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Inventory of streams on Theodore Roosevelt Memorial Ranch Dupuyer Montana : implications for livestock grazing and ranch management

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AN INVENTORY OF STREAMS ON THEODORE ROOSEVELT MEMORIAL RANCH, DUPUYER, MONTANA: IMPLICATIONS FOR LIVESTOCK GRAZING AND RANCH MANAGEMENT

by

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An Inventory of Streams on Theodore Roosevelt Memorial Ranch, Dupuyer, Montana: Implications for Livestock Grazing and Ranch Management

Director: Donald F. Potts DFP

This study is an inventory and baseline survey of all streams on Theodore Roosevelt Memorial Ranch, near Dupuyer, Montana. TRM Ranch, located on the northern Rocky Mountain Front, serves as a research, education, demonstration and public service facility. The primary methods of stream inventory follow Rosgen (1996) and Harrelson et al. (1994). This methodology includes surveying current channel morphology and historical analysis from aerial photographs. Results from this study indicate that stream crossings such as, fords and bridges, and an irrigation diversion have increased channel width-to-depth ratios and changed channel slope and particle size distributions. I also found, as predicted, that width-to-depth ratios of small streams (Rosgen E stream types) with predominantly silt and clay banks, are significantly higher when subject to spring and summer livestock grazing, compared to no grazing. The results of this research indicate that Rosgen's stream classification and channel morphology measurements are useful management tools on Montana's northern Rocky Mountain Front.

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INTRODUCTION

Overgrazing in riparian areas in the western U.S. has degraded thousands of miles of streams (Armour et al. 1994) and threatens the integrity of headwater stream habitats (Behnke and Zarn 1976). Studies have demonstrated that livestock grazing in riparian areas increases runoff and erosion, alters species abundance and composition, destabilizes streambanks, increases fine sediment, reduces pool frequency and depth, reduces undercut banks, widens channels, and increases summer stream temperatures (Armour et al. 1994, Behnke and Zarn 1976, Kauffman and Krueger 1984, Kondolf 1994, Marlow et al. 1987, Platts 1991). Such changes in stream channels are related to decreases in salmonid populations (Platts 1991, Riemann and McIntyre 1995).

Though many studies have found negative effects of livestock grazing, they have not fully identified the problems, described their magnitude or provided methods for their solution (Platts 1991). Previous studies have been inconclusive or confounding due to one or more of the following factors: 1) a lack of pretreatment data (Rinne 1988); 2) ineffective methods (Platts 1991); 3) spatial and temporal variability in streams (Rinne 1988); and 4) the short-term nature of most scientific studies. These factors lead (Rinne 1988) to suggest that future studies include complete watersheds, pretreatment data, and be long-term in nature. In addition, livestock grazing occurs on 114 million ha of public land and on 82 million ha of private land in the western U.S. (Kondolf 1994). However, most research regarding livestock and riparian areas has focused on headwaters on public land.

The purpose of this study was to inventory and describe the current and historic condition of streams on privately owned Theodore Roosevelt Memorial Ranch (TRM Ranch) and begin monitoring these streams to assess long term changes due to ranch activities. Specifically, we were interested in differentiating between the cumulative effects of livestock grazing and other ranching activities and that of natural disturbances such as large floods. To realize this goal we inventoried and began monitoring streams using the Rosgen inventory and classification system (Rosgen 1994). This approach uses channel morphology, channel stability ratings, bank erosion ratings, riparian vegetation, streamflow, and sediment data to describe the condition of the stream and departure from its potential (Rosgen 1996). Rosgen (1996) describes stream potential as the "best channel condition, based on quantifiable morphological characteristics, for each stream type." Because streams vary both temporally and spatially, defining the "best channel condition" for a particular stream can be subjective and may vary by geographic region. Only by monitoring these streams over many years will we be able to determine the compatibility of livestock grazing and other ranching activities with the goals of maintaining or restoring healthy, functioning aquatic and riparian systems. These long-term data will be used to develop a regional database of stream condition ratings for each stream type that is based on both physical and biological properties of streams. Such a regional database will guide future resource/land management decisions on Montana's northern Rocky Mountain Front.

STUDY SITE DESCRIPTION

Dupuyer Creek, at the downstream boundary of TRM Ranch, drains a 9,350-ha watershed on the northern Rocky Mountain Front, west of Dupuyer, Montana (Figure 1) and is composed of three main forks (Figure 2). The North and South forks are the primary drainage's and are nearly equal in size. The Middle fork drainage is smaller and contributes little streamflow, much of which is withdrawn for irrigation. Middle Fork Dupuyer Creek contains one of the few remaining populations of pure westslope cutthroat trout (*Oncorhynchus clarki lewisi*) (Robb Leary Pers. Comm. 1996). Much of the watershed is located in the Bob Marshall Wilderness of the Lewis and Clark National Forest and is not subject to intensive anthropogenic influences such as logging, mining or road building. The watershed is frequented by hunters, hikers, and campers and is subject to grazing on both public and private lands, and water diversions for irrigation.

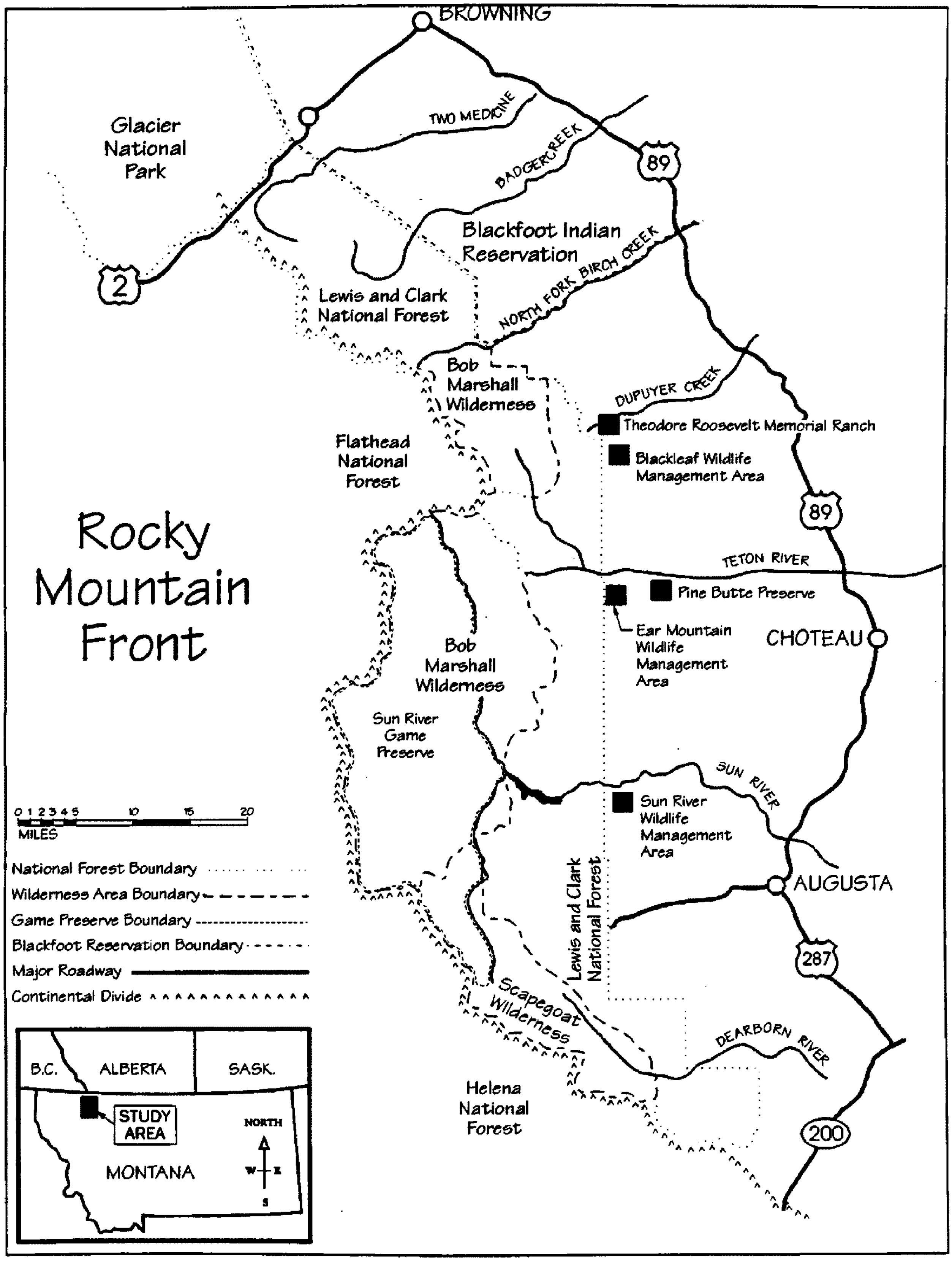

Figure 1. Site location map.

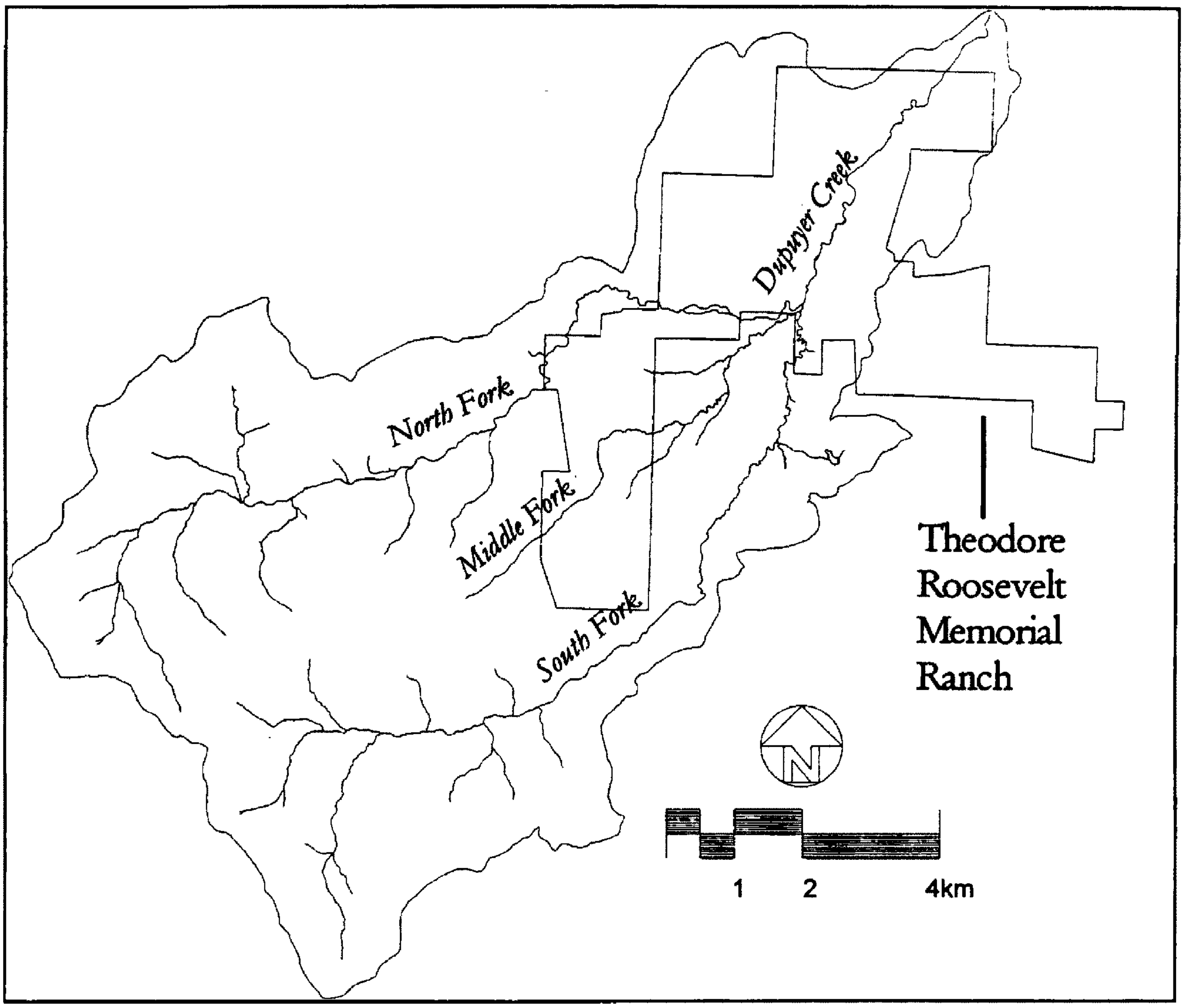

Figure 2. Map of Dupuyer Creek watershed showing third order and higher streams and boundaries of Theodore Roosevelt Memorial Ranch.

Geography and regional geologic structure

The Dupuyer Creek watershed lies in the Sawtooth Range of the Northern Rocky Mountains. The Sawtooth Range is defined by its high ridges and deep valleys that trend from north to south. The ridge and valley configuration is determined by Paleozoic strata separated by Mesozoic beds (Alt 1985). The Mesozoic beds are more erodible and form deep valleys. The successive ridges are a series of south-westward-dipping overthrust and high angle reverse faults. The east front of the Sawtooth is an abrupt escarpment of Mississippian limestones that have been thrust over Mesozoic shales and sandstones (Alt 1985). Debris avalanches are frequent in the upper watershed as evidenced by tracts of younger vegetation and abundance of talus slopes. Bedrock outcrops are numerous especially along scarp faces where vegetation is sparse.

The highest point in the watershed is Mt. Frazier at 2,533 m. The lowest elevation, where Dupuyer Creek leaves the ranch boundary, is approximately 1,400 m. The change in elevation divided by the length of the basin, from the highest point in the watershed to the ranch boundary is .07 or a 7% gradient. However, over the first 5 km, the western portion of the basin, the relief ratio is approximately 0.17 or 17% gradient. This is considerably steeper than the lower, eastern portion that has an average gradient of 2.8%.

In the upper watershed deep valleys that formed in erodible sedimentary rocks trend generally north and south, while the main channel flows easterly dissecting less erodible limestones. Smaller tributaries connect with the main channel forming a trellis like drainage pattern (Figure 2). However, this pattern is not as clearly defined in the Dupuyer Creek basin as in other nearby watersheds such as in Muddy Creek and Blackleaf Creek or the headwaters of the Teton River drainage located just west and south of Dupuyer Creek. Field investigation of several tributaries in the North Fork and South Fork drainage basins found many channels flowing directly over bedrock.

Within the Dupuyer Creek watershed, vegetative associations vary from grassland with a cottonwood/willow watercourse at low elevations, to limber pine, Douglas fir, Engleman Spruce and other conifers at higher elevations. Cottonwoods are present in the upper watershed, but are not nearly as abundant as in the lower elevations. The riparian vegetation along Dupuyer Creek on TRM Ranch is characterized primarily as *Populus trichocarpa/Cornus stolonifera* (black cottonwood/red-osier dogwood) community type (Hansen et al. 1995).

Most water resources on TRM Ranch are streams, however there are a few small lakes (not including beaver ponds) present in the lower portion of the drainage basin. These lakes appear to be associated with pleistocene glaciation and are found in terminal moraines. For example, on the face of Walling Reef, there is evidence of alpine glaciers with lakes in the resulting cirque basins. In the far western portion of the basin, in both the North and South Forks, there are a couple of lakes that have formed in what appears to be colluvium or possibly depressions in poorly developed cirque basins. There are two small ponds in the watershed.

One pond, on Middle Fork Dupuyer Creek was created by an earthen dam in the 1960's or 1970's. This pond serves as a detention basin, to augment water used for irrigation on a neighboring ranch. A second pond, located on McCarthy Creek appears to be a natural depression, resembling a glacier formed kettle. However, the origin of this depression is uncertain. Both of these ponds support large populations of trout. The former contains native cutthroat trout (*Oncorhynchus clarki lewisi*) the latter non-native brook trout (*Salvelinus fontinalis*).

METHODS

Aerial photographs, USGS topographical maps (1:24,000), previous geologic reports, and field investigation were used to identify watershed and stream characteristics. Streams on TRM Ranch were classified using the Rosgen stream classification system (Rosgen 1994). The Rosgen classification groups stream reaches with similar channel and floodplain dimensions and allows for comparisons between watersheds and between stream reaches in the same watershed (Rosgen 1994). All stream channels and selected geomorphic features were digitized into PAMAP Geographical Information System (GIS). Aerial photographs were used to digitize historical channels and Global Positioning System was used to digitize current channels. The watershed and sub-watershed boundaries were interpreted from USGS topographical maps and incorporated into the GIS to calculate area, perimeter, and stream length.

Geomorphic Description

Stream order was determined by the Strahler method and includes crenulations as drawn on USGS 7.5 Minute Series. Crenulations are depressions in hillslopes, but cartographers rarely draw them as stream channels because they conduct water for a limited part of the year. It is standard practice to include them in drainage basin calculations (Leopold 1994). Including crenulations in stream order calculations increases stream order by one or more levels, but is more consistent than using blue lines (perennial streams) drawn on topographic maps. Blue lines tend to be subjective and vary depending on individual cartographers (Leopold 1994).

Streamflow

The USGS maintained a stream gauging station on Dupuyer Creek, about 29-km east of TRM Ranch from 1913 to 1937. These data and precipitation data from the nearby town of Valier, 45-km east of TRM Ranch, were graphed (Figures 5 & 6 and Appendix A) to describe the historic hydrologic regime and to better understand the influence of precipitation and snowmelt on the hydrograph of Dupuyer Creek. During this study, streamflow on TRM Ranch was monitored with a stilling well and Stevens type F recorder to record stage. Both of these were installed in the spring of 1995 prior to spring runoff. Stage rating curves were established beginning that spring using 20 discharge measurements at a variety of streamflows (Appendix B). Stream discharge was measured using a Price Type AA current meter. We also measured discharge in North Fork Dupuyer Creek and associated irrigation ditches to determine the amount and percent of streamflow diverted for irrigation. Precipitation data for the upper watershed were acquired from the NRCS SNOTEL site located near Middle Fork Dupuyer Creek and about 1.6 km west of TRM Ranch, at an elevation of 1737-m.

Channel Morphology

Channel morphology was determined from field data taken at a reach scale—usually 20-25 channel widths in length. Sites selected for data collection are called reference reaches. Interpretations based on reference reaches can be extrapolated to other similar reaches where field data are not available (Rosgen 1996). Hence, reference reaches on TRM Ranch (Figure 3) were selected to include: 1) at least one, but usually several reaches per stream type; 2) areas with different grazing regimes; and 3) reaches with obvious geomorphic differences, such as vehicle crossings. Once the reference reach was chosen, several cross-sections were surveyed—the number and location of cross sections varied depending on the complexity or heterogeneity of a given reach. For example, at each reference reach we surveyed at least one pool and one riffle but also included obvious areas of high bank erosion, anthropogenic disturbance, and/or livestock trampling. A few vehicle crossings were surveyed to assess their effects on channel morphology. This deviates slightly from selection criteria described in Harrelson et al. (1994), but is consistent with the objectives of this study.

A morphological description of channels includes: width-at-bankfull, mean and maximum depth-at-bankfull, width-to-mean-depth ratio, width-to-maximum-depth ratio, area-at-bankfull, entrenchment, slope, sinuosity, pool-to-riffle ratio, and streambed particle size distribution (Rosgen 1996, Overton et al. 1995). Bankfull elevation was estimated in the field by identifying flat depositional areas, a marked change in vegetation, a change in slope of the streambank and changes in size distribution of particles at the surface (Leopold 1994, Harrelson et al. 1994). Williams (1978) found that visual determination of bankfull in the field is a reliable method for determining bankfull, especially when marked along the longitudinal profile. Entrenchment is the ratio of floodprone-width to bankfull-width, where floodprone-width is the width of the channel at an elevation two times maximum depth at bankfull. These data were obtained by surveying 74 cross sections, longitudinal profiles at twenty reaches, mapping the entire stream, and taking pebble counts at 14 reaches on TRM Ranch. Surveying and pebble count procedures followed Harrelson et al. (1994) and Rosgen (1996). Pebble counts were not done on small silt and clay dominated streams.

Bridge and ford crossings alter channel dimensions and affect the energy available for sediment transport. Although not a morphological feature, shear stress is influenced by channel shape, and by estimating mean shear stress at all cross-

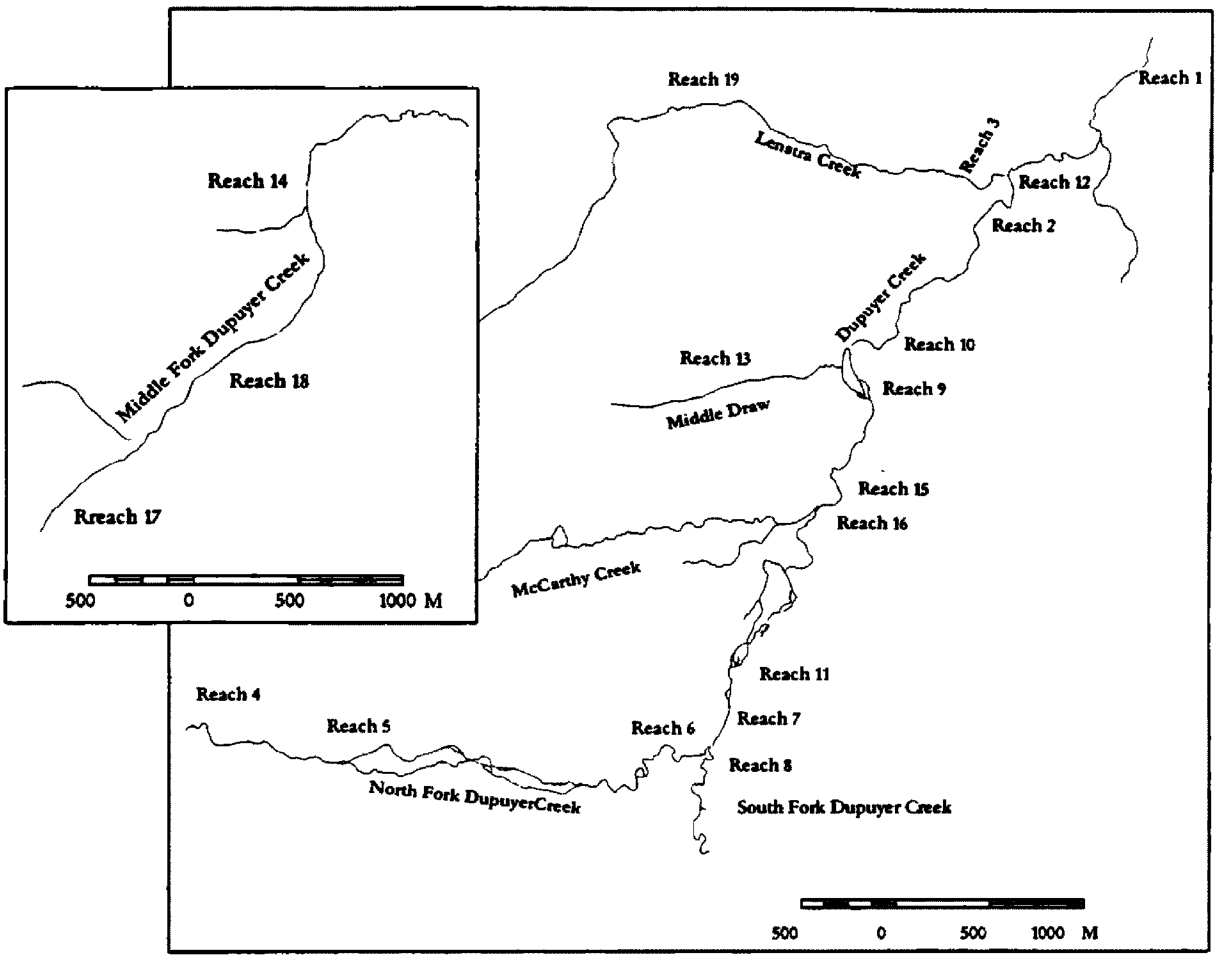

Figure 3 Map of Dupuyer Creek and its tributaries; showing locations of individual reaches. Inset shows Middle Fork Dupuyer Creek, refer to figure 2 for geographical location.

sections we can better understand the effect that crossings have on bedload transport. Shear stress is the frictional force causing flow resistance along the channel boundary (Gordon et al. 1992) and corresponds to the ability of the stream to transport sediment (Leopold 1994). In general, the higher the shear stress the larger the particle the stream is capable of transporting. Other factors, such as clumping, sorting, and hiding also influence bedload movement. Such factors are included in an equation proposed by Bathurst et al. (1987). The Bathurst equation includes adjustments for hiding and exposure and attempts to predict entrainment of individual particle sizes. This is called critical unit discharge and varies depending on individual characteristics of streams. Whitaker and Potts (1996) found that Dupuyer Creek exhibits a greater degree of mobility and size selectivity in bedload transport than previously reported in the literature for gravel bed streams. Bedload transport was monitored at only one cross-section on Dupuyer Creek, thus we can not know conclusively that similar mobility and selectivity apply elsewhere on Dupuyer Creek. Our observations suggest that such high mobility is occurring throughout the stream. If we assume that streambed characteristics are similar throughout, we can use mean shear stress as a way of comparing energy among cross-sections on Dupuyer Creek. Shear stress at bankfull is calculated by (Leopold 1994):

$$\tau = \gamma R s \tag{1}$$

where:

τ = shear stress (lbs./sq. ft.)
γ = density of water
R = hydraulic radius[1]
s = stream slope

[1] Hydraulic Radius was calculated with XSPRO Professional cross-section analyzer, public domain software.

