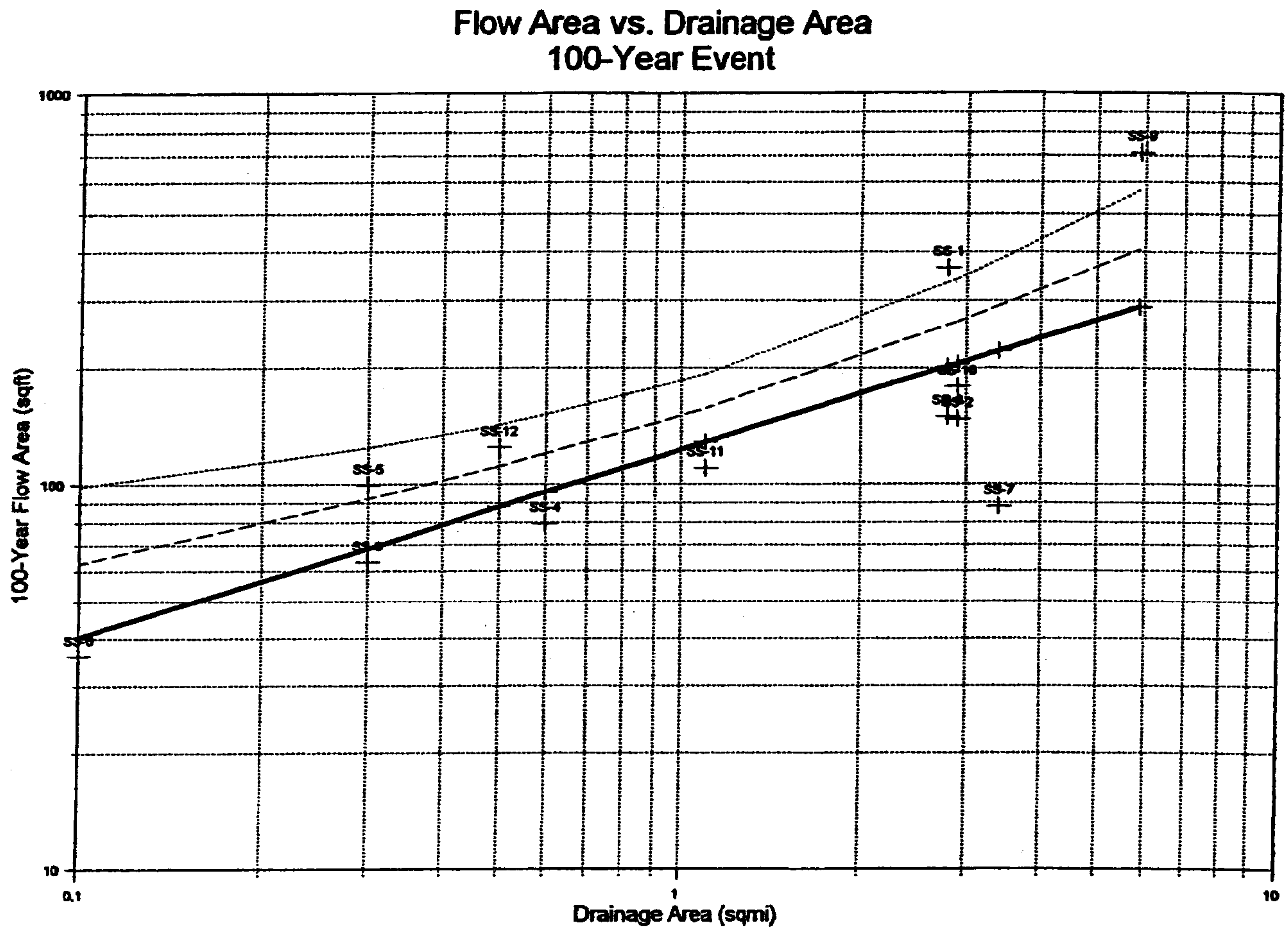


Figure D-5. Rainfall-runoff regression plot for 100-year channel design parameters, Glenrock area.



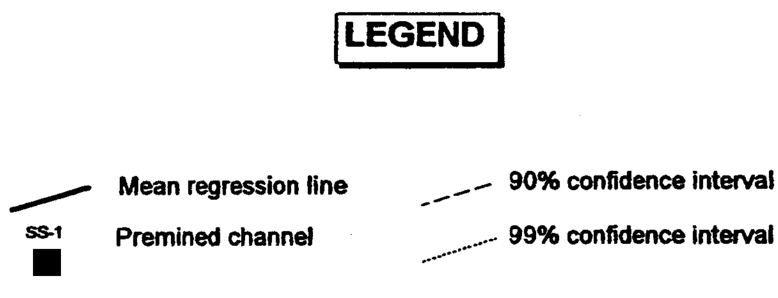


Figure D-6. Regional analysis regression plot for 100-year channel design parameters, Glenrock area.

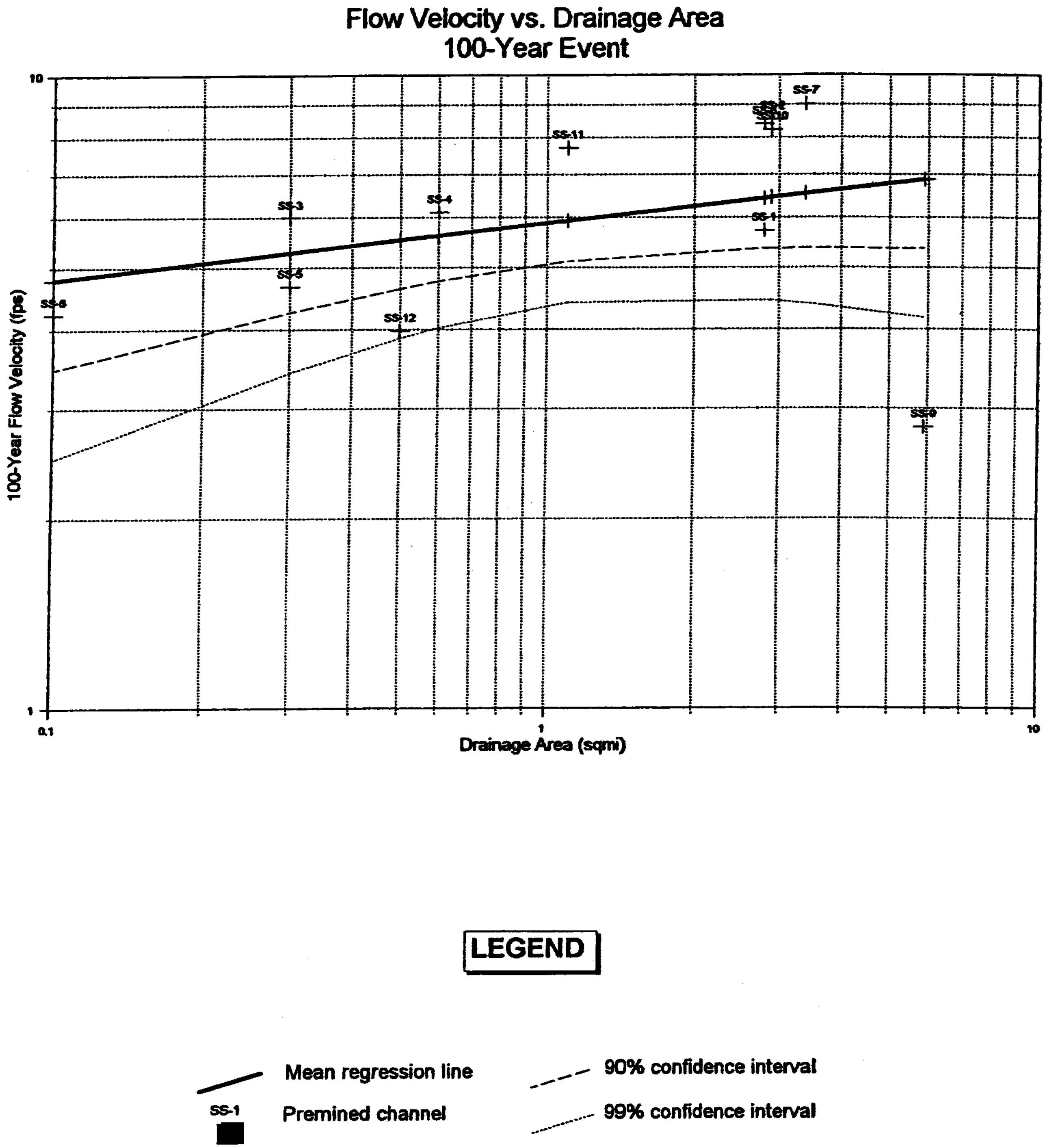
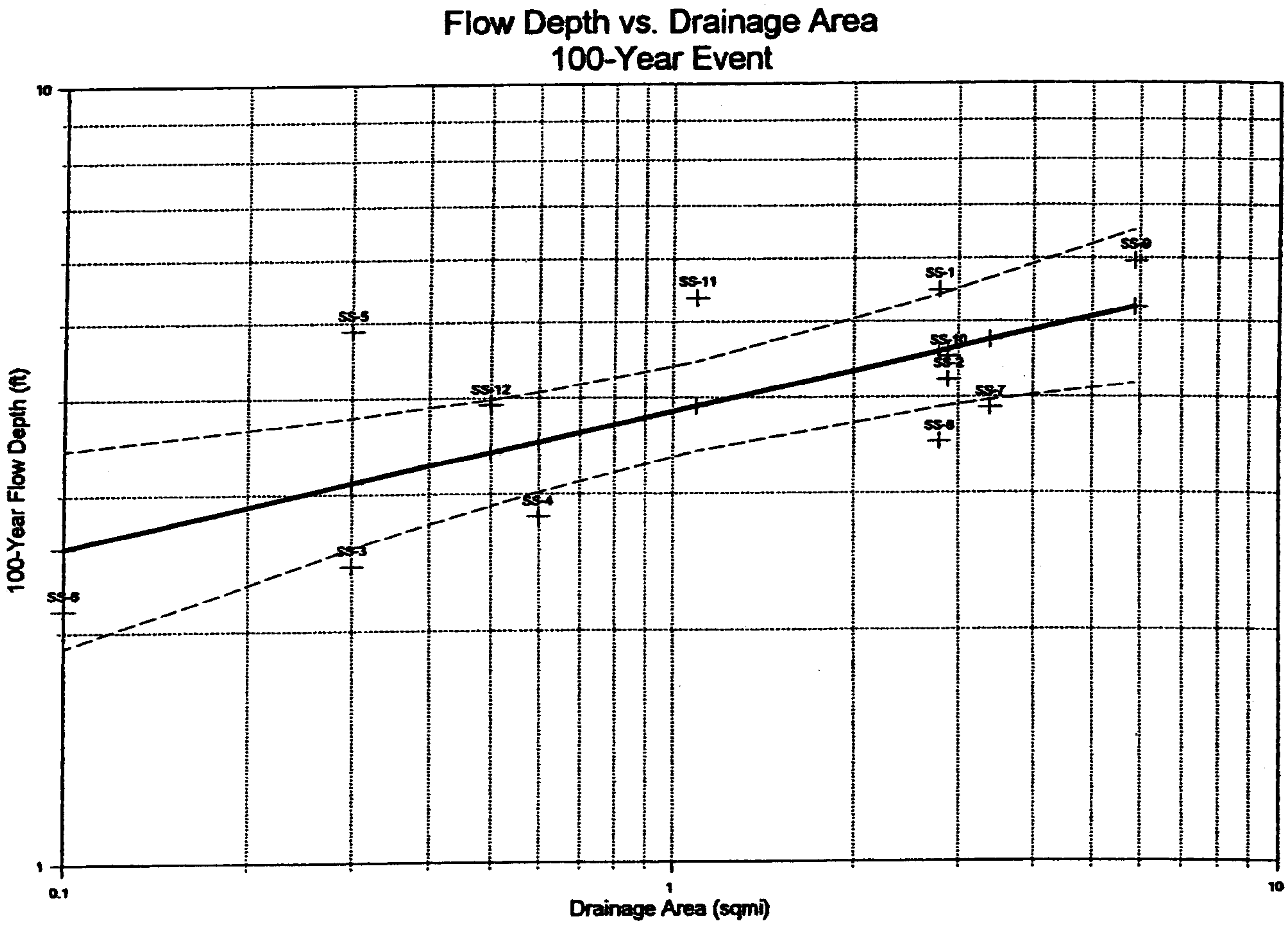


Figure D-7. Regional analysis regression plot for 100-year channel design parameters, Glenrock area.