Leopold (1994) provides a graph of shear stress values (Figure 4) required to entrain a given particle size. He cautions that these values represent simple conditions and should only be used as a first approximation. Since, we are not trying to predict exact particle sizes entrained by bankfull, it is reasonable to use such a comparison to illustrate the effect that vehicle crossings have on bedload transport. Such a comparison helps to explains why bridges on Dupuyer Creek routinely wash out during moderate to large floods.

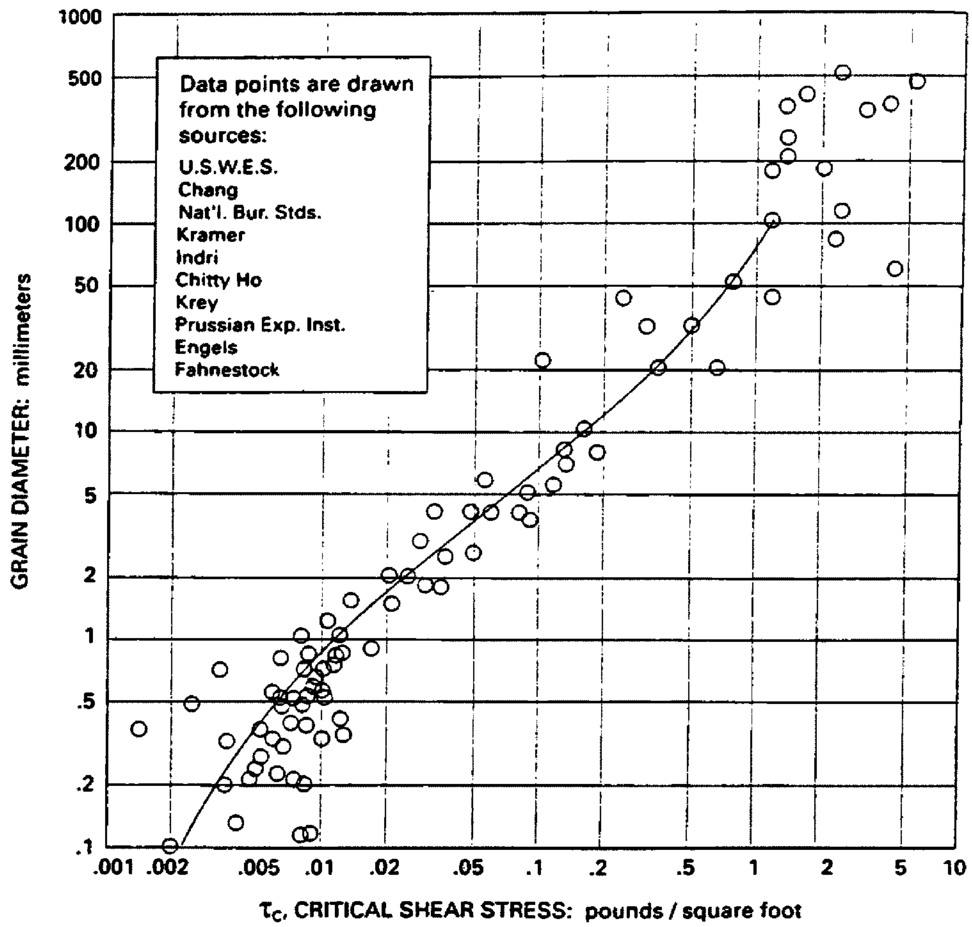

Figure 4. Laboratory and field data on critical shear stress required to initiate movement of grains (after Leopold 1994)..

In 1987, four 1-ha grazing exclosures were established on spring-fed Lenstra Creek and Middle Draw. These exclosures are paired grazing treatments that include no grazing (cattle or wildlife) and wildlife grazing only. There are also large hay meadows along both creeks. Hay meadows are not grazed in summer but are often grazed during other seasons. We surveyed four channel cross-sections in Middle Draw, one in each grazing treatment. We also surveyed three cross-sections on upper Lenstra Creek associated with three different grazing treatments. We analyzed these cross-sections as described in the next section.

Analysis

The effects of livestock grazing on channel morphology are a function of stream type and grazing intensity and duration (Platts 1981, Rosgen 1996, Myers and Swanson 1992). Width-to-mean-depth ratio is one of the more widely reported channel morphology measurements because it relates to the function of streams, namely transporting water and sediment. Width-to-depth ratio is in turn affected by the timing and amount of water and sediment delivered and presumably by land use activities. Faush et al. (1988) reviewed 99 different models that predict standing crop of stream fish from habitat variables. They found that many models include some measure of width and depth and when applied locally these models often explained a large portion of the variation in fish population size. The US Forest Service uses wetted width-to-mean-depth and width-to-maximum-depth ratios to describe fish habitat in their R1/R4 (Northern Region/Intermountain Region) fish habitat inventory procedures (Overton et al. 1995). However, hydrologists and geomorphologists use bankfull width-to-depth ratios when describing streams, primarily for two reasons: (1) water levels vary throughout the year and (2) bankfull discharge is believed to be the channel forming discharge (Leopold 1994, Wolman and Miller 1960) Because water level varies throughout the year, we chose to use bankfull channel dimensions in all analyses.

We could not compare width-to-depth ratios for large streams on TRM Ranch for the following reasons: (1) although both Dupuyer Creek and North Fork Dupuyer Creek are primarily C4 stream types, Dupuyer Creek has more than twice the drainage area as North Fork Dupuyer Creek and may pre-dispose it to higher width-to-depth ratios; (2) North Fork Dupuyer Creek is grazed primarily in summer where as Dupuyer Creek is grazed primarily in spring; (3) there are no grazing exclosures on Dupuyer Creek or North Fork Dupuyer Creek large enough to compare in statistical tests; (4) confounding effects of vehicle crossings and the straightening of Dupuyer Creek that resulted from a 1964 flood (Moeckel et al. 1996) would have made results of any tests difficult to interpret.

We were able to compare width-to-depth ratios for small streams, which are similar stream type and do not have large differences in drainage area. They are not affected by vehicle crossings and do not show widespread effects of the 1964 flood. In addition, there were a sufficient number of no-grazing areas (n=4) to allow an unbiased sample for the following comparison. Values for bankfull width-to-mean-depth and width-to-maximum-depth ratios for these streams do not meet the assumptions of normal distribution or homogeneity of variance even after standard transformations; therefore, ANOVA was not applied. Instead, we used the Kruskal-Wallis 1-Way Anova (Knapp and Matthews 1996) to test for significant differences in the effects of grazing versus no grazing on bankfull width-to-mean-depth ratio and width-to-maximum-depth ratio. The Kruskal-Wallis 1-Way Anova is not concerned with specific parameters, such as the mean, only the distribution of the variates (Sokal and Rohlf 1995). To further distinguish effects of grazing treatments on bankfull width-to-mean-depth and width-to-maximum-depth ratios, we used a Wilcoxon Rank Sum test to compare width-to-mean-depth and width-to-maximum-depth ratios pairwise between three grazing treatments, no grazing (n = 7), summer grazing (n = 6), and spring grazing (n=10). Because these test statistics were not independent, we used a sequential Bonferroni test (Rice 1989) to calculate the minimum table wide significance of p-values from the Wilcoxon Rank Sum test.

Stream Condition

Stream condition categories and ratings include: 1) riparian vegetation type and density (visual estimate); 2) flow regime; 3) size and stream order; 4) depositional patterns; 5) meander patterns; 6) debris and channel blockages; 7) stream channel stability rating; 8) streambank erosion potential and near-bank stress; and 9) degree of alteration. The first three categories are self explanatory; however, the remaining five categories and ratings require some explanation.

Depositional patterns are descriptions of channel bar features observed in streams, and meander patterns are categorized into one of eight different, yet commonly observed patterns (Table 1) (Rosgen 1996). Similarly, stream channel debris and blockages are categorized into one of ten different categories depending on the size and extent. The Pfankuch stability rating (Pfankuch 1978), used widely by the U.S. Forest Service, was originally developed for moderate gradient, forested streams; therefore, the ratings were not widely applicable to all stream types without modification (Rosgen 1996). The modifications applied here are presented in Rosgen (1996).

Table 1. Depositional features and meander patterns as described in Rosgen (1996).

B-1	Point Bars	M-1	Regular meander
B-2	Point bars with few mid-channel bars	M-2	Tortuous meander
B-3	Numerous mid-channel bars	M-3	Irregular meander
B-4	Side bars	M-4	Truncated meanders
B-5	Diagonal bars	M-5	Unconfined meander scrolls
B-6	Main channel branching with numerous mid-bars and islands	M-6	Confined meander scrolls
B-7	Side bars and mid-channel bars with length exceeding 2 to 3 times channel	M-7	Distorted meander loops
B-8	Delta bars	M-8	Irregular with oxbows, oxbow cutoffs

Bank erodibility ratings use field-determined data to categorize the potential for bank erosion. The variables measured include: 1) bank height/bankfull height; 2) root depth/bank height; 3) root density; 4) bank angle; 5) surface protection; and 6) bank materials (Rosgen 1996). Each variable gets a score from 1-10 except bank materials which are included separately. A summation of scores for each variable provides an erodibility rating of very low (score 5-9.5), low (score 10-19.5), moderate (score 20-29.5), high (score 30-39.5), very high (score 40-45), and extreme (score 46-50). Depending on bank materials, scores are adjusted according to the following guidelines: 1) bedrock, always very low; 2) boulders, always low; 3) cobble, decrease by one category unless mixture of gravel/sand is over 50% then no adjustment; 4) gravel, adjust values up by 5-10 points depending on composition of sand; 5) sand, adjust values up by 10 points; 6) silt/clay, no adjustment (Rosgen 1996).

The actual amount of bank erosion is also dependent on the amount of force applied to the bank by running water. To estimate this force, we divided the bankfull cross-section into thirds and calculated the percent of the total cross-section in the third nearest the bank (Rosgen 1996). This force is called stress in the near-bank region and is calculated by (Rosgen 1996):

$$\text{Near-bank Stress} = \text{nb A}/\text{A} \qquad (2)$$

where:

nb A = width*mean depth for 1/3 of the channel width in the near-bank region
A= cross sectional area at bankfull

This equation yields values between 1.0 and 0.0, where ratings of stress are assigned as follows:

Table 2. Calculated stress values and adjective rating as presented by Rosgen (1996).

Calculated Stress	Rating
0.32 or less	Low
0.33 - 0.41	Moderate
0.42 - 0.45	High
0.46 - 0.50	Very high
0.51 or more	Extreme

Bank erodibility and stress in the near-bank region were applied to 41 of 74 cross-sections; primarily the main fork of Dupuyer Creek and North Fork Dupuyer Creek.

Overton et al. (1995) defined stable banks as showing no evidence of active erosion, breakdown, tension cracking, or shearing. This definition classifies streambanks as stable or unstable, however placing such limits tends to ignore the middle range, which may be more useful in determining trends. In an effort to compare bank stability as assessed here with the results of Overton et al. (1995), we have further simplified our bank erodibility and near-bank stress ratings as follows: 1) stable (little if any observed bank erosion); 2) moderately stable (some signs of erosion but usually not major sloughing or calving); and 3) unstable (obvious sloughing, usually several to many feet of bank erosion annually). Actual erosion in 1995, was measured at six cross-sections and estimated during floods at the other cross-sections. Most cross-sections in this study were initially surveyed after spring runoff 1995 and re-surveyed in August 1996.

Assessing degree of alteration involves describing probable historic condition versus current observed condition. Examples of alteration include channelizing streams for bridge or ford crossings, constructing berms for irrigation diversions, and streambank trampling by livestock. Manure piles and bank trampling are the primary evidence of livestock use.

Monitoring

Each cross-section was resurveyed following spring runoff 1995 and 1996. We also monitored bedload transport as part of companion study of bedload hydraulics (Whitaker 1996). In this paper, we will discuss briefly maximum particle sizes gathered in bedload samples and how that relates to channel stability.

Bank erosion was monitored in three ways: (1) toe-pins—as described in Harrelson et al. (1994)—were installed at six cross-sections to provide detailed vertical profiles of streambanks; (2) annual re-survey of cross-sections indicates distance that streambanks eroded; and (3) visual observation of streambanks eroding during floods.

RESULTS

The results in this study consist largely of cross-sections, long profiles, pebble counts from study reaches, and personal observations over a three year period. These data are summarized in this paper and are presented in full in Appendices (A-F) as indicated below.

Geomorphic Characterization

Drainage density is a quantitative description of the total length of streams in a given area that reflects the climate, geology, soils, and vegetation cover in a drainage basin. Drainage density for Dupuyer Creek is 4.64 km/km^2 (7.47 mi/mi^2) as mentioned previously, crenulations were included in our analysis and increased drainage density significantly. By excluding all crenulations—most of which are not drawn as perennial streams on the topographic maps—the estimated drainage density decreases to 0.98 km/km^2 (1.58 mi/mi^2). These numbers are at the low end of the spectrum for drainage density for the Rocky Mountain region, which has a

Table 3. Summary of standard drainage basin calculations (Selby 1985, Gordon et al. 1992) for Dupuyer Creek drainage basin to TRM Ranch.

Drainage Density =4.64 km/km^2	Length of Basin = 15.82 km
Width of Basin =9.25 km	Basin Form Factor = .37
Basin Elongation = .69	Relief Ratio = .0715
Basin Area = 93.5 km^2	Basin Perimeter = 58.24 km
Basin Shape = 2.68	Circularity Ratio = .35

range from 8 to 16 mi/mi^2 and 50 to 100 mi/mi^2 for drier areas (Strahler 1964). As a comparison, drainage densities in the Badlands National Monument, SD range from 200 to 400 mi/mi^2.

Stream order is a quick and easy method of classifying streams, and can be a useful tool for stratifying stream surveys in a given region. The main fork of Dupuyer Creek is a sixth order stream and has a total length on TRM Ranch of 9.0-km. Middle Fork Dupuyer Creek is 3rd order, North Fork Dupuyer Creek and South Fork Dupuyer Creek are 5th order, Lenstra Creek is a 2nd order, and McCarthy and Middle Draw are 1st order streams. Additional drainage basin metrics are presented in Table 3.

Streamflow

The peak flow hydrograph for Dupuyer Creek is dominated by snowmelt and spring rainstorms (Figure 4 & 5). Peak streamflows occur between March and July but most frequently in May and June (Appendix A). May and June are also typically the wettest months of the year averaging about 3.8 and 4.3 inches of precipitation per month respectively at the SNOTEL (12 year average from 1984 through 1995). Mean precipitation in May and June at Valier, MT averages 1.6 and 2.2 inches respectively.

Spring rainstorms strongly influence the magnitude and timing of runoff. In 1995, two large peak flows, one May 6 the other June 7, resulted from several days of moderate to heavy rain (Figure 5). These storms deposited 4.5 and 6 inches of rain respectively at the SNOTEL precipitation gauge near Middle Fork Dupuyer Creek. On TRM Ranch a precipitation gauge showed about 4 and 5 inches of rain, respectively. Many soils on TRM Ranch have a high clay content (personal observation and soil texture analysis), and when saturated, overland flow is common and probably decreases the time required for delivery to the stream. During these spring storms, overland flow on hillsides leading to Dupuyer Creek was common, especially along game and livestock trails. Snowmelt may have contributed largely to the flood in May. However, on June 2 we hiked in the Dupuyer Creek watershed and saw virtually no snow remaining, therefore snowmelt did not contribute significantly to the June peak other than saturating soil and possibly decreasing water infiltration rate. Precipitation at the SNOTEL guage (elevation 1737 m) from October 1 to April 30 was actually slightly higher for 1996 than for 1995 at 20.7 and 19.2 inches respectively (12 year average = 15.9 inches). In 1996, there were no large spring rains like those observed in 1995, and although winter precipitation was measured at well over 100% of normal, streamflow did not reach bankfull.

Streamflow monitoring at cross-section 2.3 yielded an estimated bankfull discharge of 220 cfs. At bankfull discharge, particle sizes between 98 and 125-mm, measured on the b-axis, were observed moving. This range in particle size corresponds to d84 - d95 (meaning 84 to 95 percent of particles in the streambed are smaller than these particles), and indicates that Dupuyer Creek is capable of transporting nearly all of its bed material at bankfull stage. For further discussion on sediment transport in Dupuyer Creek see Whitaker (1996).

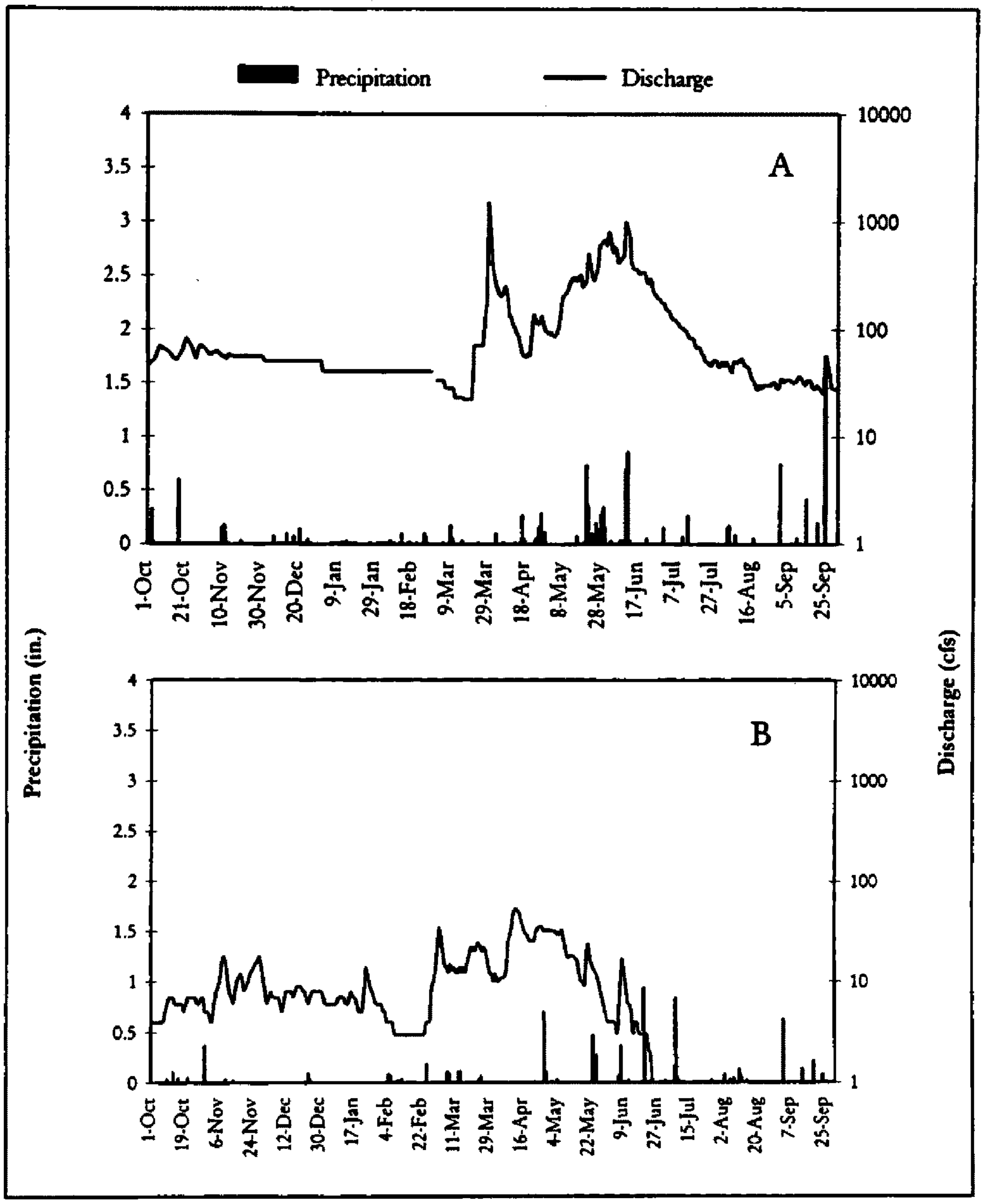

Figure 5. Annual hydrograph for Dupuyer Creek and daily precipitation in Valier, MT, water years 1917 (panel A) and 1937 (panel B). Data from USGS stream guage located between Dupuyer and Valier, MT. Notice the contrast in peak discharge and summer baseflow between water years.

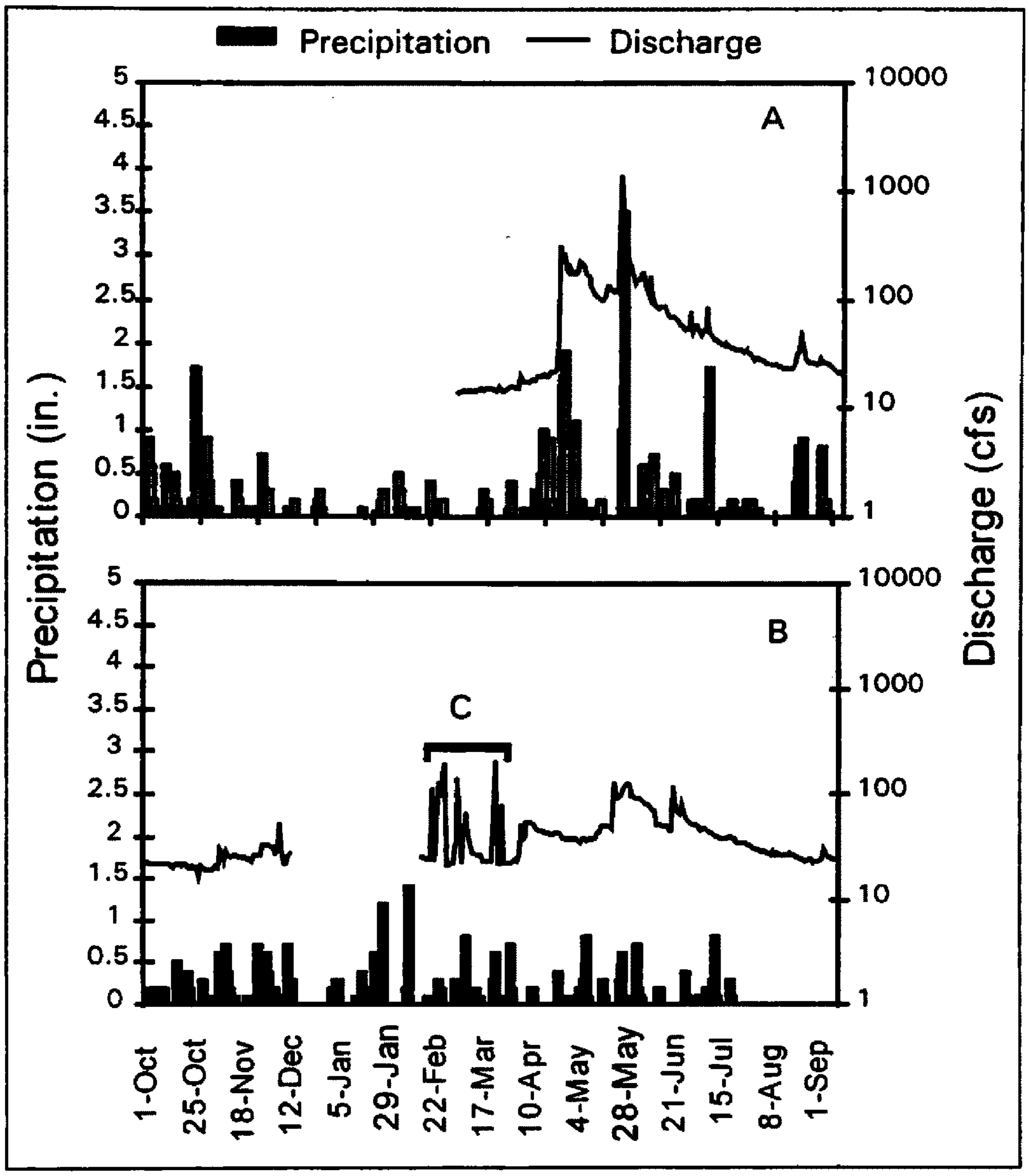

Figure 6. Annual hydrograph for Dupuyer Creek, water years 1995 (panel A) and 1996 (panel B) and daily precipitation at SNOTEL site in the watershed. Streamflow data from stream guage located on TRM Ranch. Area below [c] shows possible malfunction of gauge due to ice in or around the stilling well.