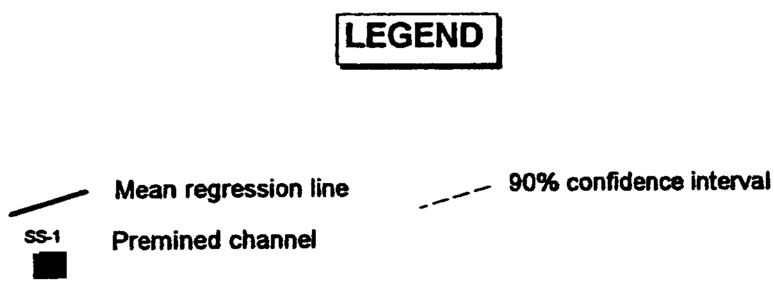


Figure D-8. Regional analysis regression plot for 100-year channel design parameters, Glenrock area.

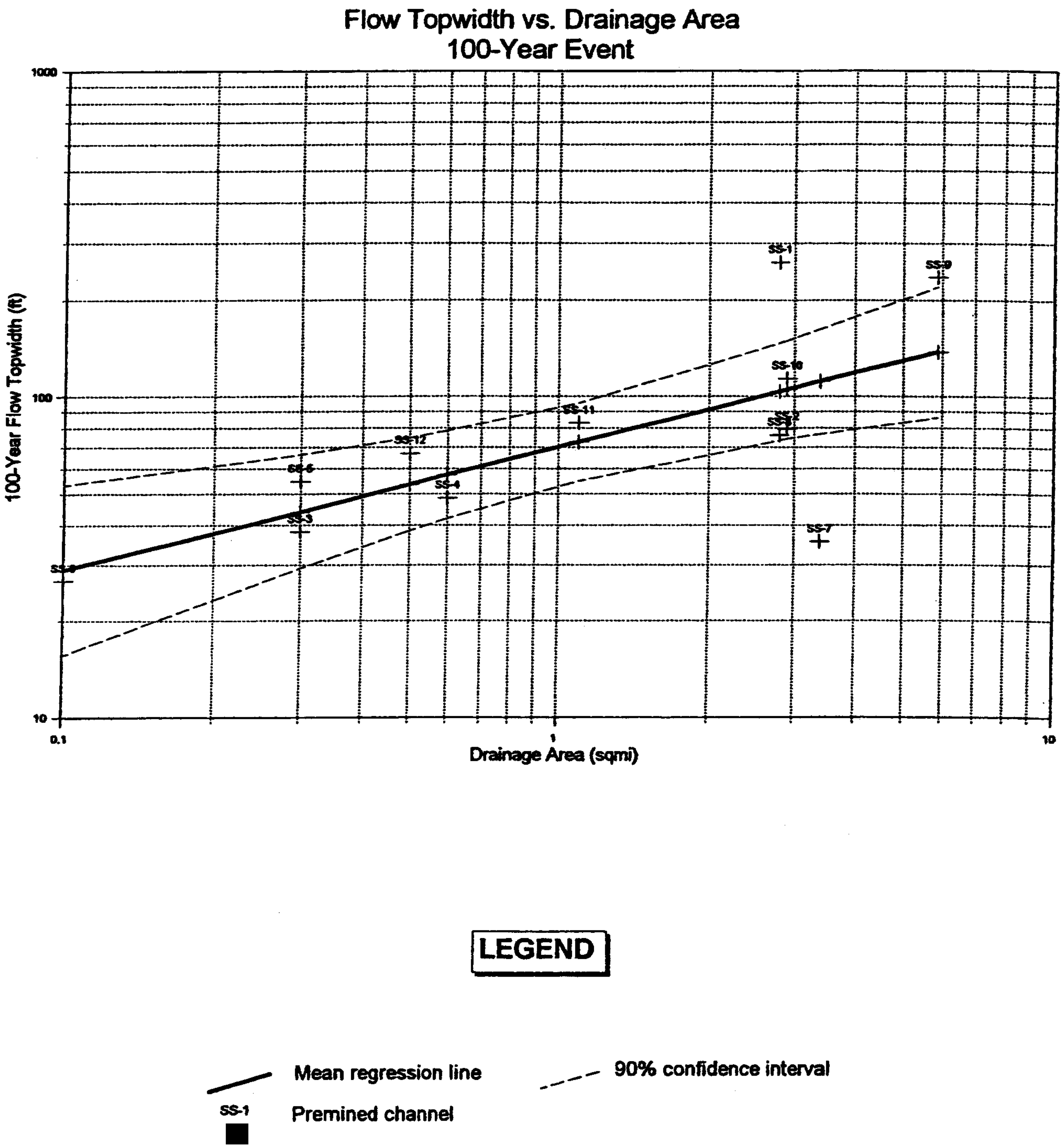


Figure D-9. Regional analysis regression plot for 100-year channel design parameters, Glenrock area.