Channel Morphology and Stream Condition

Channel morphology and condition categories are summarized by groups based on similar morphology and location on TRM Ranch. The location of individual reaches are represented in Figure 3, channel morphology data are summarized in Table 4 and listed by cross-section number in Appendix C. Mean width-to-mean-depth and width-to-maximum-depth ratios are listed by stream type and similar channel size in Table 5. Stream condition categories and grazing treatments are summarized by reach number in Table 6. Bank erodibility and stress in the near-bank region for all streams are summarized in Figure 6. Graphs of longitudinal profiles are presented in Appendix D, individual cross-sections are presented in Appendix E, and graphs of streambed particle size distributions are presented in Appendix F.

Main Fork Dupuyer Creek

There are nine reaches and twenty-eight permanent cross-sections on the main channel of Dupuyer Creek (Figure 3). These nine reaches are in five different pastures, which are primarily grazed in spring and summer, with a small reach grazed in winter (Table 5). There are no reaches where grazing is excluded except for the Dupuyer Creek cattle exclosure (reach 10 in Figure 3) near middle crossing. Some reaches of Dupuyer Creek are less affected by livestock than others due to restricted access because of beaver ponds or steep hillslopes. Reach 1, 2 and 16 fit into this category, while reaches 7, 9, 10, 11, 12, and 15 are heavily used by livestock. Dupuyer Creek is primarily a C4 stream type with a mean width-to-mean-depth ratio of 32.4 (Table 5). Reaches that are not a C4 stream type include Johnson's crossing (reach 11), Middle crossing (reach 9) and a few short reaches intermittently throughout that are entrenched and therefore are F4 stream types.

Depositional features in Dupuyer Creek are primarily point bars with few mid-channel bars, however reach 11 has numerous mid-channel bars, diagonal bars, and islands. The meander pattern for Dupuyer Creek is irregular. Channel debris/blockages, for most of Dupuyer Creek, consist of small to medium sized materials, such as large tree limbs, branches, or portions of logs that when accumulated effect 10% or less of the active channel. Exceptions to this pattern are reach 11, which has numerous downed trees either blocking or partially blocking the active channel. Intermittently in Dupuyer Creek, a downed cottonwood tree lies in the channel creating a deep scour pool—cross-section 16.2 is a good example of this type of pool.

Riparian vegetation along most of Dupuyer Creek is primarily cottonwood (*Populus* spp.) and willow (*Salix* spp.), but other common types of vegetation include red osier dogwood (*Cornus stolonifera*), Woods rose (*Rosa woodsii*), Kentucky bluegrass (*Poa pratensis*), Timothy (*Phleum pratense*), Smooth brome (*Bromus inermis*), silver berry (*Elaeagnus comutata*), and many others (for complete species list, see Hurlburt 1996). Young cottonwoods and willows are abundant on the low terrace and many seedlings appear on recently developed gravel bars.

Most streambanks along Dupuyer Creek rated as high, very high, or extreme erodibility (Rosgen 1996) while very few reaches rated as very low, low, or moderate. During peak flows in 1995, streambanks at cross-section 1.1 and 2.1 eroded 13 and 11 feet respectively (Figure 8); their bank erodibility and nearbank stress ratings were high, extreme and very high, extreme, respectively. Conversely, cross-section 2.5, which has a bank erodibility rating of moderate and nearbank stress rating of very high, showed no evidence of bank erosion during this study (Figure 9). Dupuyer Creek has very few undercut banks and many banks are nearly vertical, which increases erodibility ratings.

Channel dimensions, at reaches 9, 11, and 12, are most affected by vehicle crossings. Two of these reaches, 9 and 12 have a narrow rail-car bridge and low water ford crossing, while reach 11 (Johnson's crossing) is a low water ford crossing only. Bridge crossings create an entrenched channel, with very low width-to-mean-depth ratios and steep banks. At estimated bankfull, the hydraulic radius for cross-section 12.2 is 1.78 and stream slope is 1%, from equation (1), shear stress equals 1.11 lbs./$ft.^2$, which corresponds to a particle size of about 120 mm (Leopold 1994). Cross-section 2.3, a few hundred feet upstream, had a calculated shear stress of 0.96 lbs./$ft.^2$, which corresponds to a particle size of about 75 mm. Higher shear stress at bridge crossings resulted in rapid bank erosion in 1995, causing the middle crossing bridge to collapse and nearly collapsing two others. That summer all bridges were reinstalled. The banks upstream of the lower bridge crossing were armored with rip rap. The rip rap armor consists of mostly boulders, which are more resistant to erosion. Similarly, the bridge at middle crossing (reach 9), was washed out completely in 1995 and had to be moved to a newly formed channel about 150 feet away. At the ford crossing (Johnson's Crossing, reach 11) the stream is artificially widened causing the channel to aggrade several feet. This deposition has resulted in a sharp change in stream slope (Figure 9) and vastly different particle size distribution (Appendix F) at the ford crossing compared to upstream. This reach is very unstable despite the abundance of riparian vegetation.

Channel cross-sections surveyed before and after spring runoff 1995 and 1996, showed that Dupuyer Creek is rapidly eroding many of its banks at flows of bankfull and larger (Figure 8). Peakflow in 1995 was about 5 to 6 times bankfull discharge. Stream discharge in 1996 did not reach bankfull and no appreciable changes were measured.

Table 4. Summary of channel morphology values for Dupuyer Creek and its tributaries.

			Main Fork Dupuyer Creek		
Variable	Mean	Std. Dev.	Min.	Max.	n
Slope %	1.0	0.31	0.6	1.8	29
Mean Depth (ft.)	1.3	0.45	0.5	2.6	29
Max. Depth (ft.)	2.4	0.85	1.1	5.9	29
Width Bankfull (ft.)	53.8	35.66	21.0	164.7	29
Width Floodprone (ft.)	137.5	99	28.6	400.0	29
Area Bankfull (sq. ft.)	57.5	17.75	35.0	111.9	29
Entrenchment Ratio	2.8	1.7	1.1	6.7	25
Width-to-mean-depth Ratio	58.5	71.62	11.4	290.8	29
Width-to-max.-depth Ratio	27.3	28.57	7.3	130.1	29
			North Fork Dupuyer Creek		
Variable	Mean	Std. Dev.	Min.	Max.	n
Slope %	1.5	0.49	0.8	2.6	20
Mean Depth (ft.)	1.1	0.3	0.6	1.8	20
Max. Depth (ft.)	1.9	0.34	1.2	2.4	20
Width Bankfull (ft.)	24.4	7.46	16.8	45.4	20
Width Floodprone (ft.)	105.7	52.34	37.1	200.0	20
Area Bankfull (sq. ft.)	24.6	6.8	15.5	42.0	20
Entrenchment Ratio	4.4	2.05	2.1	8.8	18
Width-to-mean-depth Ratio	27.0	15.25	13.3	66.8	20
Width-to-max.-depth Ratio	13.3	5.72	8.1	28.7	20
			Middle Fork Dupuyer Creek		
Variable	Mean	Std. Dev.	Min.	Max.	n
Slope %	1.9	1.12	0.1	3.8	7
Mean Depth (ft.)	0.6	0.19	0.3	0.8	7
Max. Depth (ft.)	1.0	0.28	0.6	1.5	7
Width Bankfull (ft.)	7.0	3.98	3.0	15.0	7
Width Floodprone (ft.)	21.1	4.61	16.5	31.0	7
Area Bankfull (sq. ft.)	4.0	1.63	2.2	6.2	7
Entrenchment Ratio	3.7	1.77	1.3	6.7	7
Width-to-mean-depth Ratio	13.7	11.71	4.0	36.6	7
Width-to-max.-depth Ratio	8.0	5.5	2.5	18.3	7
	Lenstra Creek, Middle Draw, and Middle Fork Dry Fork Marias Creek				
Variable	Mean	Std. Dev.	Min.	Max.	n
Slope %	2.1	1.31	0.2	4.3	16
Mean Depth (ft.)	0.7	0.18	0.3	1.0	16
Max. Depth (ft.)	1.0	0.28	0.5	1.5	16
Width Bankfull (ft.)	4.0	1.46	1.5	6.7	16
Width Floodprone (ft.)	12.0	8.2	4.6	30.0	16
Area Bankfull (sq. ft.)	4.1	2.89	0.7	9.8	16
Entrenchment Ratio	3.7	3.27	1.0	12.1	16
Width-to-mean-depth Ratio	4.8	2.7	1.3	12.9	16
Width-to-max.-depth Ratio	5.5	5.83	2.6	26.4	16

Table 5. Means and standard deviations for bankfull channel and wetted channel width-to-depth ratios by Rosgen stream type.

Rosgen Stream Type	Sample Size	Means and Standard Deviations: Bankfull Channel: Width-to-Mean Depth Ratio		Bankfull Channel: Width-to-Max. Depth Ratio		Wetted Channel: Width-to-Mean Depth Ratio		Wetted Channel: Width-to-Max. Depth Ratio	
									Main Fork Dupuyer Creek
B4c	2	35.61	(19.08)	18.82	(3.85)	38.78	(16.43)	24.88	(10.95)
C4	15	32.38	(19.28)	17.84	(9.98)	53.24	(36.24)	25.11	(13.64)
D4	7	152.26	(98.78)	59.28	(44.32)	118.03	(107.76)	45.6	(38.93)
F4	4	23.98	(6.5)	15.46	(5.65)	39.97	(21.18)	24.84	(15.11)
G4c	1	12.57	(n/a)	8.40	(n/a)	26.42	(n/a)	12.07	(n/a)
									North Fork Dupuyer Creek
C3	6	16.1	(2.79)	10.39	(1.75)	31.24	(13.52)	16.33	(6.6)
C4	17	27.02	(15.31)	13.40	(4.99)	31.36	(16.00)	16.96	(7.52)
D4	2	42.08	(2.76)	22.72	(4.62)	67.03	(16.96)	26.44	(9.74)
									Middle Fork Dupuyer Creek
C4	1	21.88	(n/a)	11.67	(n/a)	(n/a)	(n/a)	(n/a)	(n/a)
E4	2	11.1	(0.96)	6.59	(2.15)	21.29	(19.77)	12.64	(11.7)
E4b	3	5.25	(2.05)	4.21	(2.26)	9.94	(3.87)	5.73	(2.8)
F4	1	36.59	(n/a)	18.29	(n/a)	48.40	(n/a)	17.37	(n/a)
									Lenstra Creek, Middle Draw,and Middle Fork Dry Fork Marias Creek
B6	1	26.8	(n/a)	12.88	(n/a)	1.10	(n/a)	0.37	(n/a)
E6	7	5.1	(2.33)	2.96	(1.02)	8.56	(2.68)	4.45	(2.19)
E6b	1	3.19	(n/a)	2.78	(n/a)	(n/a)	(n/a)	(n/a)	(n/a)
G6	7	6.88	(1.84)	5.23	(1.55)	18.67	(17.59)	11.13	(9.64)

Table 6. Condition categories, grazing regime, pool-to-riffle ratio, and particle size listed by reach number and stream (DC = Dupuyer Creek; NFDC = North Fork Dupuyer Creek; SFDC = South Fork Dupuyer Creek; MFDC = Middle Fork Dupuyer Creek).

Reach	Stream	Stream Type	Grazing Season	Channel Stability	Bank Erodibility	Pool-Riffle Ratio	Sinuosity	d50 (mm)	d84 (mm)
1	DC	C4	late winter	poor	extreme	31 to 69	1.3	30	65
12	DC	C4	early spring	fair	very high	25 to 75	1.2	42	124
2	DC	C4	late winter	fair	very high	24 to 76	1.2	42	91
10	DC	C4	late spring	fair	high	39 to 61	1.2	32	84
9	DC	D4	late spring	poor	low	26 to 74	1.1	42	124
15	DC	C4	late spring	poor	high	32 to 68	1.2	51	110
16	DC	C4	winter	fair	high	43 to 57	1.2	35	94
11	DC	D4	summer	poor	high	10 to 90	n/a	27	47
7	DC	C4	summer	fair	high	45 to 55	1.1	42	124
6	NFDC	C4	summer	fair	moderate	40 to 60	1.4	50	95
5	NFDC	C4	summer	good	low	36 to 64	1.1	50	130
4	NFDC	C3	summer	good	low	42 to 58	1.4	65	190
8	SFDC	C4	summer	fair	moderate	55 to 45	1.5	50	110
14	MFDC	C4	summer	good	moderate	10 to 90	1.3	28	75
17	MFDC	E4b	None	good	low	50 to 50	1.2	9	105

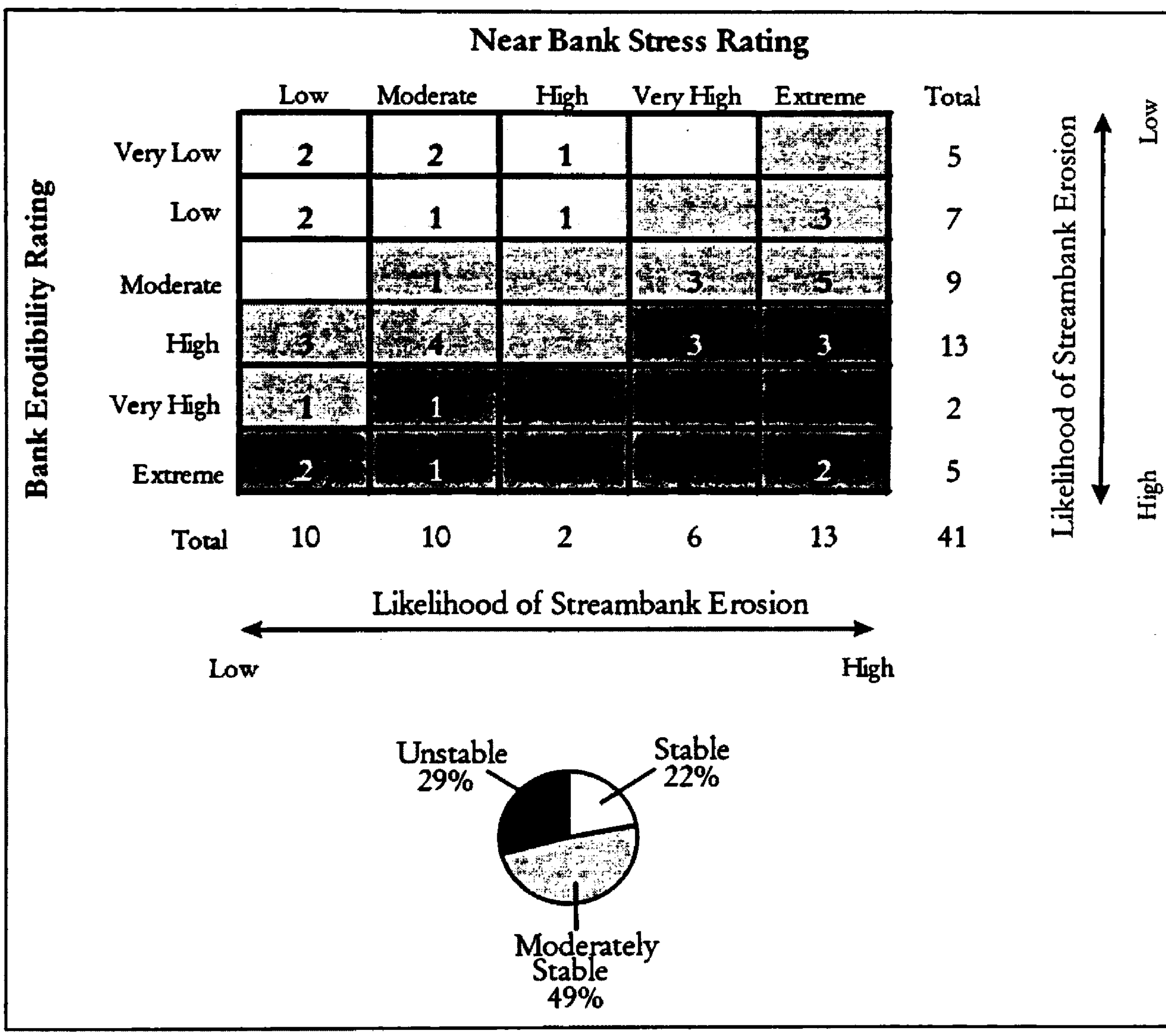

Figure 7. Streambank erodibility and near-bank stress for cross-sections on Dupuyer Creek. Numbers in each cell indicate the number of cross-sections in each category. Pie chart indicates streambank stability as percentage of 41 cross-sections.

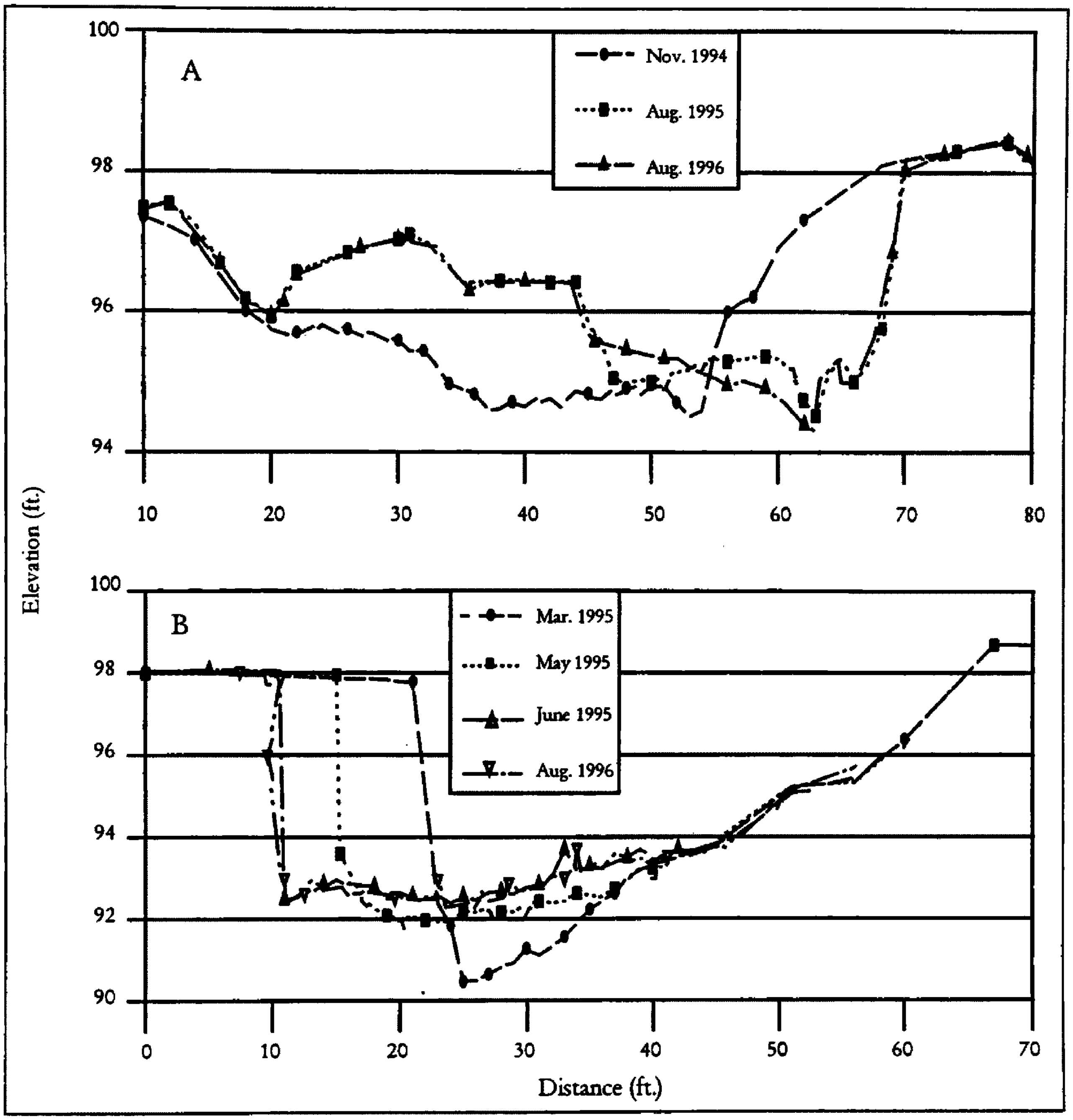

Figure 8. Cross-section 1.1 (panel A) and cross-section 2.1 (panel B) showing extreme bank erosion following May 1995 and June 1995 peak flows and very little bank erosion following peak flows in 1996.