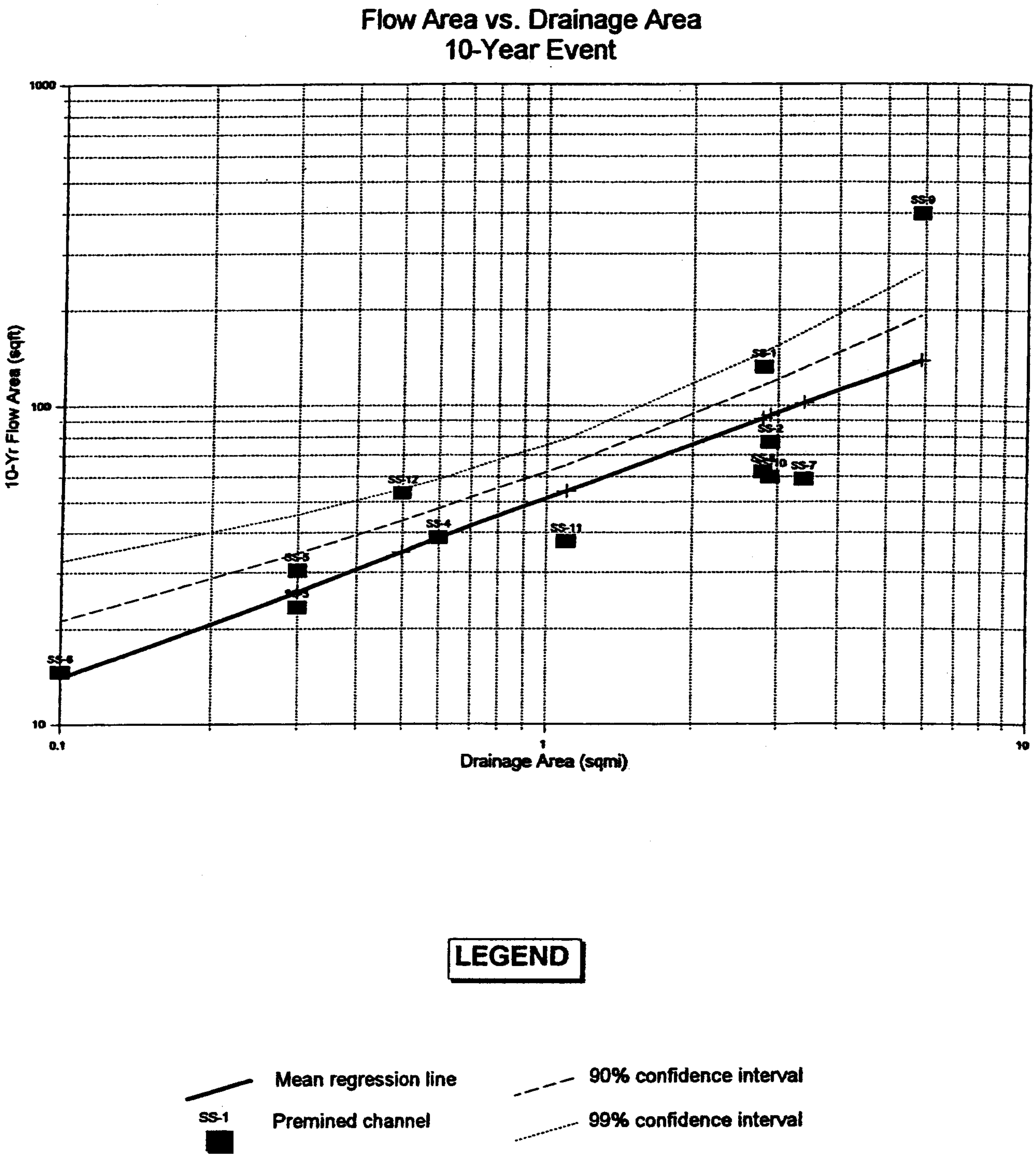


Figure D-10. Rainfall-runoff regression plot for 10-year channel design parameters, Glenrock area.

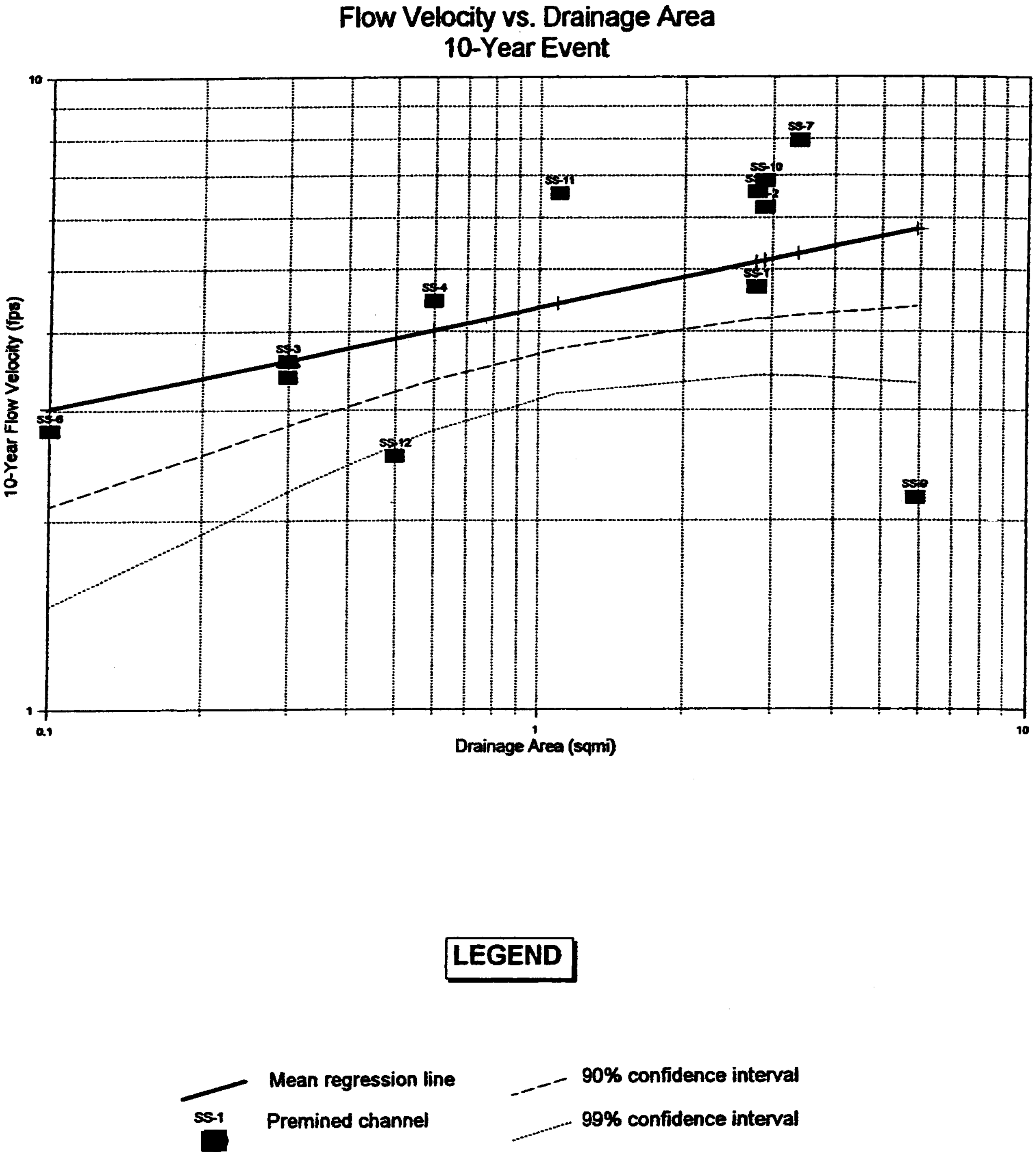


Figure D-11. Rainfall-runoff regression plot for 10-year channel design parameters, Glenrock area.

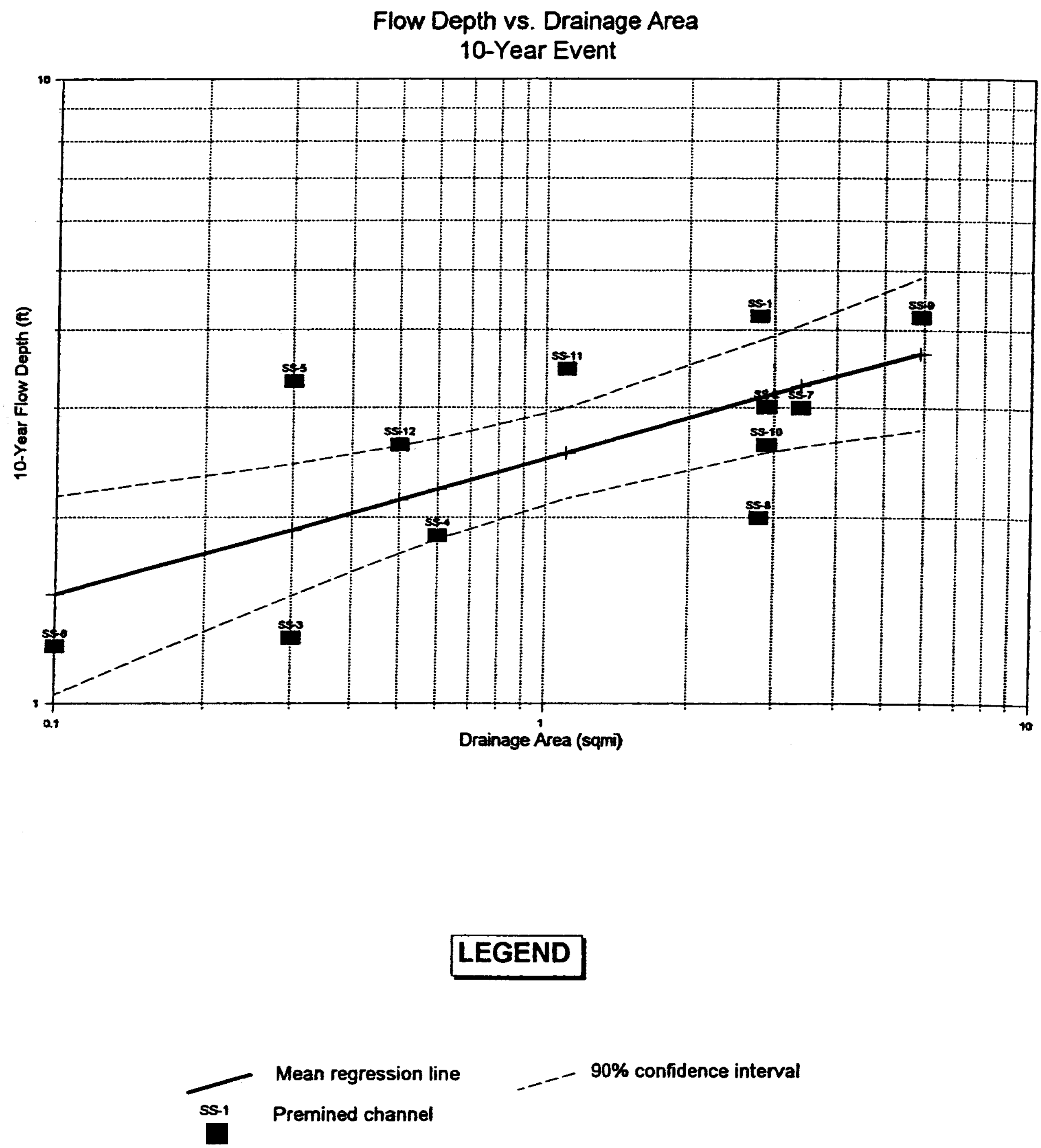


Figure D-12. Rainfall-runoff regression plot for 10-year channel design parameters, Glenrock area.