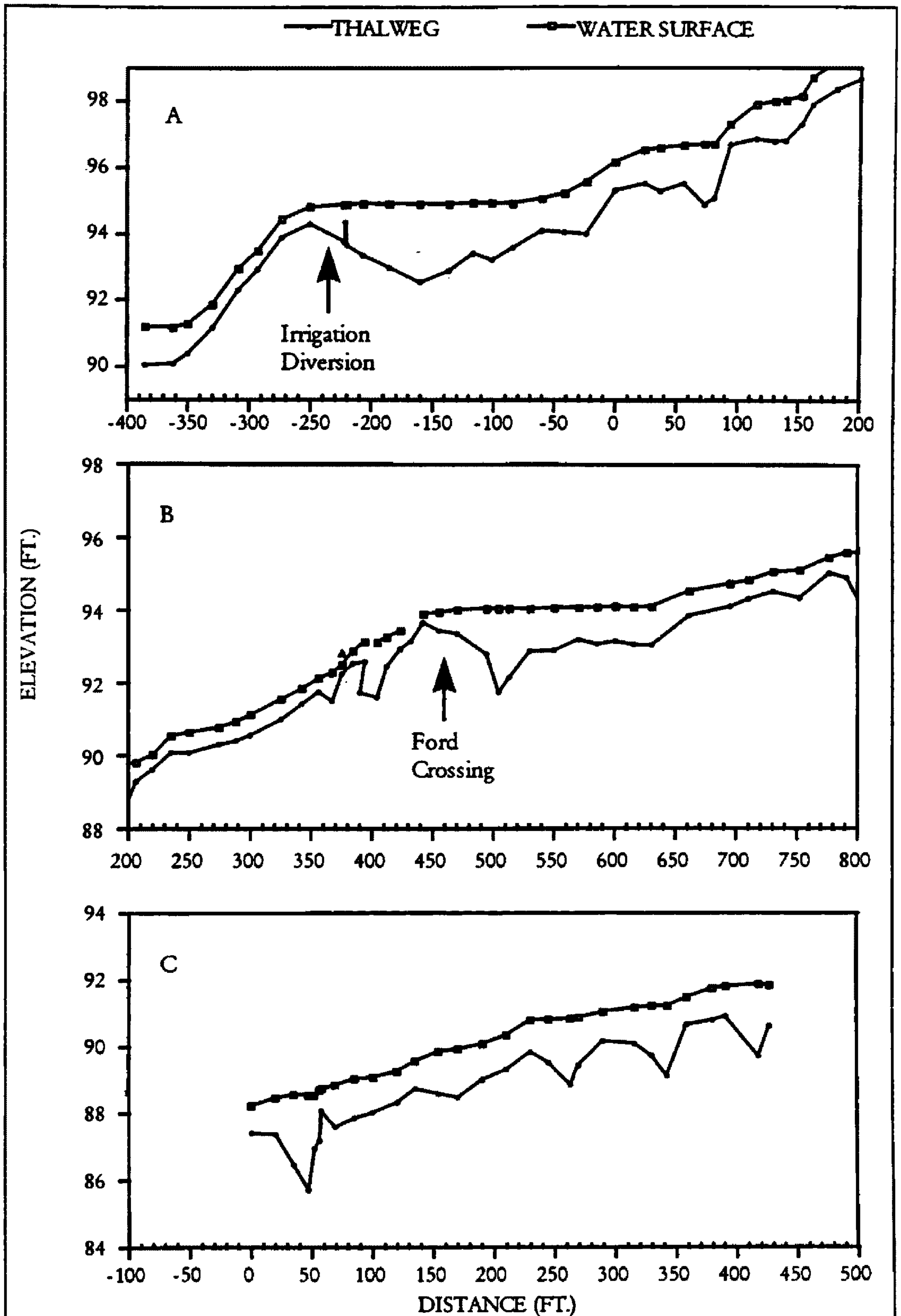

Figure 9. Longitudinal profile of reach 4 (panel A), reach 11 (panel B), and reach 10 (panel C). Horizontal and vertical axis are equal among the three panels. Note the contrast between disturbed (panels A& B) and fairly undisturbed (panel B) reaches.

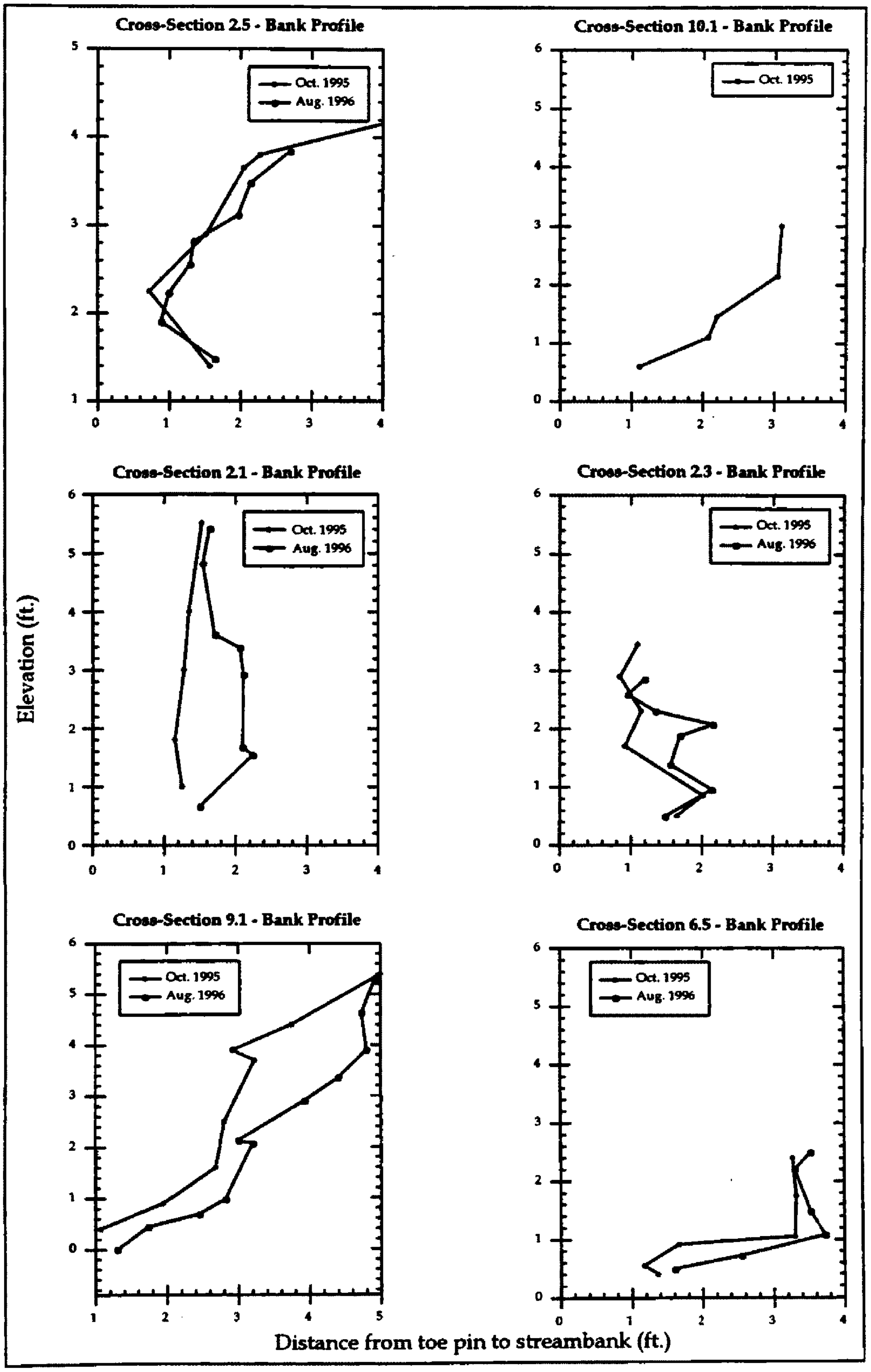

Figure 10. Streambank profiles for selected cross-sections on Dupuyer Creek. Vertical axis represents elevation above arbitrary datum..

North Fork Dupuyer Creek

There are four reaches and eighteen permanent cross-sections on North Fork Dupuyer Creek; two additional cross-sections were measured at the North Fork Bridge crossing. These four reaches are grazed primarily in summer (Table 5). Riparian vegetation along North Fork Dupuyer Creek is dominated by fairly young cottonwood (*Populus* spp.) and willow (*Salix* spp.). In historical aerial photographs (Sept. 1937 and Oct. 1951), North Fork Dupuyer Creek is virtually devoid of any riparian vegetation from the irrigation diversion to near the confluence with the South Fork. In 1937 photographs, the stream is dry from just below the diversion down to the confluence. This section of stream also appeared to be braided, with many active channels during these years. By 1978, this reach had considerably more riparian vegetation but much of the stream was still braided. Presently, there is more riparian vegetation along the North Fork than at any other time observed in aerial photographs. However, there are still many active channels at low flow.

At most cross-sections, streambanks along North Fork Dupuyer Creek rated as moderate-to-very-low-erodibility. Cross-section (6.2) has a bank erodibility rating of high that is due to heavy livestock trampling along a fence line. A predominance of large particle sizes (cobble and boulder) in streambanks along North Fork Dupuyer Creek decreased bank erodibility ratings by one category and presumably inhibits bank erosion.

The irrigation diversion for TRM Ranch is located on North Fork Dupuyer Creek several hundred feet upstream of the TRM Ranch boundary (Anderson's property). The diversion was initially constructed sometime before the 1930's, and is reconstructed almost annually depending on magnitude of peak flows each spring. A hand constructed boulder and cobble berm diverts water into a small channel. This diversion channel carries water to two irrigation ditches, which are controlled by headgates. Total water diverted into ditches is usually between 10 and 20 cfs based on discharge measurements taken on 16 June 1995 and 27 June 1996, respectively. Water not diverted, returns to the main channel via an overflow channel. Although irrigation is limited to about 1 month a year, usually during peak flows, the diversion channel carries water year around. Estimated bankfull discharge above the diversion is 100 cfs, therefore the irrigation channel diverts about 10 to 20% of bankfull discharge. The berm constructed for diversion is located at about the minus 220 foot mark on panel B in Figure 9. Just below the irrigation diversion, the stream is aggrading, resulting in a braided channel.

Middle Fork Dupuyer Creek

Middle Fork Dupuyer Creek has two permanent reference reaches with 5 cross-sections and two additional cross-sections that were surveyed in conjunction with a fish survey in 1996. High width-to-mean-depth ratios at cross-section 14.1 and 18.2 are due to bank trampling by livestock. Cross-section 14.1 is severely trampled by livestock and had a width-to-mean-depth ratio of 36.6. Cross-section 14.3, just 30 m upstream and showing very little evidence of livestock trampling, had a width-to-mean-depth ratio of 11.8. Cross-sections 17.1 and 17.2 are on National Forest and show no evidence of grazing. Width-to-mean-depth ratios for these two cross-sections were 4.1 and 7.6, respectively.

Coarse woody debris is important in pool formation in this stream; making up a about 50% of pools. The upper reaches have occasional debris jams with plunge pools below. Channel dimensions indicate primarily an E4 stream type, but it has an uncharacteristically low sinuosity ratio of about 1.5. A road paralleling the stream for most of its length on TRM Ranch, is severely eroded and is contributing large amounts of fine sediment to the stream. Streambanks on Middle Fork Dupuyer Creek are composed of a high percentage of silt and clay with lesser amounts of gravel and some very large boulders. Some reaches of Middle Fork Dupuyer Creek are heavily trampled by cattle and contribute a lot of fine sediment to the stream.

Small Streams

Small streams on TRM Ranch include: Lenstra Creek, Middle Draw, McCarthy Creek, and Middle Fork Dry Fork Marias Creek. McCarthy Creek is dominated by beaver ponds for about half of its length, otherwise it is similar to Lenstra Creek, but with slightly higher baseflow. In fall 1996, streambanks along McCarthy Creek were severely trampled by cattle. Among surveyed cross-sections, there were large differences in width-to-mean-depth ratios in different grazing treatments in Middle Draw, but not in Lenstra Creek. In the Middle Draw cattle exclosure width-to-mean-depth ratio was 3 and entrenchment was 3.2; compared to outside the exclosure where width-to-mean-depth ratio was 26 and entrenchment was 1.6, indicating a shift in stream type, from an E to an F, due to grazing by cattle and probably elk. Similarly, two cross-sections on opposite sides of a fence had width-to-mean-depth ratios of 3 and 9, the latter is grazed in spring, the former showed no evidence of livestock grazing. Vegetation along most of Middle Draw is primarily sedge (*Carex* spp.) and willow (*Salix* spp.). Upper Middle Draw was grazed season long during summer 1995; sedges and willows were used heavily and streambanks were severely trampled throughout most of the pasture. This pasture was not grazed in 1996, and vegetation responded well, however streambanks still showed signs of the previous years trampling.

Middle Fork Dry Fork Marias has two pastures. The upper, southern most pasture is grazed summer long while the northern most pasture is a hay meadow, grazed occasionally in early fall. We measured one cross-section on the lower end of this stream, it had a width-to-mean-depth ratio of 3 and entrenchment of 6.7 (because there were no signs of livestock grazing in this reach it was included in the no grazing data set). There are many beaver ponds in the upper pasture and a few, recently constructed ponds near the boundary fence in the lower pasture. This stream is an E6 stream type, and riparian vegetation is predominantly willow and sedge. Riparian vegetation in this reach was in good condition with several young willows and abundant sedges. Although not surveyed, the upper, grazed portion of the stream does show signs of bank damage from livestock trampling.

Statistical Analysis

Results of the Kruskal-Wallis 1-Way Anova indicate a significant ($p < 0.05$) effect of grazing treatment on stream width-to-mean-depth and width-to-maximum-depth ratios (Table 7). Pairwise comparisons, using Wilcoxon rank sum test with P-values adjusted by sequential Bonferroni, of effects of grazing treatment showed that grazing in both spring and summer had significant effects on width-to-mean-depth ratios of small streams (Table 8). There were also significant differences in width-to-max.-depth ratios for summer versus no grazing and nearly significant for summer versus spring and spring versus no grazing. It is likely that larger sample sizes would have found significant effects for all grazing treatments tested in this analysis.

Table 7. Results of Kruskal-Wallace 1-Way Anova for small streams on TRM Ranch.

	Mean Rank		
Grazing Treatment	*Width-to-mean-depth ratio*	*Width-to-max.-depth ratio*	Cases
Spring	12.50	12.50	10
Summer	18.33	17.83	6
None	5.86	6.29	7
	P = 0.0040	**P = 0.0088**	

Table 8. P-values from Wilcoxon Rank Sum test for small streams, adjusted by sequential Bonferroni (Rice 1989).

Pairwise Grazing Treatments	P- Values	
	Width-to-mean-depth ratio	*Width-to-max.-depth ratio*
Spring vs. Summer	0.0302	0.0650
None vs. Summer	0.0297	0.0300
None vs. Spring	0.0297	0.0626

DISCUSSION

The importance of riparian areas for wildlife habitat and ranching can not be overstated. Characteristics of riparian zones are determined by the quantity and timing of water delivered to the site and the geology, vegetation and soil of the site (Platts 1981, Platts 1991, Thomas et al. 1979). Despite this complexity all riparian zones in the western United States have the following in common: 1) they create well-defined habitat zones within much drier surrounding areas; 2) they make up a minor proportion of the overall area; 3) they produce more biomass—plant and animal—than the remainder of the area; and 4) they support most biodiversity of rangelands (Thomas et al. 1979). Aquatic insects, fish, waterfowl, and beavers depend entirely on riparian zones. Deer, elk, moose, bears, and birds spend a large part of their time in riparian zones for breeding or use them as corridors for migration. For example, in western Montana, 59% of land bird species breed in riparian habitats and 36% of those breed nowhere else (Kauffman and Krueger 1984). Livestock also congregate in riparian areas because they provide water, shade, highly productive forage, and more gentle topography (Kauffman and Krueger 1984, Marlow et al. 1987, Platts 1981, Platts 1991, Thomas et al. 1979)

Herbaceous productivity in riparian areas decreases when vegetation is removed by grazing and increases when grazing is reduced (Kauffman and Krueger 1984). Riparian vegetation, especially willows and grasses, form mats that reduce water velocity and erosive energy during overbank flows. By slowing the water and decreasing energy, these mats cause sediment to settle and build floodplains (Platts

1991). Schulz & Leininger (1990) found that canopy coverage of willows in exclosures was 8 1/2 times greater than grazed areas, and willows in exclosures were significantly older with mean ages of 8.1 vs. 4.8 yrs. Kauffman et al. (1983a) found that when grazing was excluded, density of cottonwood seedlings increased after two years rest. Personal observations of grazing exclosures on TRM Ranch concur with their findings. Willows appeared to do much better in exclosures as do sedges and cottonwood seedlings. While rating bank erodibility on Dupuyer Creek, two of the main categories contributing to high erodibility ratings were a lack of riparian vegetation or a lack of deep rooted species, such as willow and cottonwood, and bank heights of twice bankfull depth. Kauffman et al. (1983b) also found that grazed areas had significantly greater streambank losses compared to non-grazed areas. They suggested that livestock grazing may have weakened the streambank structure through trampling and forage removal to the point where ice flows and high water had a more damaging effect on grazed portions of the streambank.

Channel Morphology

The cattle exclosure on Dupuyer Creek is small and encompasses only about 250 feet of stream. Despite its size, there are two obvious differences inside and outside the exclosure. The most obvious is the number of hoof prints outside the exclosure, e.g. cross-section 10.2, outside the exclosure, was trampled for about 20 feet of the floodplain and contained very little vegetation except high on the banks. In contrast, cross-section 10.1, inside the exclosure, had an abundance of cottonwood seedlings and no trampling. This suggests that over many years, trampling reduces riparian vegetation. Such vegetation when mature, stabilizes streambanks.

Even with fairly small sample sizes we found a significant difference in width-to-depth ratios among grazing treatments. Grazing exclosures on TRM Ranch are still fairly new and encompass short reaches of streams, both of these factors may have limited recovery of the stream channel. Upstream disturbances might still have an effect on Lenstra Creek where grazing continues above exclosures. It is difficult to determine what effect upstream grazing might have inside the exclosures. This is not as much of a problem on Middle Draw because the exclosures include the source of the spring.

All streams used in the small stream comparison were E stream types or would be E stream types minus grazing disturbance. Lewis and Clark National Forest, on Middle Fork Dupuyer Creek, provides a relatively large non-grazed area and probably represents the best possible condition for this stream. Myers and Swanson (1992) found that stream stability could be predicted by Rosgen stream type, and that livestock trampling affected certain stream types much more than others. Our results indicate similar findings, in that E4 and E6 stream types showed significant increases in width-to-depth ratios for both summer and spring grazing versus no grazing. But, no significant effects of grazing were observed on C3 and C4 stream types. Such a disproportionate effect of livestock on small streams is likely due to two primary reasons: (1) silt and clay banks collapse more easily especially when wet, and (2) the percentage of stream width affected by a hoof is much greater for streams that are 1 or 2 feet wide versus streams that are 30 or 40 feet wide.

We were unable to assess the effects of livestock grazing on width-to-depth ratios of large streams, because of the aforementioned reasons. Nevertheless, trampling on larger streams might have a significant effect, but be more difficult to detect. Determining how far downstream from a disturbance that channel dimensions are affected is one of the biggest uncertainties confronting geomorphologists. In small streams, 1 or 2 feet wide, the distance might be as short as five or ten feet; on larger streams, 30 or 40 feet wide, downstream effects might go beyond several miles. This might seem quite a long distance, but consider that tracer particles, ranging in size from about 50 to 125 mm, in Dupuyer Creek moved a range of 0 to 3,300 ft. in one spring. Therefore, it is reasonable to suggest that gravel and cobbles knocked into the stream by livestock might be affecting downstream reaches a long way away from the point of disturbance. Whether or not these gravel and cobbles have a significant effect is probably one of the more difficult questions confronting land managers. Beschta and Platts (1986) stated that because bed material influences channel characteristics, a change in the median particle size of the bed can influence the frequency and magnitude of bedload transport and might further affect channel dimensions. In the case of ford crossings such as Johnson's crossing, there is clearly a change in bed material size at the crossing (Moeckel et al. 1996) that continues downstream for an untold distance. We also observed dramatic increases in width-to-depth ratios at the ford crossing that continue to influence channel dimensions downstream.

Water diversion for irrigation has affected the channel in two ways. First, it has resulted in an aggrading channel near the diversion, which disrupts bedload and fine sediment transport. Second, it has probably limited survival and recruitment of riparian vegetation on North Fork Dupuyer Creek, especially in the early part of this century. The size and extent of existing irrigation ditches on TRM Ranch, suggest that irrigation was probably more extensive in years past than under current management. The effect of such extensive irrigation was likely more pronounced in dry years, often a critical time for young riparian vegetation. Other possible explanations for a lack of riparian vegetation on North Fork Dupuyer Creek include, some natural fluctuation or cycle, although there is no indication of similar occurrences on Dupuyer Creek. Grazing by sheep around the turn of the century might also have had a prominent influence on riparian vegetation recruitment and survival.

Stream condition

Overton et al. (1995) state the desired future condition for a C4 stream, in the Salmon River system, with a wetted width of 25 feet should have 47 pools/mile; streambank stability should be >80% stable with >75% undercut banks with width-to-depth ratios < 10. By definition, a Rosgen C stream type can only have width-to-depth ratios greater than 10. These values of stream condition are for the Salmon River drainage, which has different geology and climate than that of the east front.

However, the study by Overton et al. (1995) is one of the few to quantify channel morphology in an undisturbed system. If we compare data from Dupuyer Creek we find a value of 30 pools/mile; streambank stability of 22% stable, and a mean width-to-depth ratio of 58.5. Although we did not measure undercut banks, it is unlikely to be greater than 20%. We do not have historical data for Dupuyer Creek, but it is unlikely that Dupuyer Creek ever had or will have width-to-depth ratios of < 10. Currently, the lowest width-to-depth ratios measured on Dupuyer Creek were in deep pools and even there width-to-depth ratios were about 12. Current channel dimensions, surveyed in 1996, indicate that 14 of 29 cross-sections have width-to-mean-depth ratios of less than 30. Considering some of the least-disturbed reaches on TRM Ranch and dimensions of an old channel, pre-1964 flood, a more reasonable target may be a width to depth ratio in the mid to high 20's.

SUMMARY

There were three primary objectives when beginning this study. The first and most immediate objective was to inventory and describe streams on TRM Ranch. This was satisfied and there is now a clearer picture of current condition of these streams. The second, more long-term objective was to try to differentiate the cumulative effects of livestock grazing and other activities from those of natural disturbances such as large floods. In this regard it appears that vehicle crossings have and continue to disrupt the function and process of streams. Livestock grazing appears to have a disproportionate effect on E4 and E6 stream types versus C4 and C3 stream types. The third objective was to develop a database of stream channel morphology and condition categories with which to guide future management decisions. This database of 74 cross-sections, long profiles, and streambed particle distributions provides a starting point from which to begin experimenting with different grazing practices. Future research should involve grazing experiments designed to study the effects of livestock grazing on different stream types. Specifically, one or more large grazing exclosures on Dupuyer Creek are needed to allow a representative sample of channel dimensions.

At this time there are more questions than answers, but we have begun what will most likely be a long process of monitoring and experimenting with different management strategies to discover the right combination of grazing intensity and grazing season that best protects streams on the northern Rocky Mountain Front. Myers and Swanson (1991) suggest that stream management must be stream type specific, and that classifying stream reaches and studying the nature and response potential of different stream types will allow managers to write objectives that target specific attainable goals. The results from this study indicate some promise in this regard.

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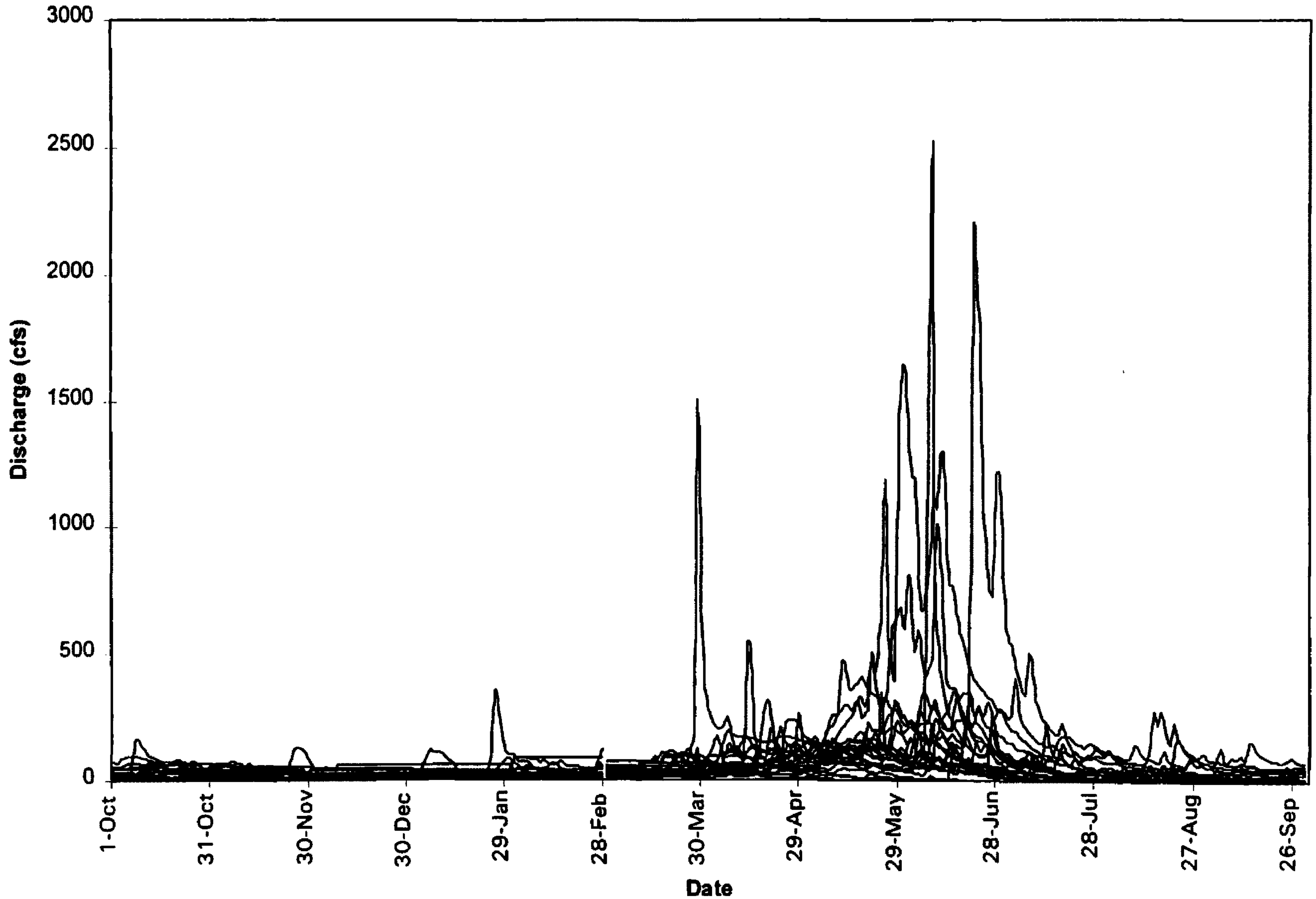
Appendix A

Annual hydrographs, 1913 to 1937, from USGS stream gauge on Dupuyer Creek near Valier, MT and box-plots of monthly precipitation at Valier, MT (1913 to 1917) and the SNOTEL site (1984 to 1995) located in the Lewis and Clark National Forest, near Middle Fork Dupuyer Creek.