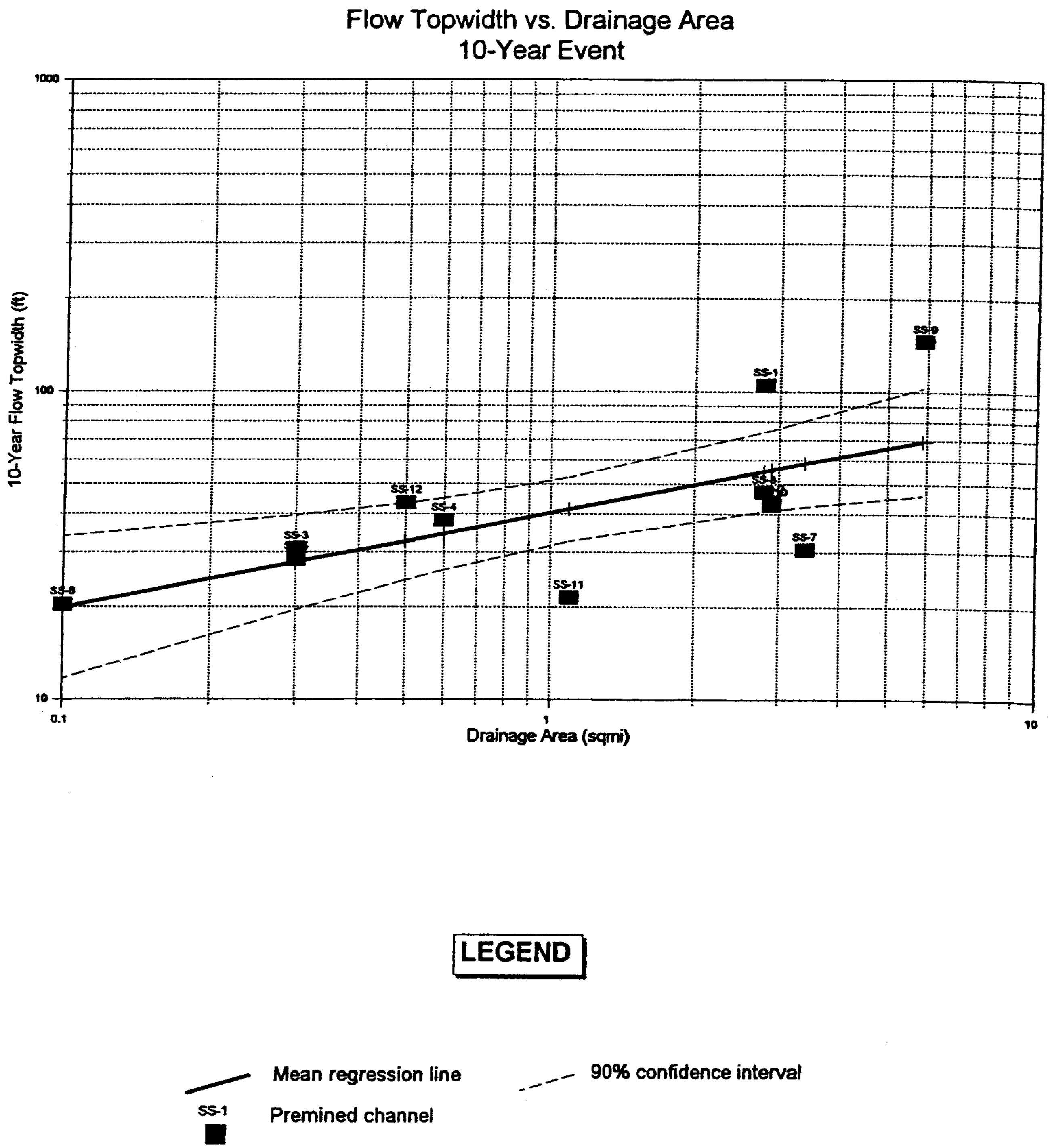


Figure D-13. Rainfall-runoff regression plot for 10-year channel design parameters, Glenrock area.

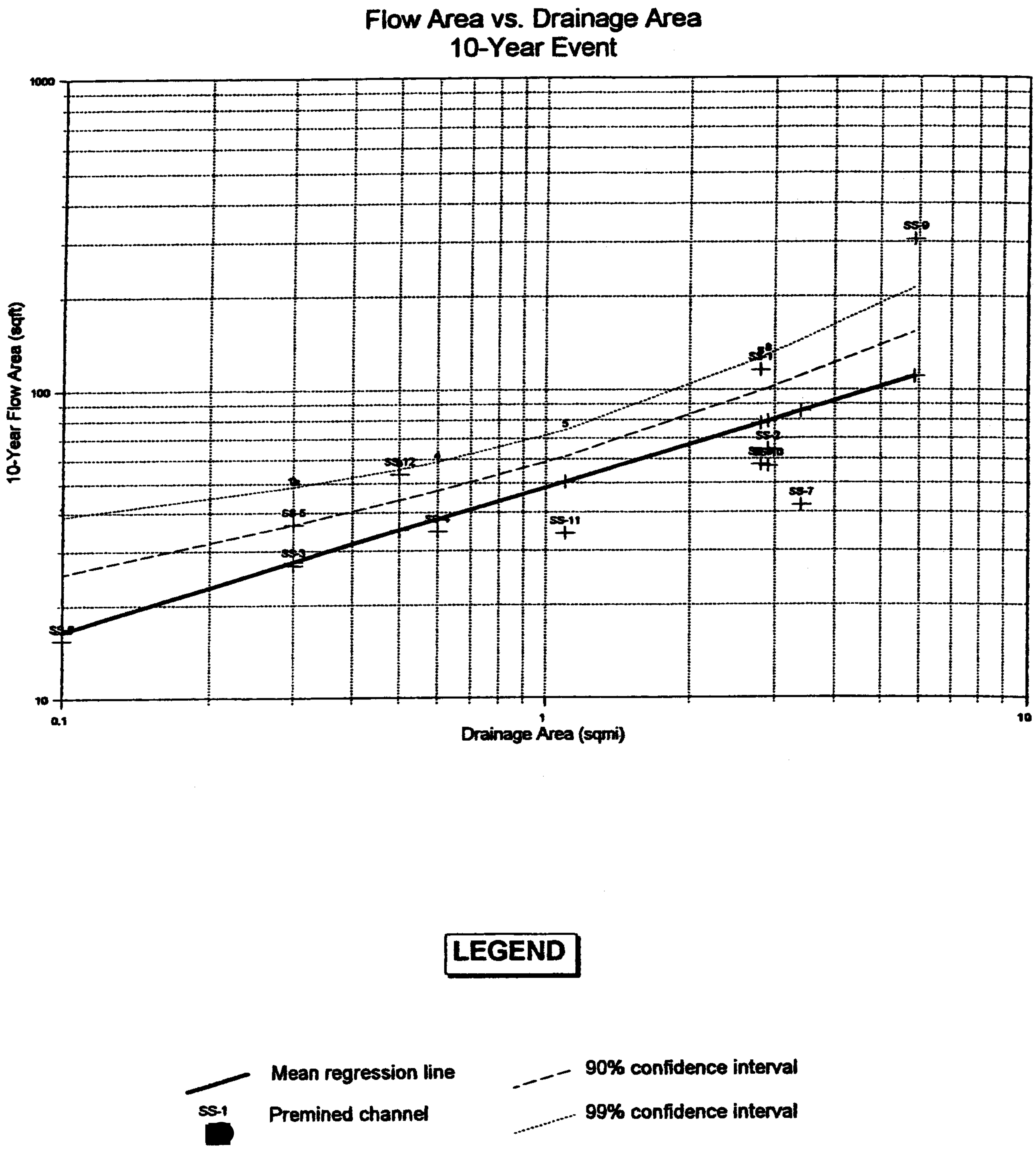


Figure D-14. Regional analysis regression plot for 10-year channel design parameters, Glenrock area.