Annual Hydrograph Dupuyer Creek, near Valier
water years 1913 - 1937



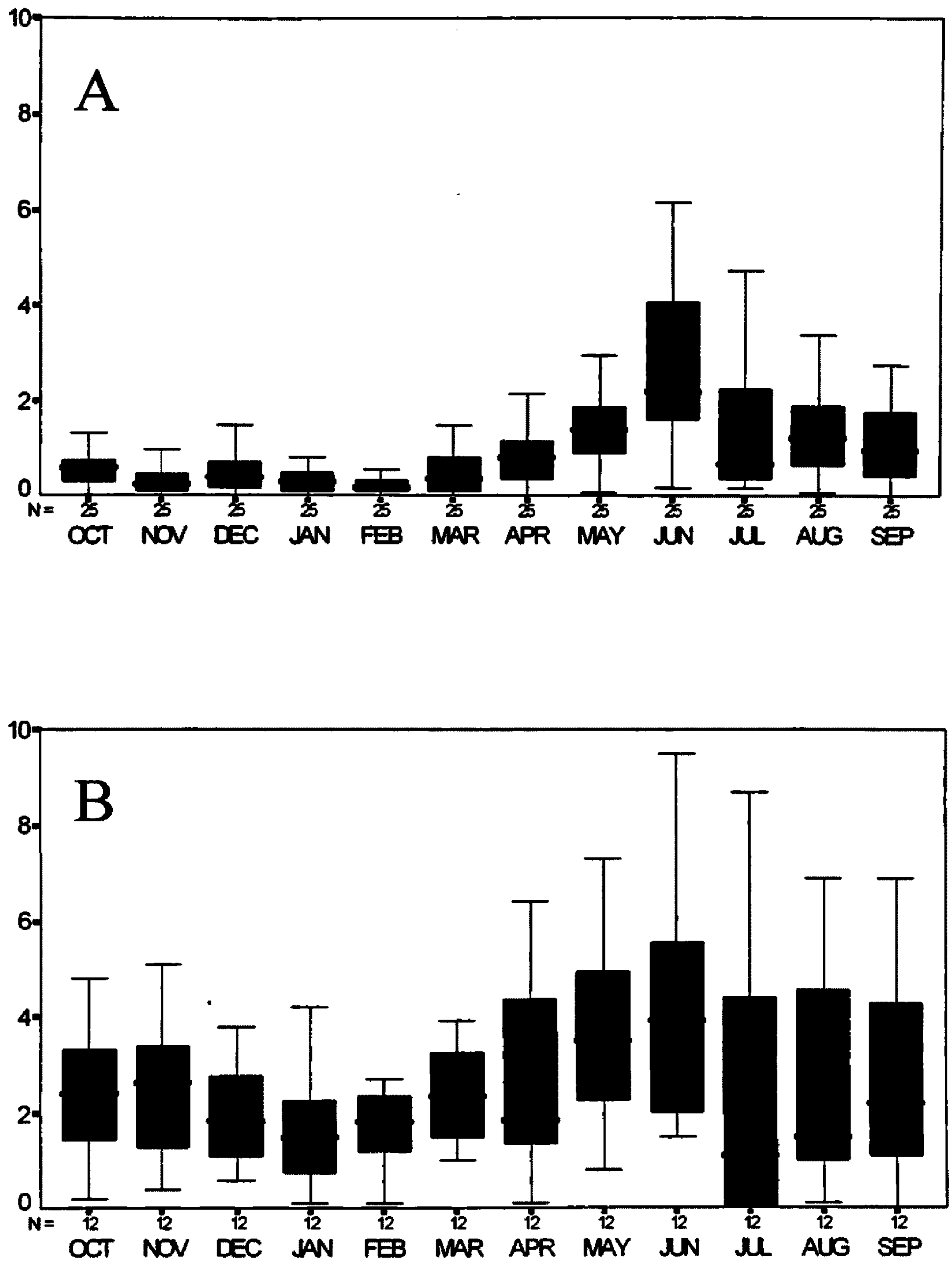
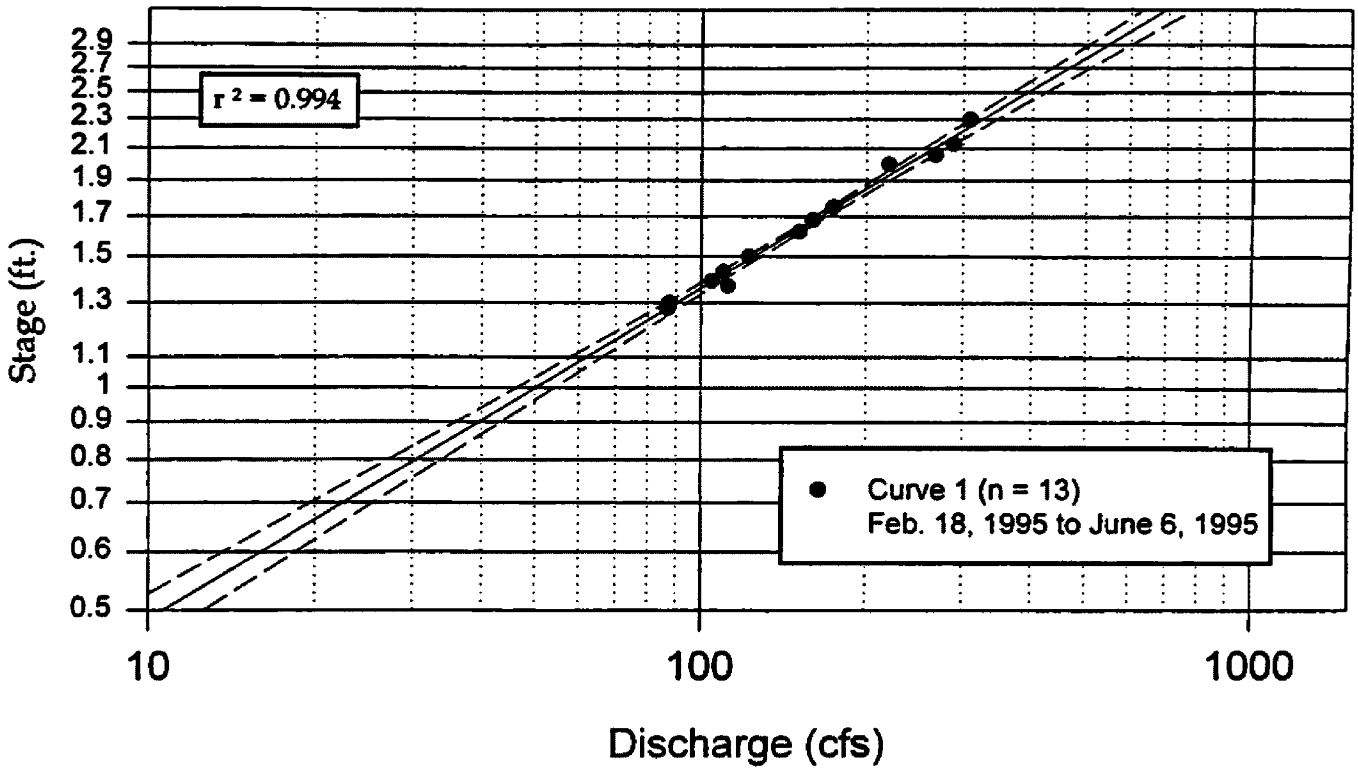


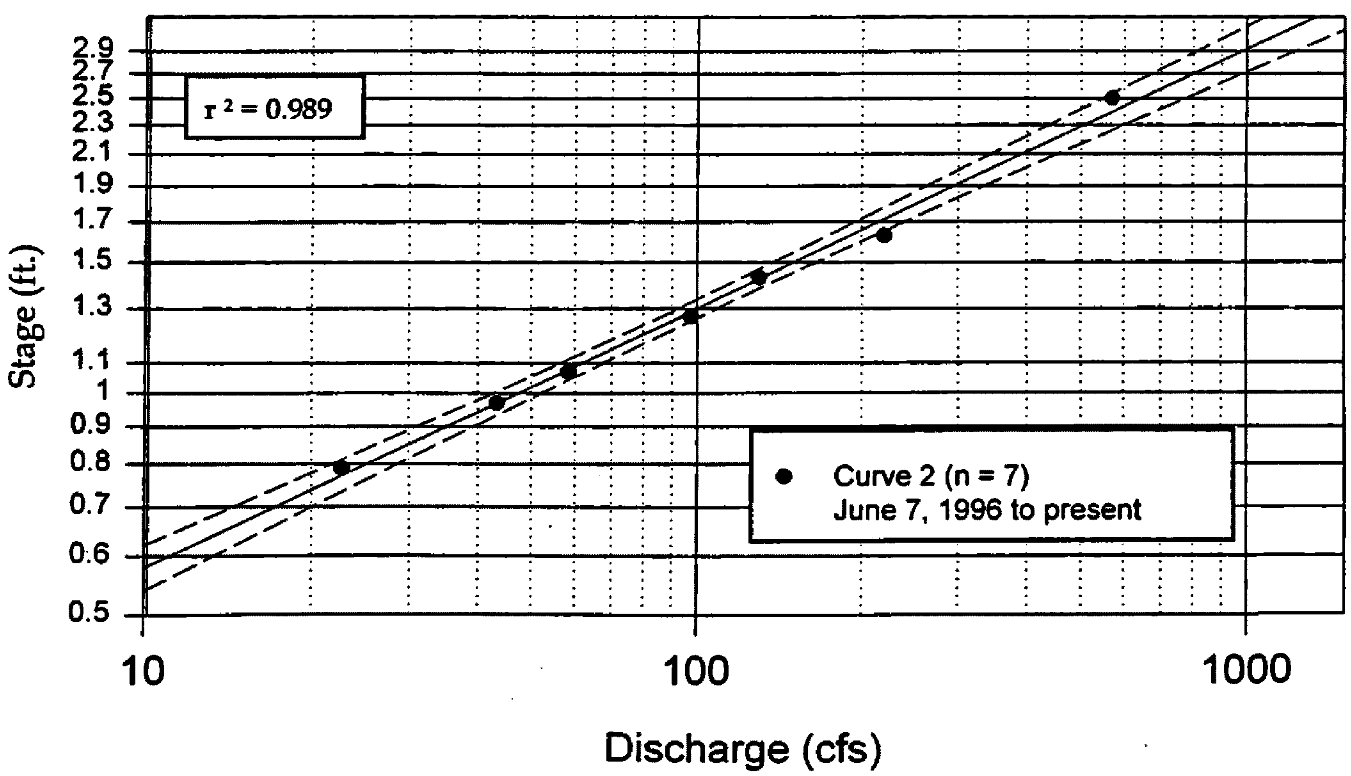
Figure A2. Mean monthly precipitation at Valier, MT (panel A) from 1912 to 1937 and mean monthly precipitation at Dupuyer Creek SNOTEL (panel B) from 1984 to 1995.

Appendix B

Stage rating curves for Stevens type F recorder, located on reach 2 of Dupuyer Creek.

Stage Rating Curves
Dupuyer Creek, TRM Ranch





Appendix C

All channel morphology and classification data for all cross-sections surveyed for this study.

Cross-Section Number	Grazing Season	Mean Depth (ft.)	Width @ Bankfull (ft.)	Maximum Depth (ft.)	Floodprone Depth (ft.)	Floodprone Width (ft.)	Area @ Bankfull (ft.^2)	Width-to-Mean-Depth Ratio	Width-to-Max. Depth Ratio	Entrench.	Water Surface Slope (ft./ft.)	Rosgen Stream Type	Wetted Mean Depth (ft.)	Wetted Width (ft.)	Wetted Cross-Sectional Area (ft.^2)	Wetted Width-to-Mean Depth Ratio	Wetted Max. Depth (ft.)	Wetted Width-to-Max. Depth Ratio
xs1.1	Spring	1.07	48.45	2.40	4.80	140.00	51.80	45.28	20.19	2.89	.008	C4	.62	22.90	14.10	37.19	1.42	16.13
xs1.2	Spring	1.10	55.00	2.30	4.60	132.00	63.00	50.00	23.91	2.40	.008	C4	.60	23.70	14.20	39.56	.90	26.33
xs1.3	Spring	1.35	33.90	3.52	7.04	150.00	45.70	25.11	9.63	4.42	.012	C4	.61	16.70	10.20	27.34	.92	18.15
xs1.4	Spring	.83	66.70	1.35	2.70	98.60	55.20	80.36	49.41	2.89	.008	C4	.26	43.90	11.50	167.58	.64	68.59
xs2.1	Spring	1.21	37.20	1.84	3.68	50.00	45.00	30.74	20.22	1.34	.015	F4	.57	23.80	13.60	41.65	.84	28.33
xs2.2	Spring	1.42	31.40	1.95	3.80	57.00	44.50	22.11	16.10	1.82	.011	B4c	.54	27.40	14.90	50.39	.84	32.62
xs2.3	Spring	1.49	30.90	1.80	3.60	35.00	46.10	20.74	17.17	1.13	.011	F4	.46	29.00	13.30	63.23	.68	42.65
xs2.4	Spring	1.56	29.90	2.10	4.20	200.00	46.60	19.17	14.24	6.69	.011	C4	.48	27.20	13.00	56.91	1.10	24.73
xs2.5	Spring	1.08	65.60	2.78	5.56	200.00	71.10	60.74	23.60	3.05	.009	C4	.46	32.60	15.00	70.85	1.62	20.12
xs3.1	Spring	.95	3.90	1.50	3.00	11.20	4.10	4.11	2.60	2.87	.002	E6	.38	2.40	.90	6.40	.50	4.80
xs3.2	Spring	.95	4.00	.84	1.68	7.00	4.20	4.21	4.76	1.75	.014	E6	.40	3.50	1.40	8.75	.48	7.29
xs3.3	Spring	.62	6.10	.72	1.44	6.80	9.80	9.84	8.47	1.11	.034	G6	.10	5.90	.60	58.02	.18	32.78
xs3.4	Spring	.60	4.50	.82	1.62	4.60	7.50	7.50	5.49	1.02	.016	G6	.24	3.80	.90	16.04	.42	9.05
xs3.5	Spring	.81	4.30	1.13	2.26	6.00	5.30	5.31	3.81	1.40	.018	G6	.36	3.60	1.30	9.97	.60	6.00
xs3.6	Spring	.67	5.40	1.00	2.00	6.50	8.10	8.06	5.40	1.20	.018	G6	.24	3.80	.90	16.04	.40	9.50
xs3.7	Spring	.71	4.90	1.06	2.12	5.60	6.90	6.90	4.62	1.14	.018	G6	.28	2.90	.80	10.51	.42	6.90
xs3.8	Spring	.74	4.70	1.15	2.30	6.10	6.40	6.35	4.09	1.30	.018	G6	.28	3.20	.90	11.38	.50	6.40
xs4.1	Sum	1.75	24.00	2.23	4.45	69.00	42.00	13.71	10.76	2.88	.010	C4	.42	20.60	8.60	49.34	.84	24.52
xs4.2	Sum	1.36	18.10	2.23	4.45	69.00	24.60	13.31	8.12	3.81	.010	C4	1.07	14.00	15.00	13.07	1.80	7.78
xs4.3	Sum	1.23	24.40	1.84	3.68	51.60	30.10	19.84	13.26	2.11	.016	C4	.49	19.60	9.70	39.60	.84	23.33
xs4.4	Sum	1.40	20.10	2.20	4.40	42.40	28.10	14.36	9.14	2.11	.008	C4	.83	16.00	13.20	19.39	1.30	12.31
xs4.5	Sum	1.22	20.00	1.96	3.92	74.00	24.40	16.39	10.20	3.70	.011	C4	.28	10.60	3.00	37.45	.62	17.10
xs4.6	Sum	1.39	26.40	2.43	4.86	90.00	36.80	18.99	10.86	3.41	.013	C4	.79	22.50	17.70	28.60	1.74	12.93
xs5.1	Sum	.72	31.70	1.22	2.44	180.00	22.80	44.03	25.98	n/a	.026	D4	.23	18.00	4.10	79.02	.54	33.33
xs5.2	Sum	.80	22.70	2.40	4.80	200.00	19.30	28.38	9.46	8.81	.025	C4	.93	7.60	7.10	8.14	1.32	5.76
xs5.3	Sum	.68	45.40	1.58	3.16	135.00	30.90	66.76	28.73	2.97	.012	C4	.43	22.30	9.70	51.27	.84	26.55
xs5.4	Sum	.94	17.60	1.46	2.92	37.10	16.50	18.72	12.05	2.11	.014	C4	.40	13.10	5.20	33.00	.70	18.71
xs5.5	Sum	.92	16.80	1.98	4.00	74.00	15.50	18.26	8.48	4.40	.017	C4	.40	12.90	5.10	32.63	.60	21.50
xs5.6	Sum	.80	32.10	1.65	3.80	81.80	27.00	40.13	19.45	n/a	.017	D4	.39	21.50	8.40	55.03	1.10	19.55

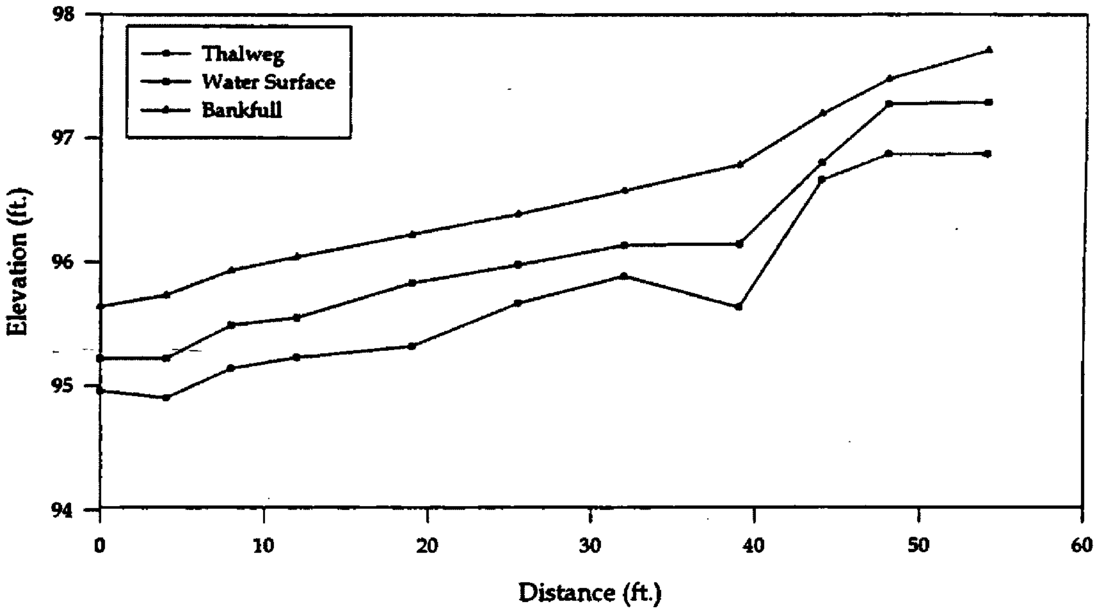
Cross-Section Number	Grazing Season	Mean Depth (ft.)	Width @ Bankfull (ft.)	Maximum Depth (ft.)	Floodprone Depth (ft.)	Floodprone Width (ft.)	Area @ Bankfull (ft.^2)	Width-to-Mean-Depth Ratio	Width-to-Max. Depth Ratio	Entrench.	Water Surface Slope (ft./ft.)	Rosgen Stream Type	Wetted Mean Depth (ft.)	Wetted Width (ft.)	Wetted Cross-Sectional Area (ft.^2)	Wetted Width-to-Mean Depth Ratio	Wetted Max. Depth (ft.)	Wetted Width-to-Max. Depth Ratio
xs5.7	Sum	1.21	21.20	2.40	4.80	120.00	17.50	17.52	8.83	5.66	.017	C4	.52	10.20	5.30	19.63	.88	11.59
xs6.3	Winter	.81	22.10	1.88	3.76	157.00	17.80	27.28	11.76	7.10	.015	C4	.76	9.70	7.40	12.71	1.28	7.58
xs6.4	Winter	.66	22.50	1.72	3.44	150.00	18.20	34.09	13.08	6.67	.014	C4	.33	6.40	2.10	19.50	.66	9.70
xs6.5	Winter	.63	37.80	1.91	3.82	200.00	23.80	60.00	19.79	5.29	.014	C4	.36	5.50	2.00	15.13	.70	7.86
xs6.1	Sum	.99	28.40	2.18	4.38	107.10	28.20	28.69	13.03	3.77	.010	C4	.66	15.50	10.30	23.33	1.34	11.57
xs6.2	Sum	1.26	18.90	1.72	3.46	145.10	23.90	15.00	10.99	7.68	.014	C4	.57	15.50	8.80	27.30	.88	17.61
xs7.1	Sum	1.45	31.00	2.18	4.34	140.00	45.00	21.38	14.22	4.52	.007	C4	.48	22.30	10.60	46.91	.86	25.93
xs7.2	Sum	1.40	29.50	2.10	4.20	148.00	41.30	21.07	14.05	5.02	.007	C4	.46	17.60	8.10	38.24	.82	21.46
xs7.3	Sum	2.02	26.10	2.80	5.60	135.00	52.70	12.92	9.32	5.17	.006	C4	.68	19.80	13.40	29.26	1.08	18.33
xs7.4	Sum	1.65	28.50	2.16	4.32	66.00	47.00	17.27	13.19	2.32	.006	C4	.36	18.10	6.60	49.64	.62	29.19
xs7.5	Sum	1.20	44.60	2.44	4.88	200.40	53.50	37.17	18.28	4.49	.016	C4	.46	29.00	13.20	63.71	1.38	21.01
xs8.1	Sum	1.10	18.00	2.02	4.04	48.00	20.00	16.36	8.91	2.67	.013	B4c	.61	9.70	5.90	15.95	.96	10.10
xs8.2	Sum	.92	23.80	1.87	3.74	37.30	22.00	25.87	12.73	1.57	.010	B4c	.48	11.70	5.60	24.44	.86	13.60
xs9.1	Spring	.65	99.70	2.94	5.92	180.00	65.10	153.38	33.91	n/a	.007	D4	.58	11.40	6.60	19.69	1.24	9.19
xs9.2	Spring	.65	96.10	2.02	4.04	300.00	62.50	147.85	47.57	n/a	.011	D4	.43	14.70	6.30	34.30	.66	22.27
xs9.3	Spring	1.67	21.00	2.50	5.00	28.60	35.00	12.57	8.40	1.36	.010	G4c	.69	18.10	12.40	26.42	1.50	12.07
xs10.1	Spring	1.36	38.10	2.64	5.28	250.00	52.00	28.01	14.43	6.56	.009	C4	.70	19.30	13.60	27.39	1.32	14.62
xs10.2	Spring	1.00	49.10	2.28	4.56	67.00	49.10	49.10	21.54	1.82	.008	B4c	.68	18.50	12.60	27.16	1.08	17.13
xs11.1	Sum	.60	164.70	1.45	3.00	400.00	98.00	274.50	113.59	n/a	.013	D4	.32	79.40	25.10	251.17	.85	93.41
xs11.2	Sum	.51	148.30	1.14	2.28	400.00	75.30	290.78	130.09	n/a	.010	D4	.27	74.40	20.30	272.68	.70	106.29
xs12.1	Spring	1.21	37.20	1.84	3.68	50.00	45.00	30.74	20.22	1.34	.015	C4	.34	28.90	9.80	85.23	.74	39.05
xs12.2	Spring	1.92	21.90	2.68	6.70	30.00	42.10	11.41	8.17	1.37	.010	C4	.79	18.30	14.50	23.10	1.32	13.86
xs13.1	Spring	.40	3.50	.94	1.88	20.00	1.60	8.75	3.72	5.71	.004	E6	.46	3.50	1.60	7.66	.94	3.72
xs13.4	Sum	.25	6.70	.52	1.04	10.80	1.70	26.80	12.88	1.61	.030	B6	1.00	1.10	1.10	1.10	3.00	.37
xs13.2	None	.74	1.90	1.50	3.00	23.00	1.40	2.57	1.27	12.11	.004	E6	.10	.60	.06	6.00	1.26	.48
xs13.3	None	.47	1.50	.54	1.08	4.80	.70	3.19	2.78	3.20	.040	E6b	NA	NA	NA	NA	NA	NA
xs14.1	Sum	.41	15.00	.82	1.64	18.90	6.20	36.59	18.29	1.26	.019	D4	.14	6.60	.90	48.40	.38	17.37
xs14.2	Sum	.72	7.50	1.48	2.96	21.30	5.40	10.42	5.07	2.84	.019	B4	.56	4.10	2.30	7.31	.94	4.36
xs14.3	Sum	.62	7.30	.90	1.80	20.00	4.50	11.77	8.11	2.74	.019	E4b	.13	4.60	.60	35.27	.22	20.91

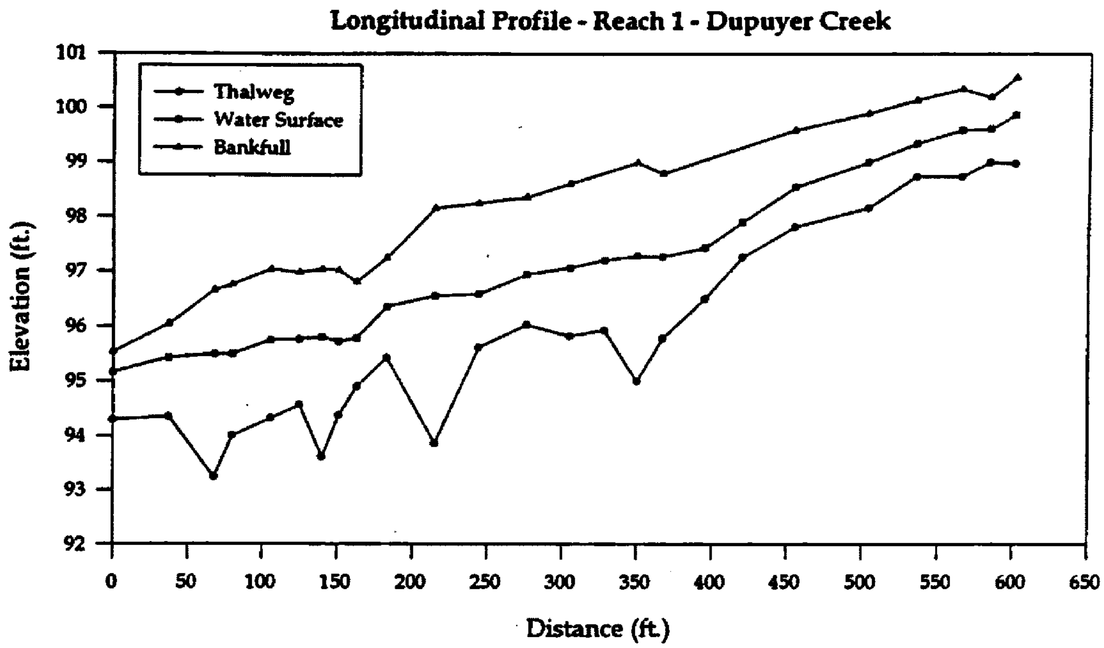
Cross-Section Number	Grazing Season	Mean Depth (ft.)	Width @ Bankfull (ft.)	Maximum Depth (ft.)	Floodprone Depth (ft.)	Floodprone Width (ft.)	Area @ Bankfull (ft.^2)	Width-to-Mean-Depth Ratio	Width-to-Max. Depth Ratio	Entrench.	Water Surface Slope (ft./ft.)	Rosgen Stream Type	Wetted Mean Depth (ft.)	Wetted Width (ft.)	Wetted Cross-Sectional Area (ft.^2)	Wetted Width-to-Mean Depth Ratio	Wetted Max. Depth (ft.)	Wetted Width-to-Max. Depth Ratio
xs15.1	Spring	1.14	61.60	3.10	6.20	110.00	70.20	54.04	19.87	1.79	.008	D4	.97	30.20	29.30	31.13	2.28	13.25
xs15.2	Spring	.93	97.40	2.06	4.12	103.40	90.50	104.73	47.28	1.06	.011	D4	.22	33.90	7.60	151.21	.78	43.46
xs15.3	Spring	1.49	37.30	2.54	5.08	85.50	55.60	25.03	14.69	2.30	.011	C4	.62	22.20	13.80	35.71	1.16	19.14
xs16.1	None	1.38	38.50	2.24	4.48	63.80	53.30	27.90	17.19	1.66	.013	F4	.72	31.10	22.40	43.18	1.40	22.21
xs16.2	None	2.60	43.00	5.92	11.84	70.00	111.90	16.54	7.26	1.63	.013	F4	2.47	29.30	72.50	11.84	4.76	6.16
xs16.3	None	1.15	46.60	2.06	4.12	96.00	53.70	40.52	22.62	2.06	.018	D4	.39	25.70	10.00	66.05	.82	31.34
xs17.1	None	.73	3.00	1.18	2.36	20.00	2.20	4.11	2.54	6.67	.038	E4b	.33	2.40	.80	7.20	.64	3.75
xs17.2	None	.80	6.10	.90	1.80	20.00	4.90	7.63	6.78	3.28	.001	E4b	.43	5.40	2.30	12.68	.70	7.71
xs18.1	Sum	.82	3.30	1.00	2.00	16.50	2.70	4.02	3.30	5.00	.026	E4B	NA	NA	NA	NA	NA	NA
xs18.2	Sum	.32	7.00	.60	1.20	31.00	2.24	21.88	11.67	4.40	.014	C4	NA	NA	NA	NA	NA	NA
xs19.1	Spring	.54	4.00	.94	1.90	30.00	2.40	7.41	4.26	7.50	.011	E6	.33	2.70	.90	8.10	.50	5.40
xs19.2	None	.67	2.40	.88	1.90	8.50	1.60	3.58	2.73	3.50	.008	E6	.20	2.00	.40	10.00	.36	5.56
xs19.3	None	.55	3.30	.88	1.76	25.00	1.80	6.00	3.75	7.60	.002	E6	.17	2.30	.40	13.22	.34	6.76
xs20.1	Sum	1.00	17.20	1.60	3.20	41.50	22.60	17.20	10.75	2.41	.022	C4	NA	NA	NA	NA	NA	NA
xs20.2	Sum	1.13	20.00	1.70	3.40	90.00	22.60	17.70	11.76	4.50	.012	C4	NA	NA	NA	NA	NA	NA
xs21.1	None	.73	2.40	1.00	2.00	16.00	1.80	3.29	2.40	6.67	.010	C4	NA	NA	NA	NA	NA	NA

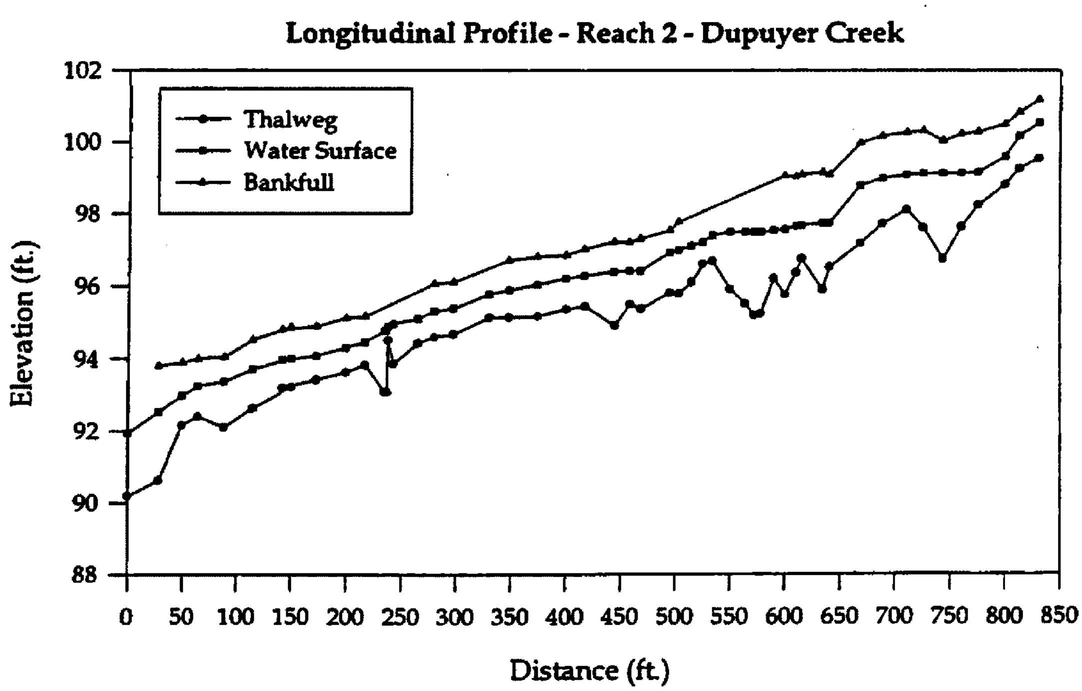
Appendix D

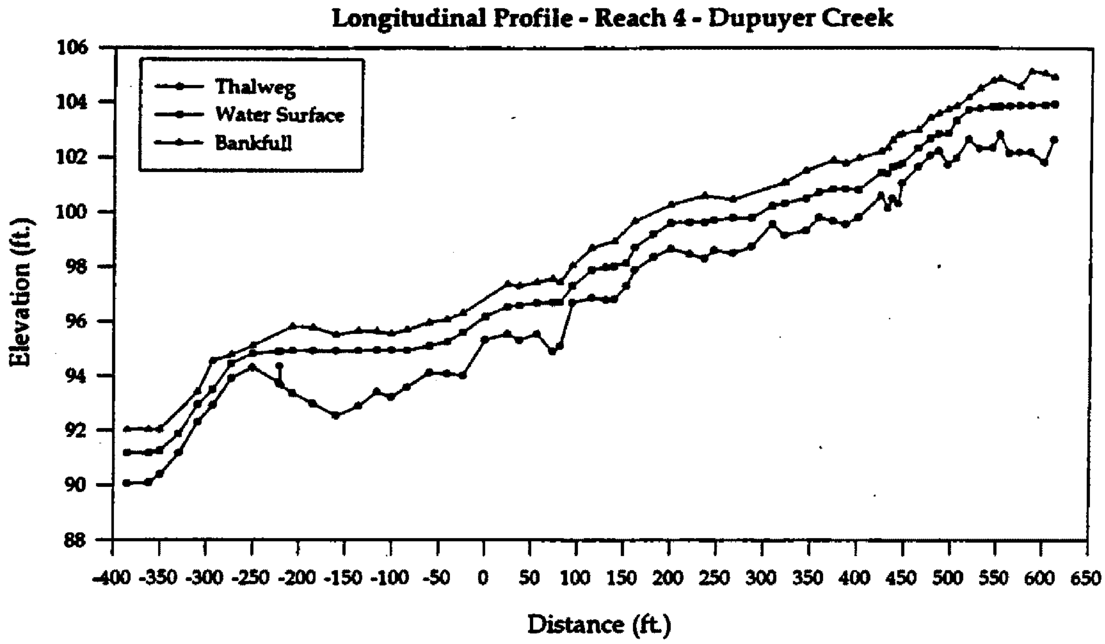
Longitudinal profiles for reference reaches (refer to figure 3 for general location) on TRM Ranch.

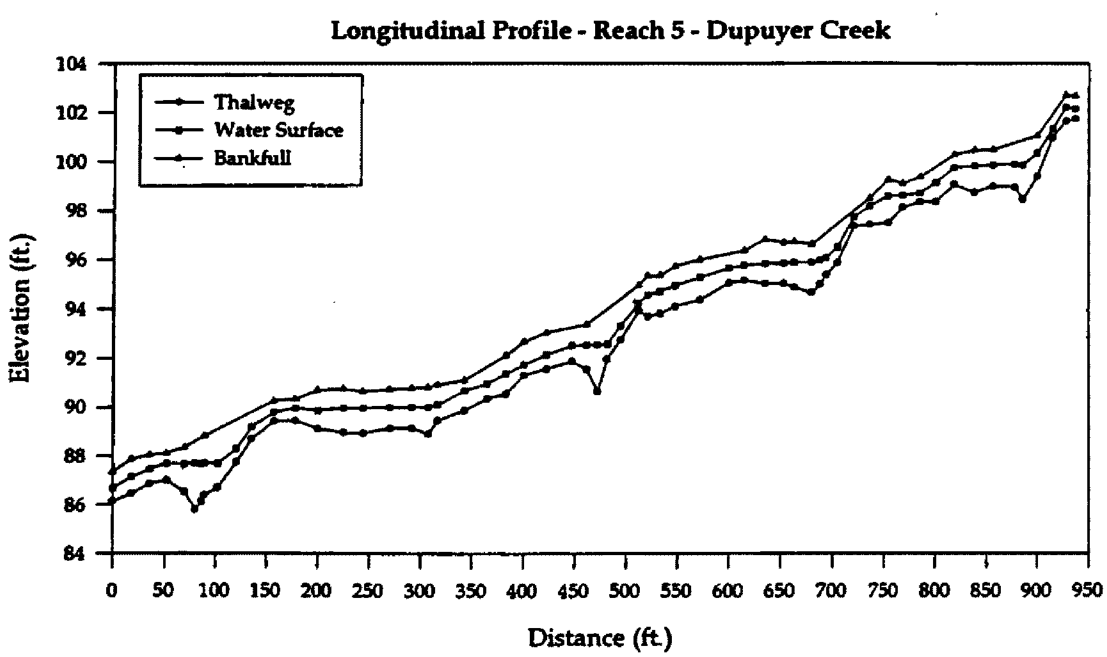
Longitudinal Profile - Reach 17 - M. F. Dupuyer Creek

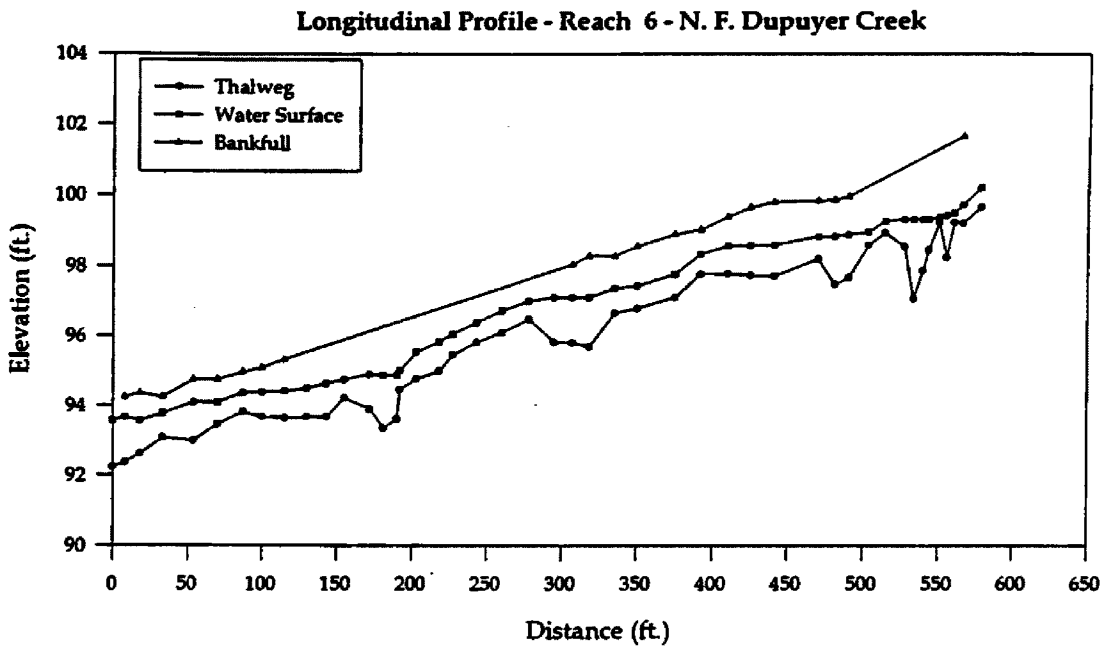


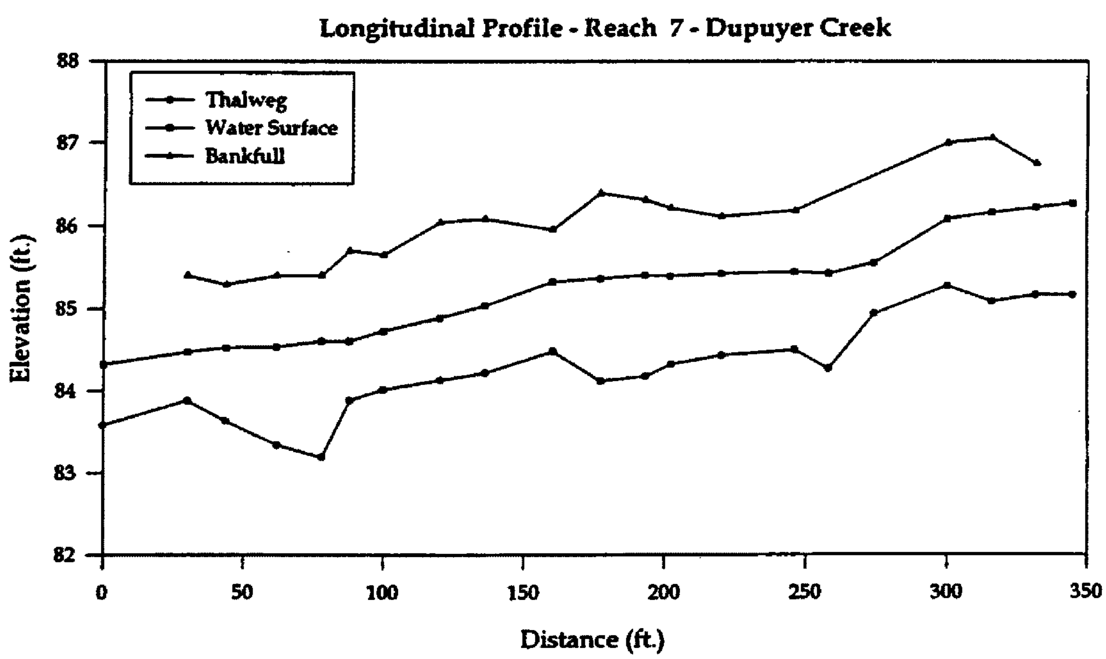

Longitudinal Profile - Reach 1 - Dupuyer Creek
Thalweg
Water Surface
Bankfull
Elevation (ft.)
Distance (ft.)
101
100
99
98
97
96
95
94
93
92
0
50
100
150
200
250
300
350
400
450
500
550
600
650

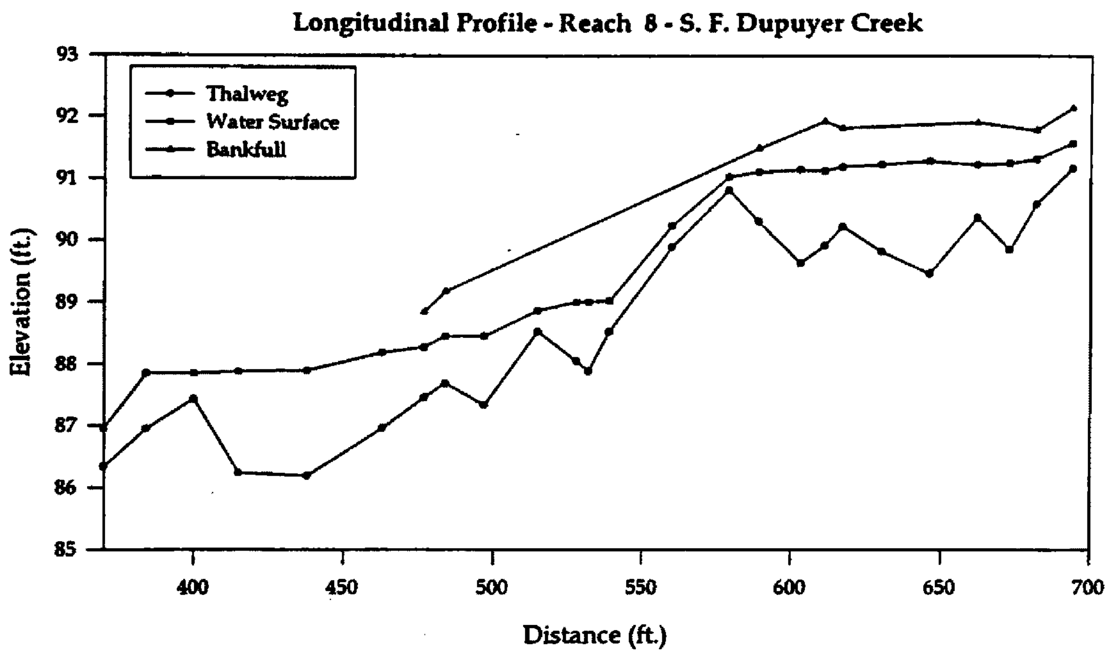

Longitudinal Profile - Reach 2 - Dupuyer Creek
Thalweg
Water Surface
Bankfull
Elevation (ft.)
Distance (ft.)
102
100
98
96
94
92
90
88
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850