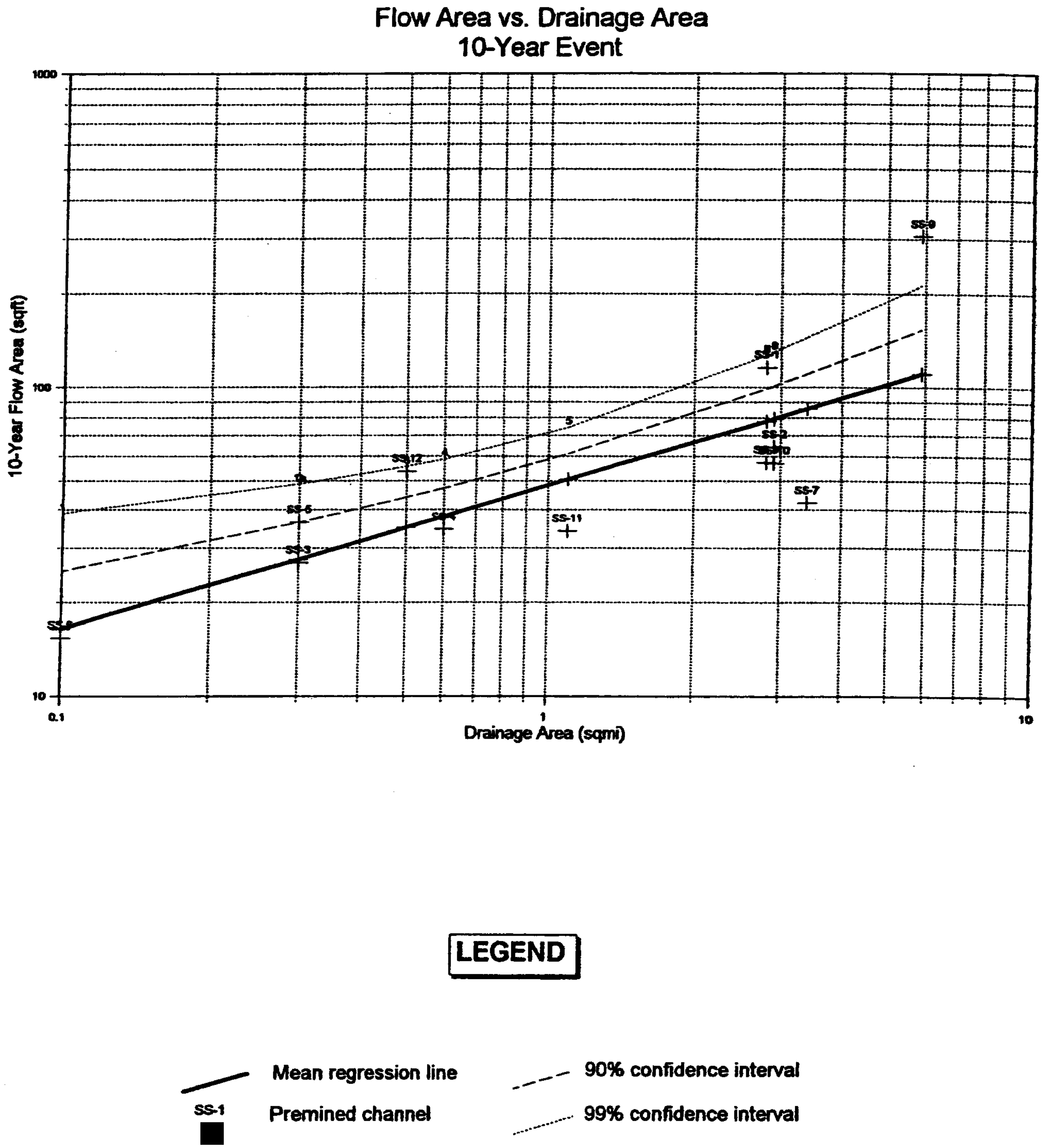
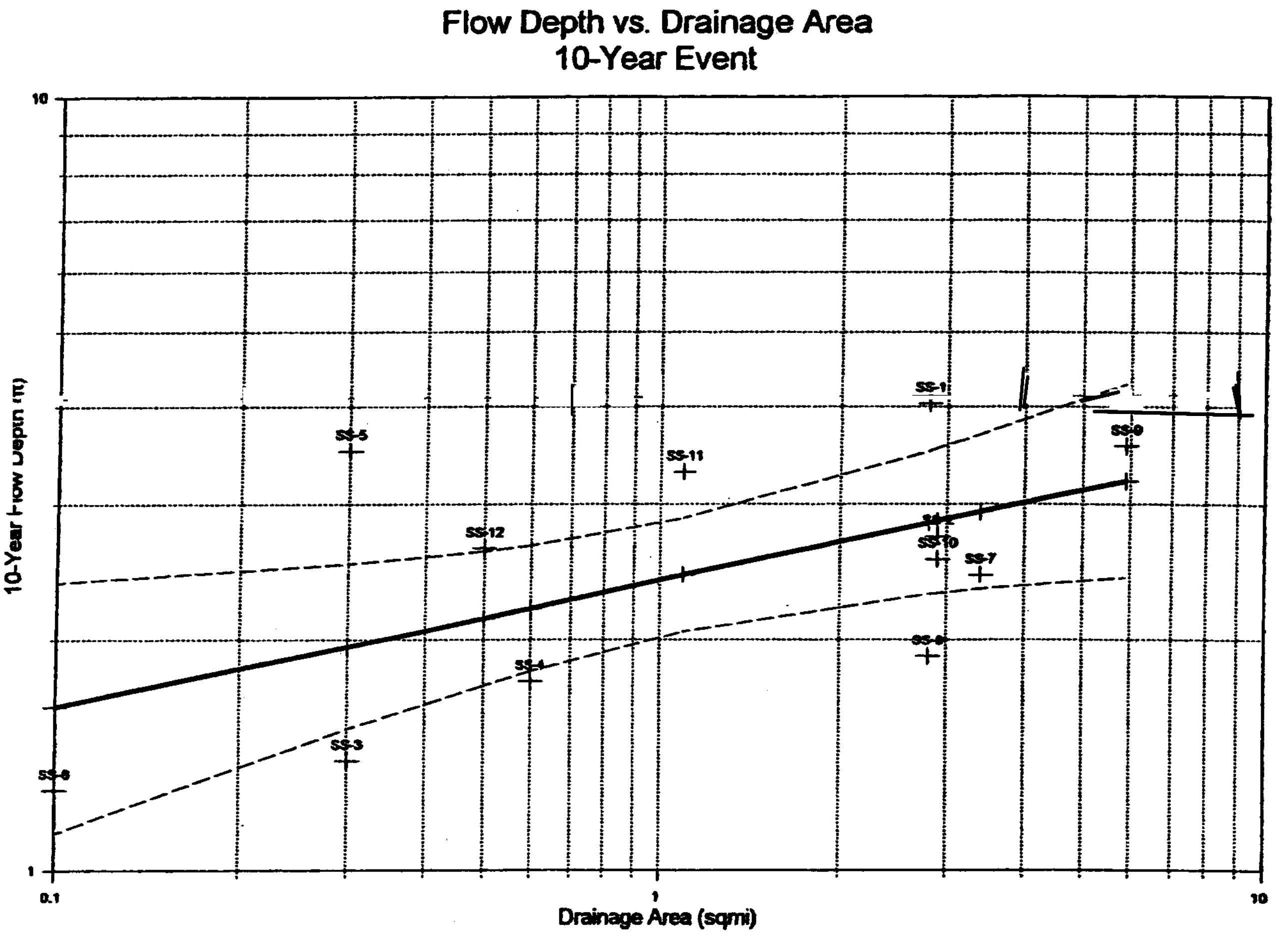