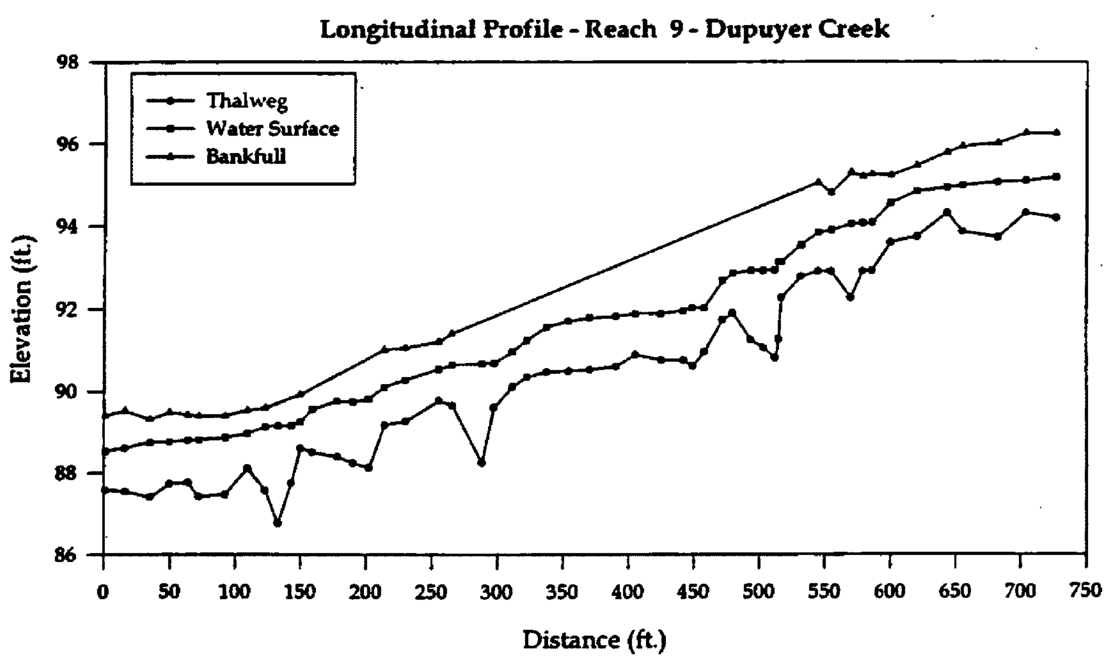

Longitudinal Profile - Reach 4 - Dupuyer Creek
Thalweg
Water Surface
Bankfull
Elevation (ft.)
Distance (ft.)
106
104
102
100
98
96
94
92
90
88
-400 -350 -300 -250 -200 -150 -100 -50 0 50 100 150 200 250 300 350 400 450 500 550 600 650

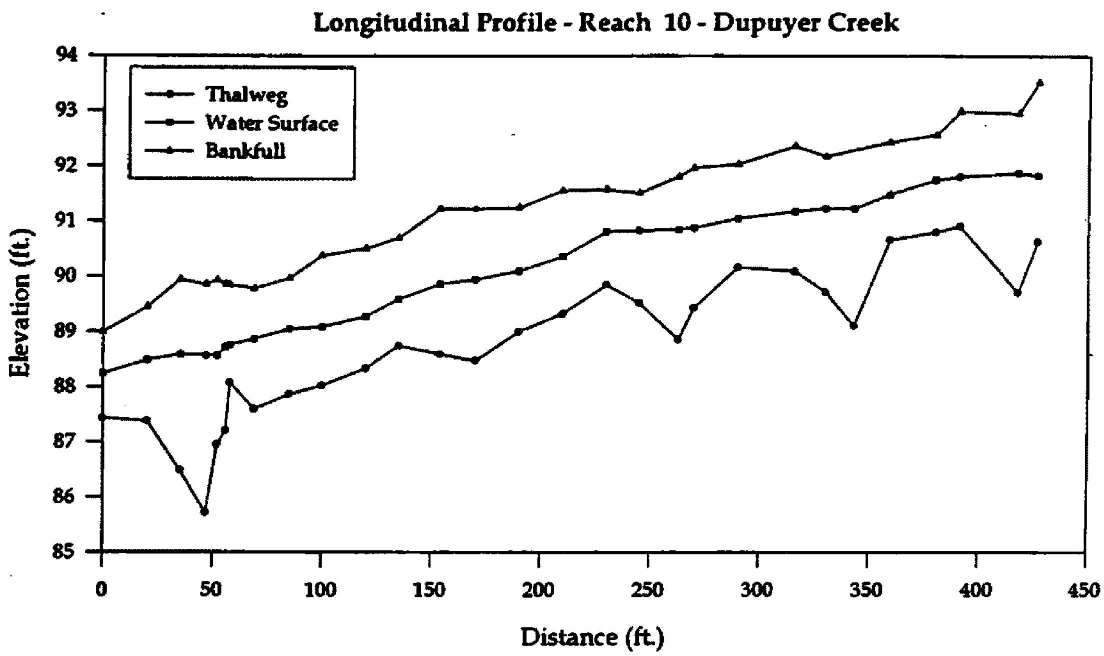

Longitudinal Profile - Reach 5 - Dupuyer Creek
Thalweg
Water Surface
Bankfull
Elevation (ft.)
Distance (ft.)
104
102
100
98
96
94
92
90
88
86
84
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950

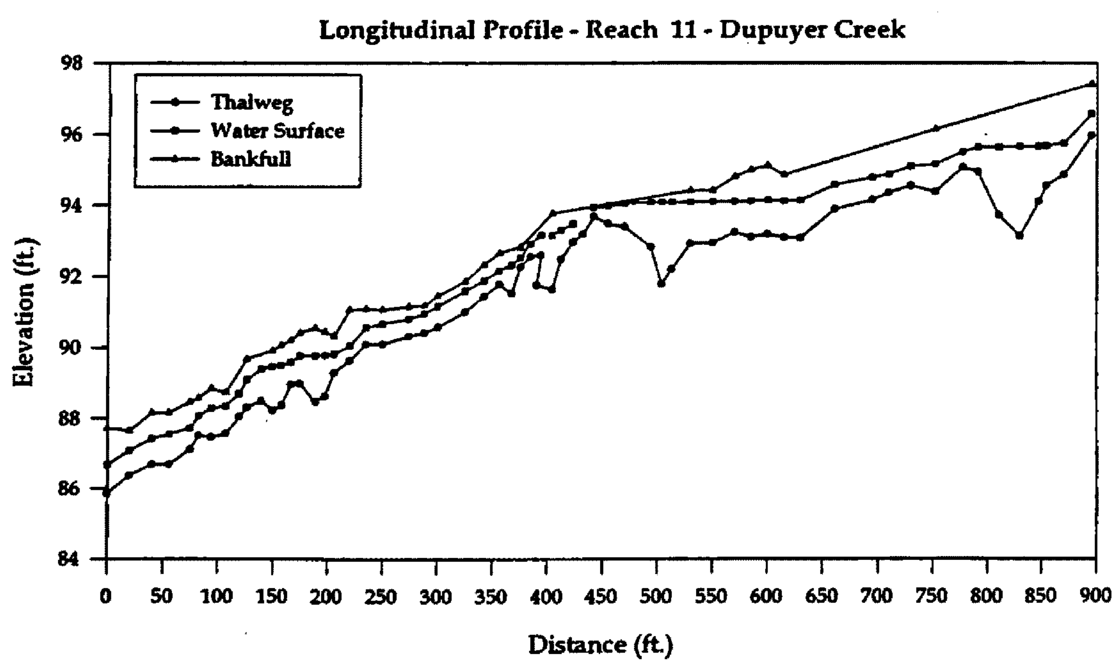

Longitudinal Profile - Reach 6 - N. F. Dupuyer Creek
Thalweg
Water Surface
Bankfull
Elevation (ft.)
104
102
100
98
96
94
92
90
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance (ft.)

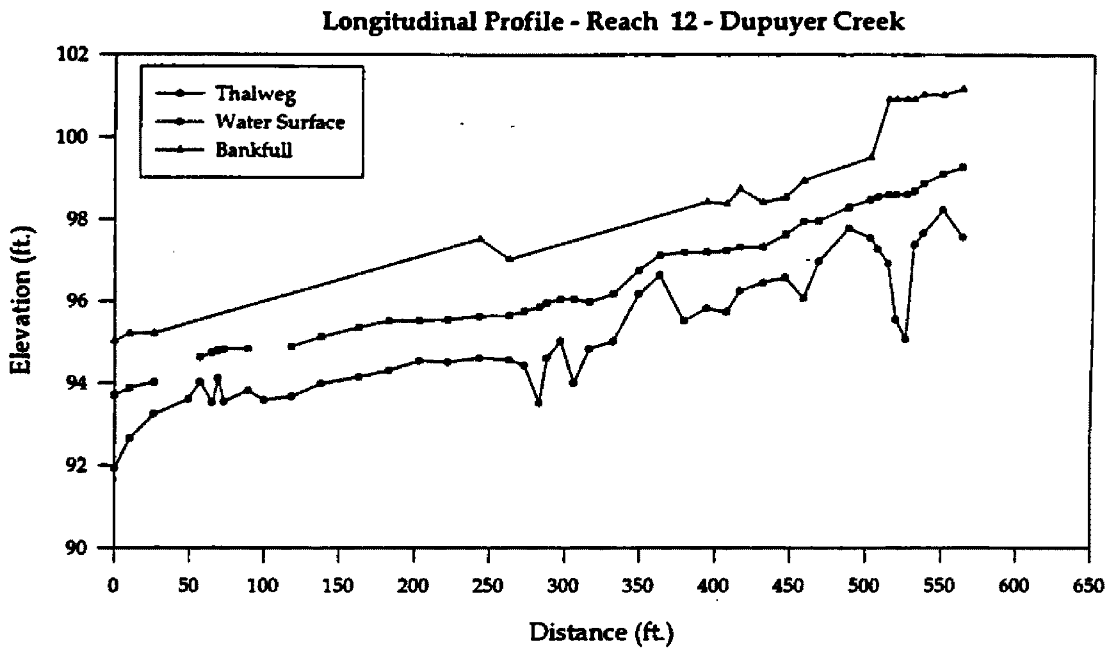

Longitudinal Profile - Reach 7 - Dupuyer Creek
Thalweg
Water Surface
Bankfull
Elevation (ft.)
88
87
86
85
84
83
82
0
50
100
150
200
250
300
350
Distance (ft.)

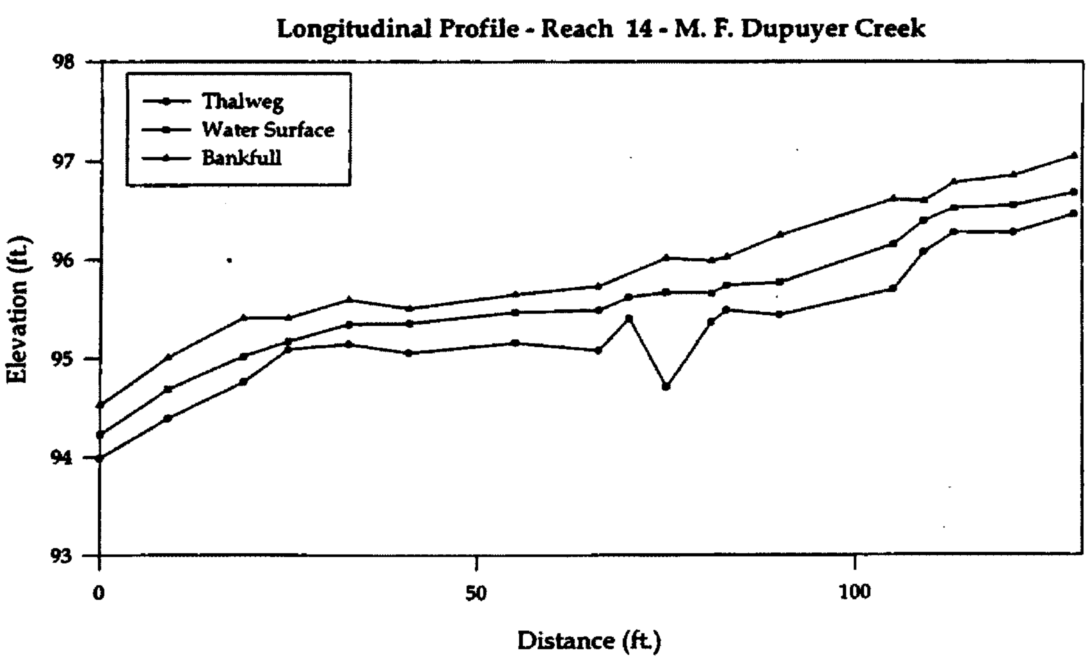

Longitudinal Profile - Reach 8 - S. F. Dupuyer Creek
Thalweg
Water Surface
Bankfull
Elevation (ft.)
93
92
91
90
89
88
87
86
85
400
450
500
550
600
650
700
Distance (ft.)

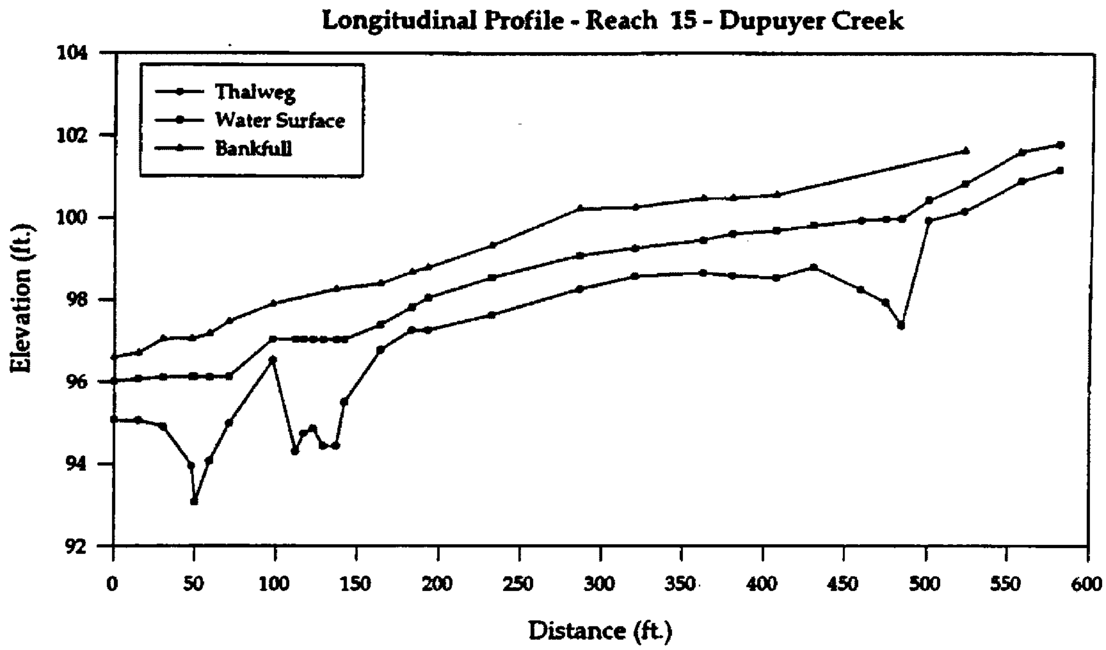

Longitudinal Profile - Reach 9 - Dupuyer Creek
Thalweg
Water Surface
Bankfull
Elevation (ft.)
98
96
94
92
90
88
86
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Distance (ft.)

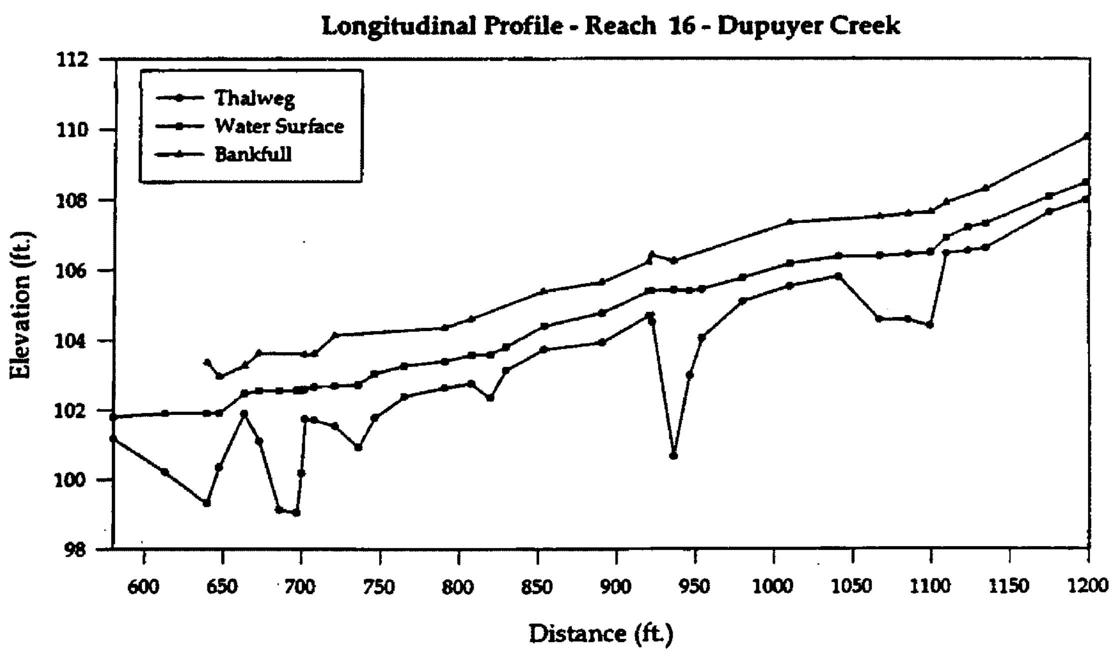

Longitudinal Profile - Reach 10 - Dupuyer Creek
Thalweg
Water Surface
Bankfull
Elevation (ft.)
Distance (ft.)
94
93
92
91
90
89
88
87
86
85
0
50
100
150
200
250
300
350
400
450


Longitudinal Profile - Reach 11 - Dupuyer Creek
Thalweg
Water Surface
Bankfull
Elevation (ft.)
Distance (ft.)
98
96
94
92
90
88
86
84
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900


Longitudinal Profile - Reach 12 - Dupuyer Creek
Thalweg
Water Surface
Bankfull
Elevation (ft.)
102
100
98
96
94
92
90
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance (ft.)


Longitudinal Profile - Reach 14 - M. F. Dupuyer Creek
Thalweg
Water Surface
Bankfull
Elevation (ft.)
98
97
96
95
94
93
0
50
100
Distance (ft.)

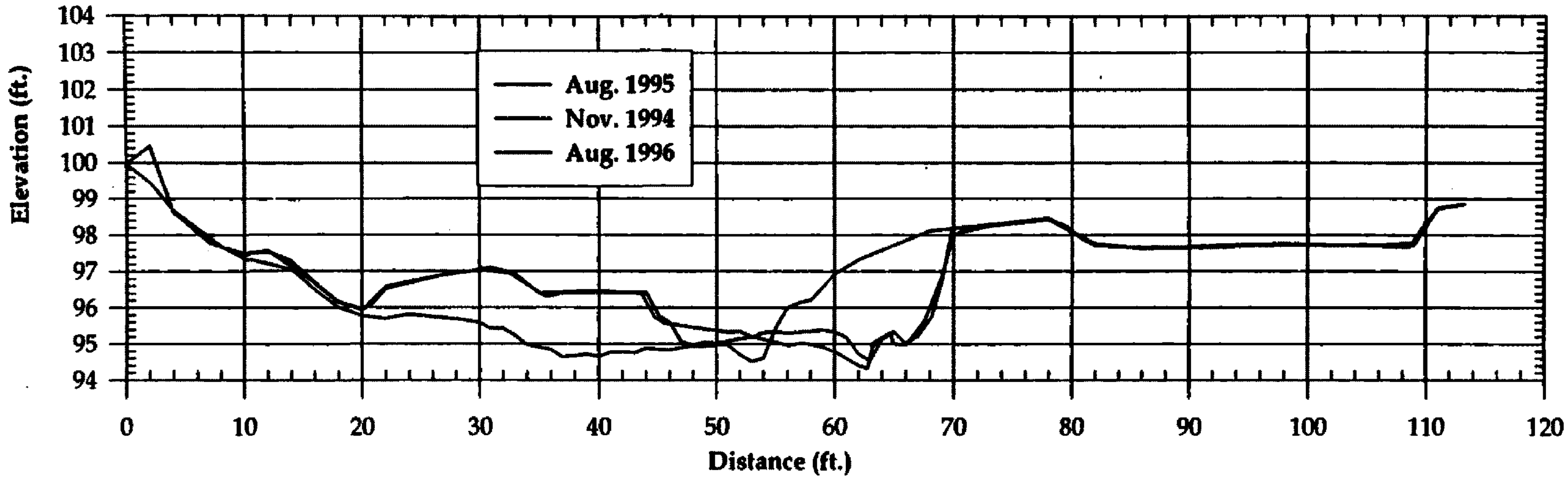

Longitudinal Profile - Reach 15 - Dupuyer Creek
Thalweg
Water Surface
Bankfull
Elevation (ft.)
104
102
100
98
96
94
92
0
50
100
150
200
250
300
350
400
450
500
550
600
Distance (ft.)


Longitudinal Profile - Reach 16 - Dupuyer Creek
Thalweg
Water Surface
Bankfull
Elevation (ft.)
112
110
108
106
104
102
100
98
600
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
Distance (ft.)

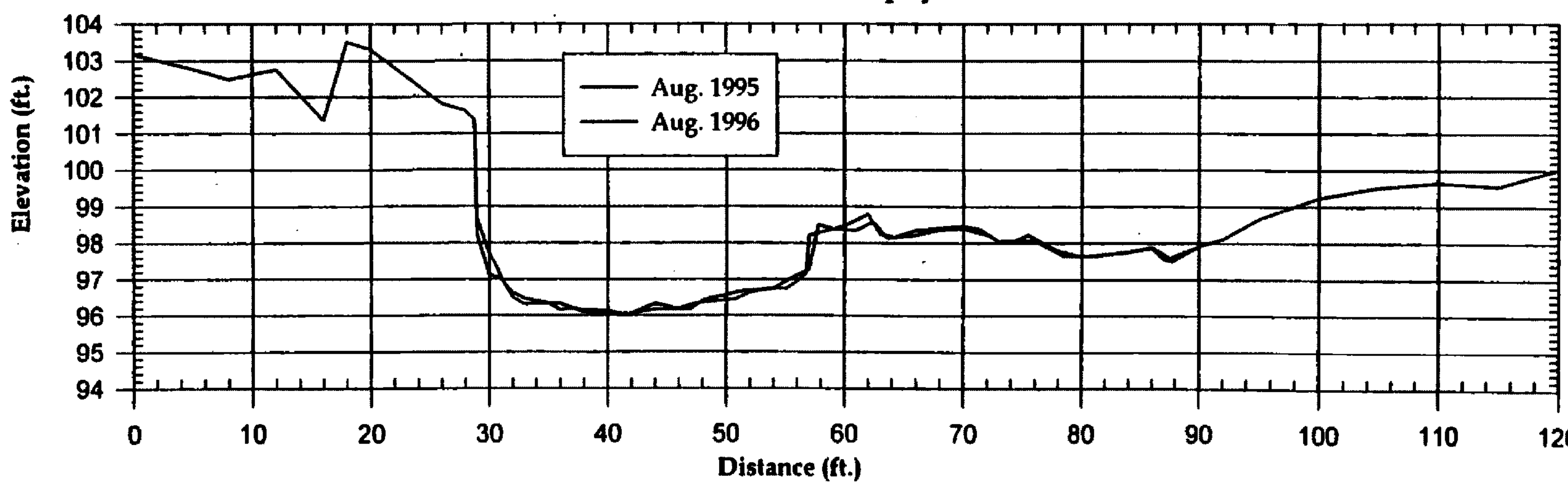
Appendix E

All cross-sections surveyed on TRM Ranch and adjacent National Forest.