Figure D-15. Regional analysis regression plot for 10-year channel design parameters, Glenrock area.



LEGEND

Mean regression line

90% confidence interval

SS-1 Premined channel

Figure D-16. Regional analysis regression plot for 10-year channel design parameters, Glenrock area.

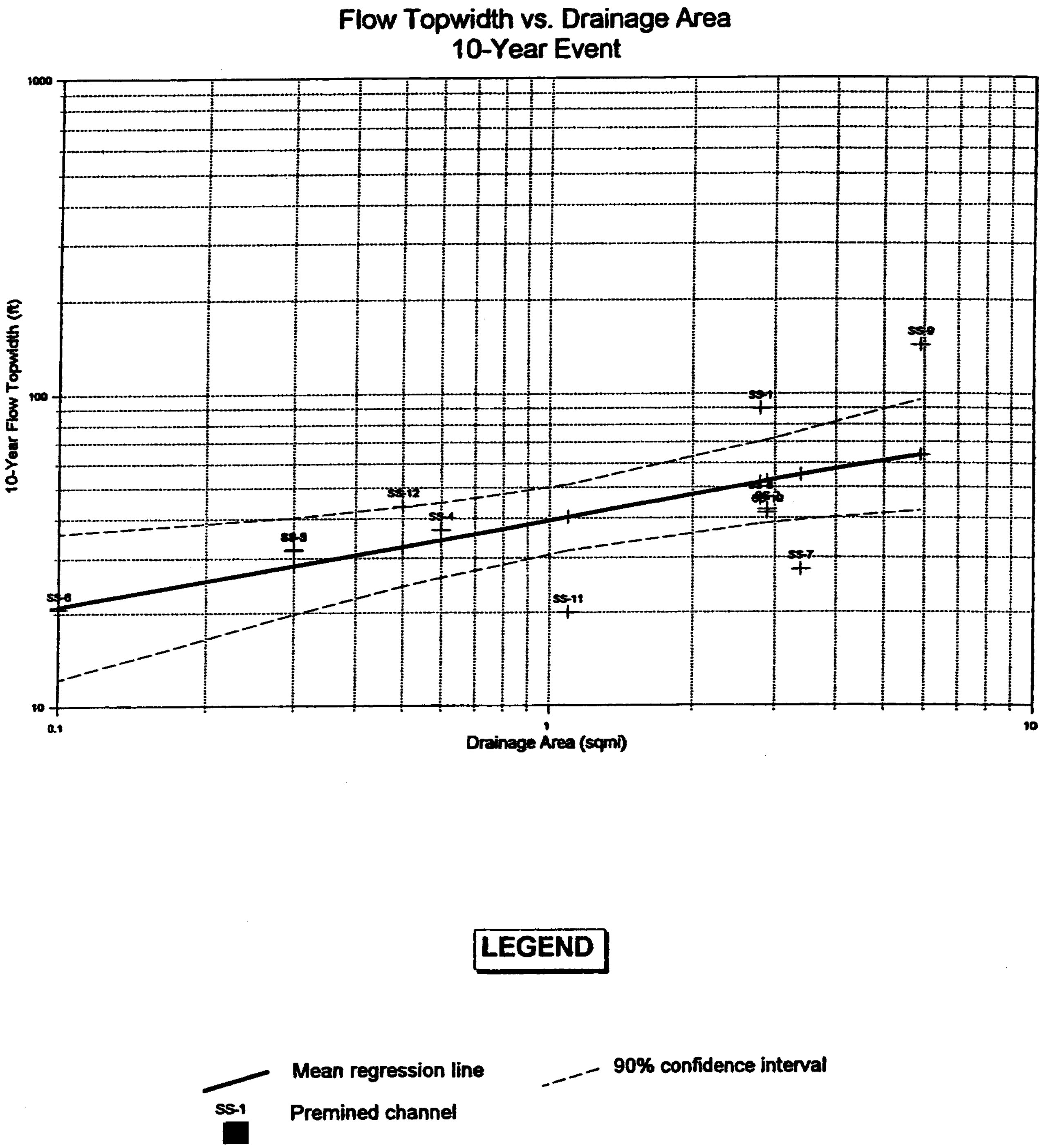


Figure D-17. Regional analysis regression plot for 10-year channel design parameters, Glenrock area.