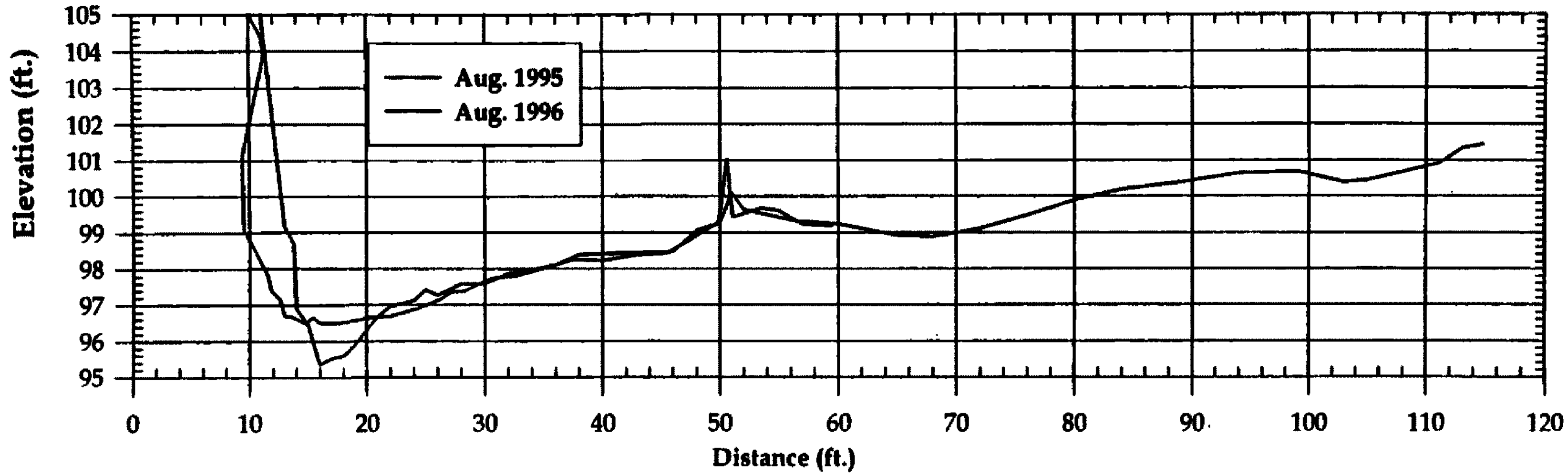
Cross-Section 1.1 - Dupuyer Creek



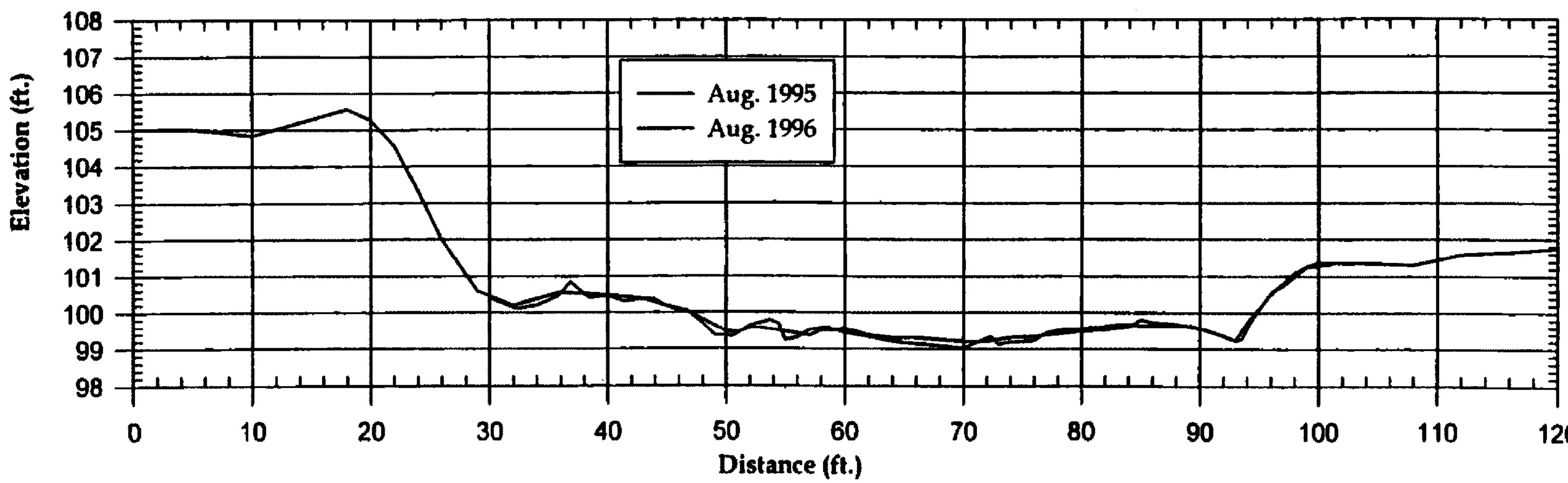
Cross-Section 1.2 - Dupuyer Creek



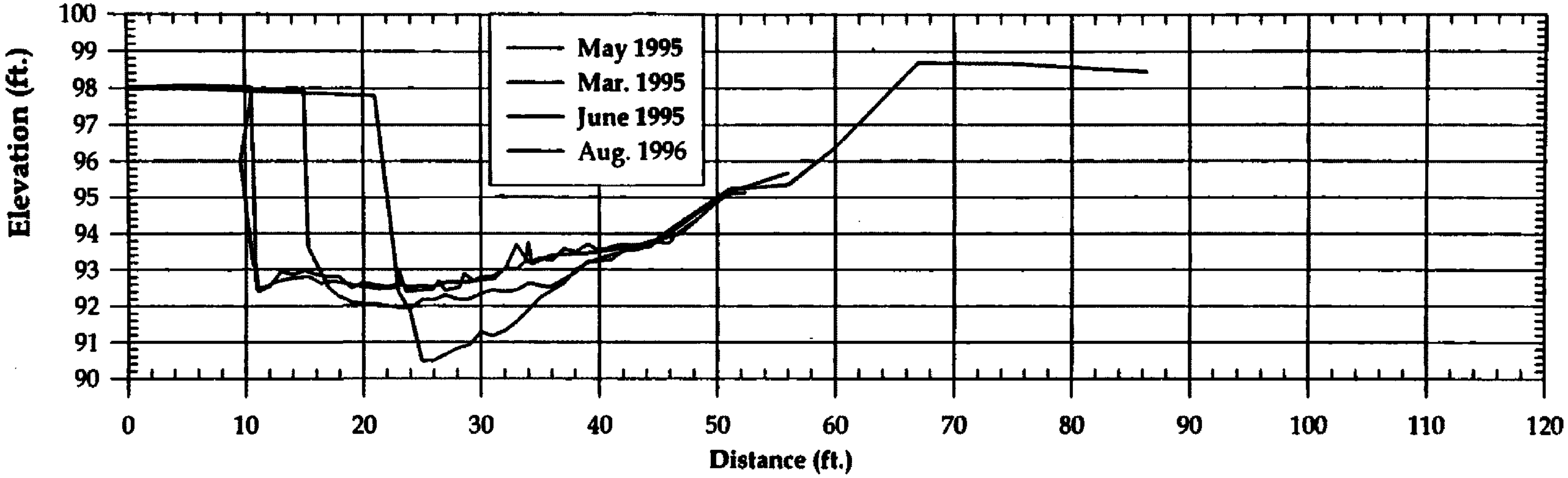
Cross-Section 1.3 - Dupuyer Creek



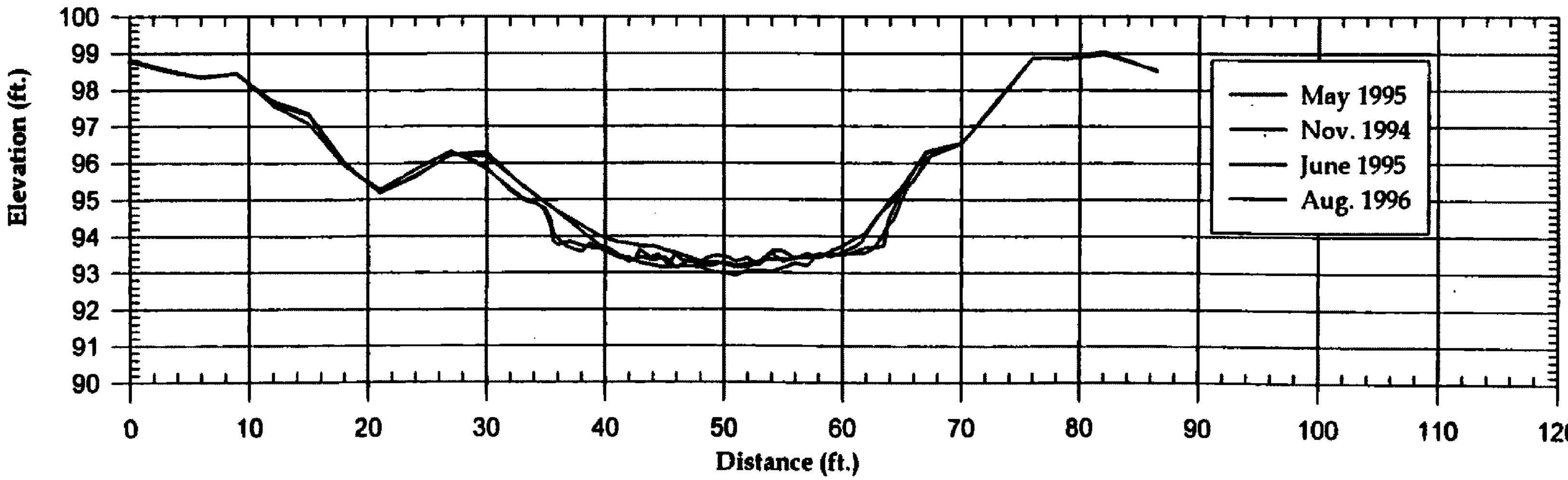
Cross-Section 1.4 - Dupuyer Creek



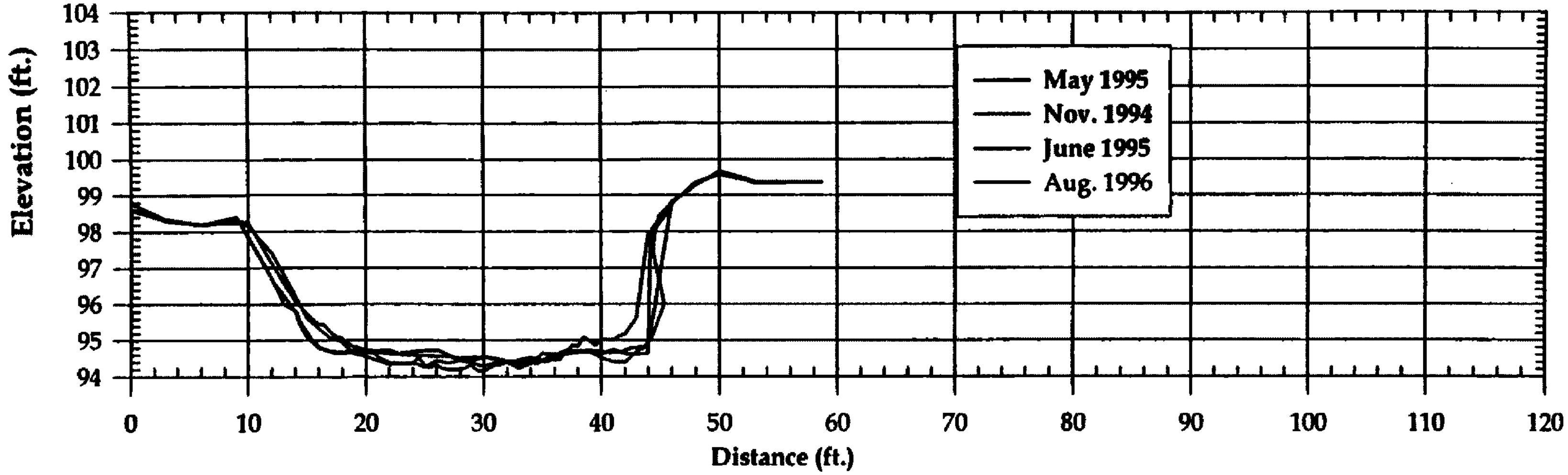
Cross-Section 2.1 - Dupuyer Creek



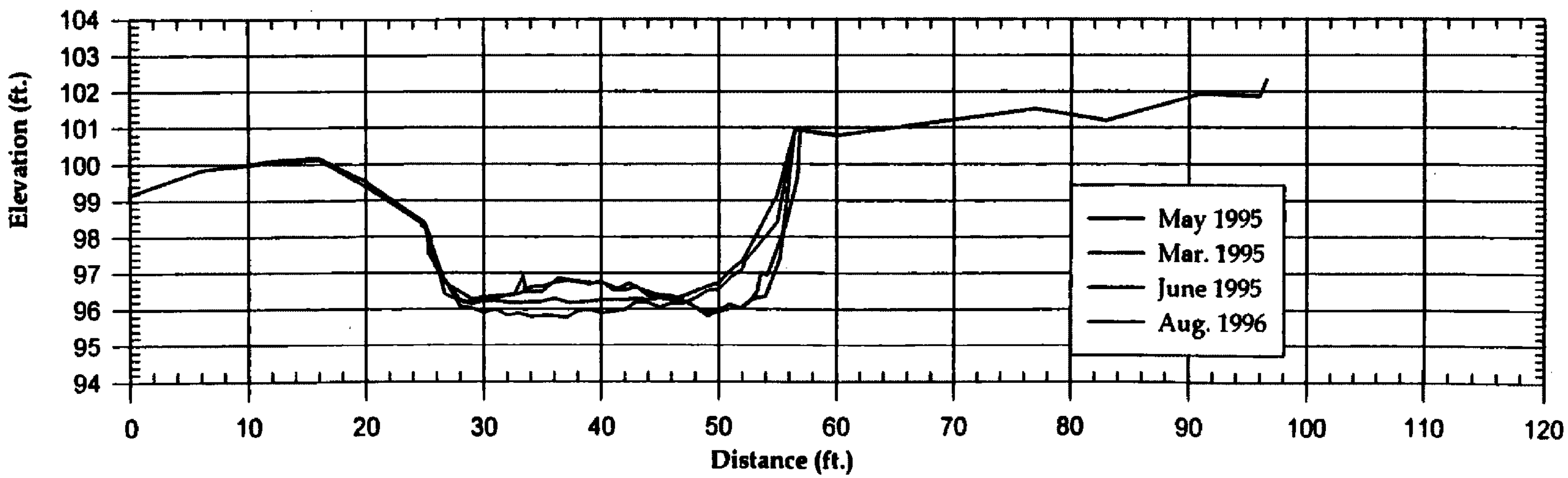
Cross-Section 2.2 - Dupuyer Creek



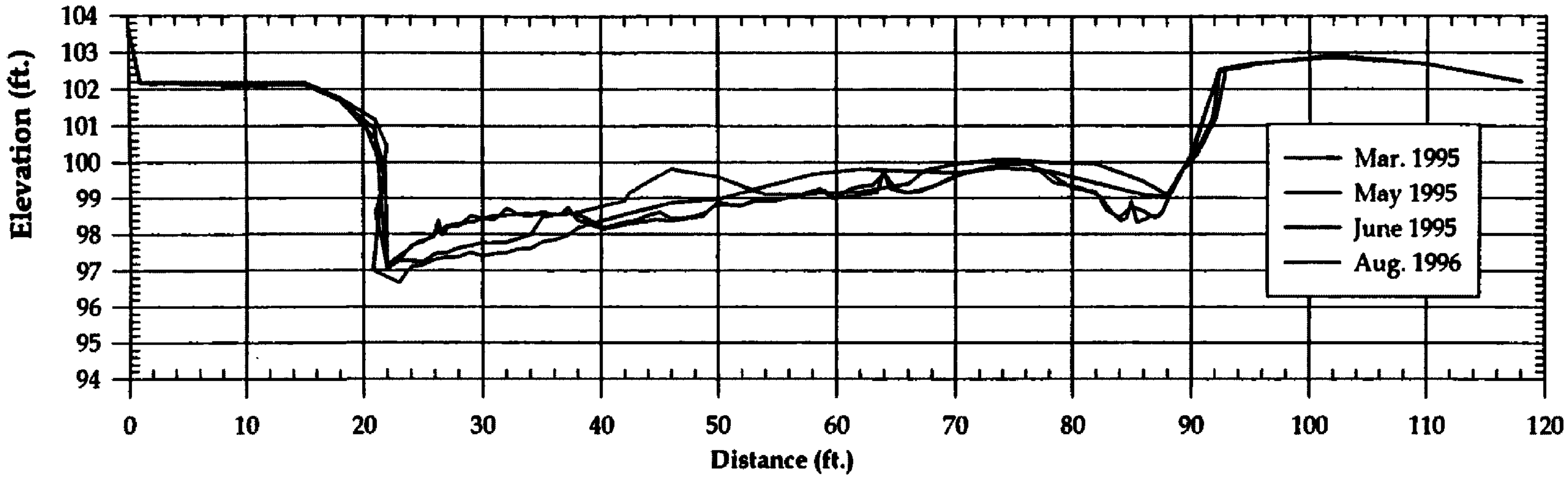
Cross-Section 2.3 - Dupuyer Creek



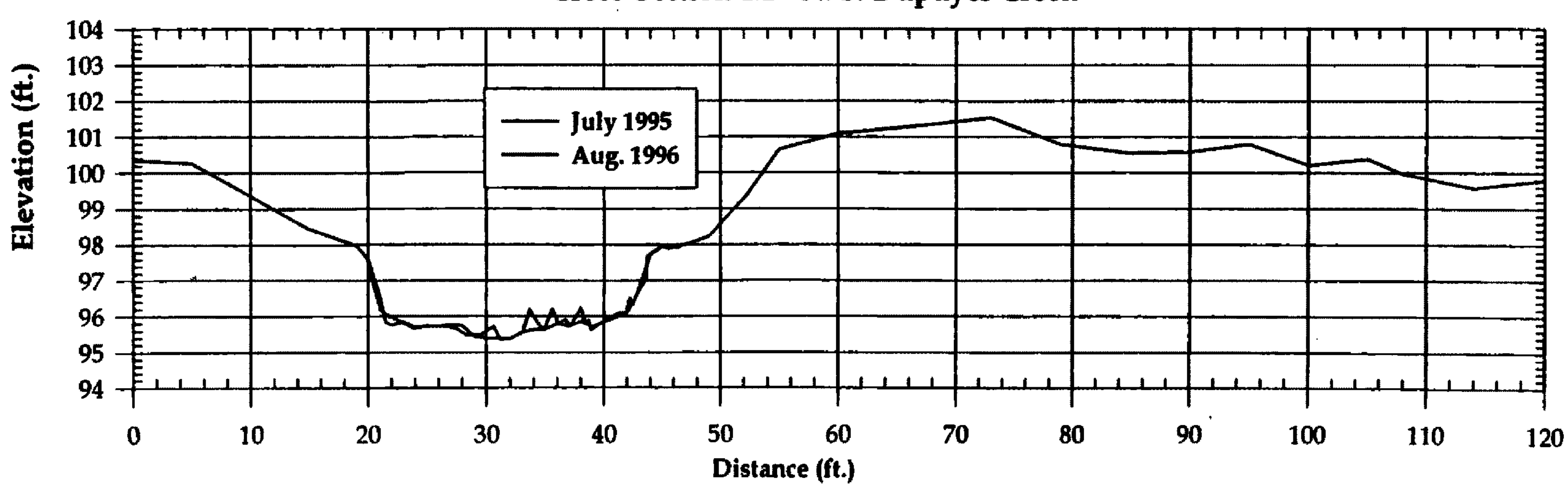
Cross-Section 2.4 - Dupuyer Creek

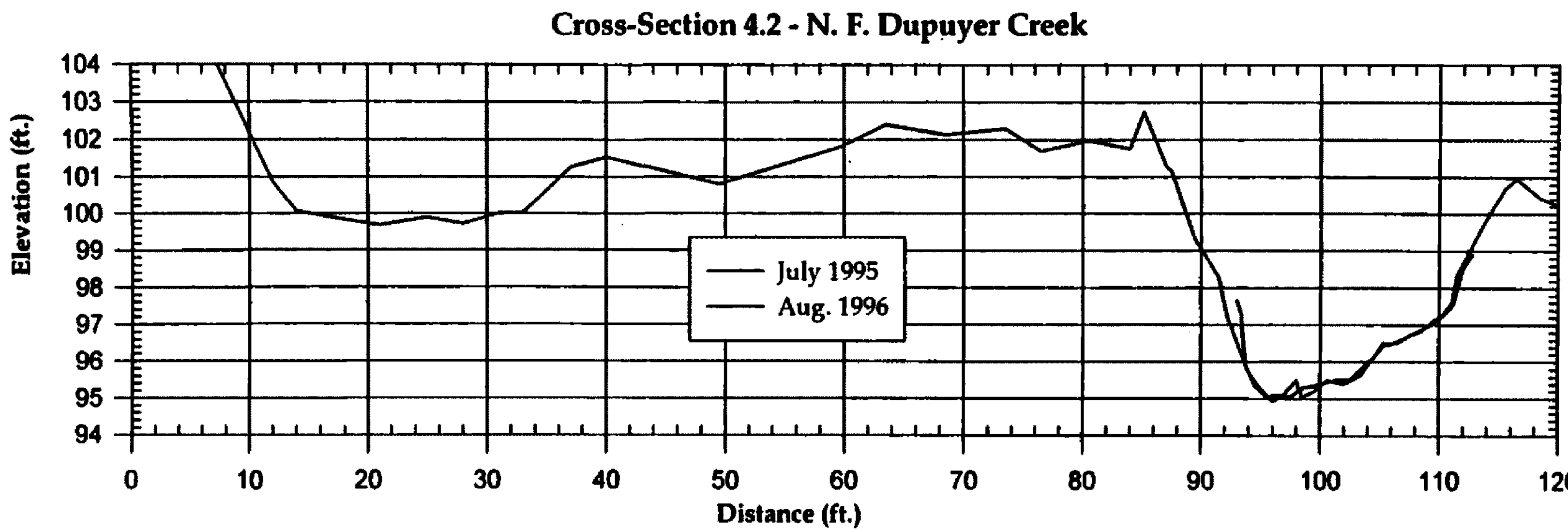


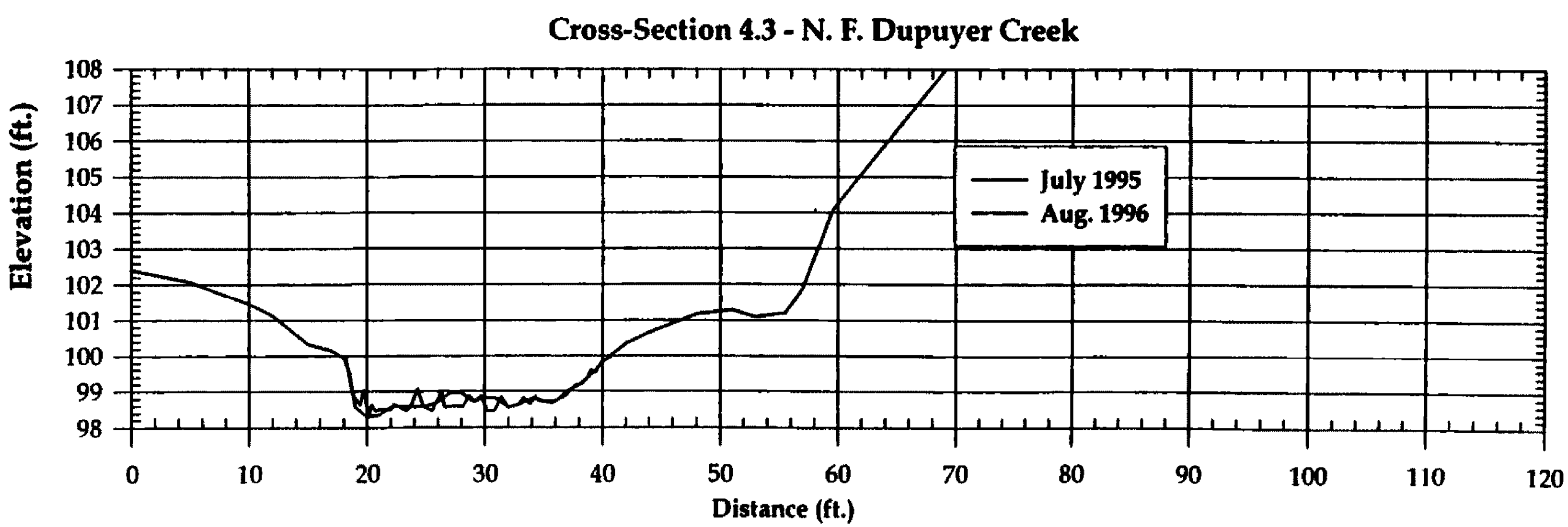
Cross-Section 2.5 - Dupuyer Creek



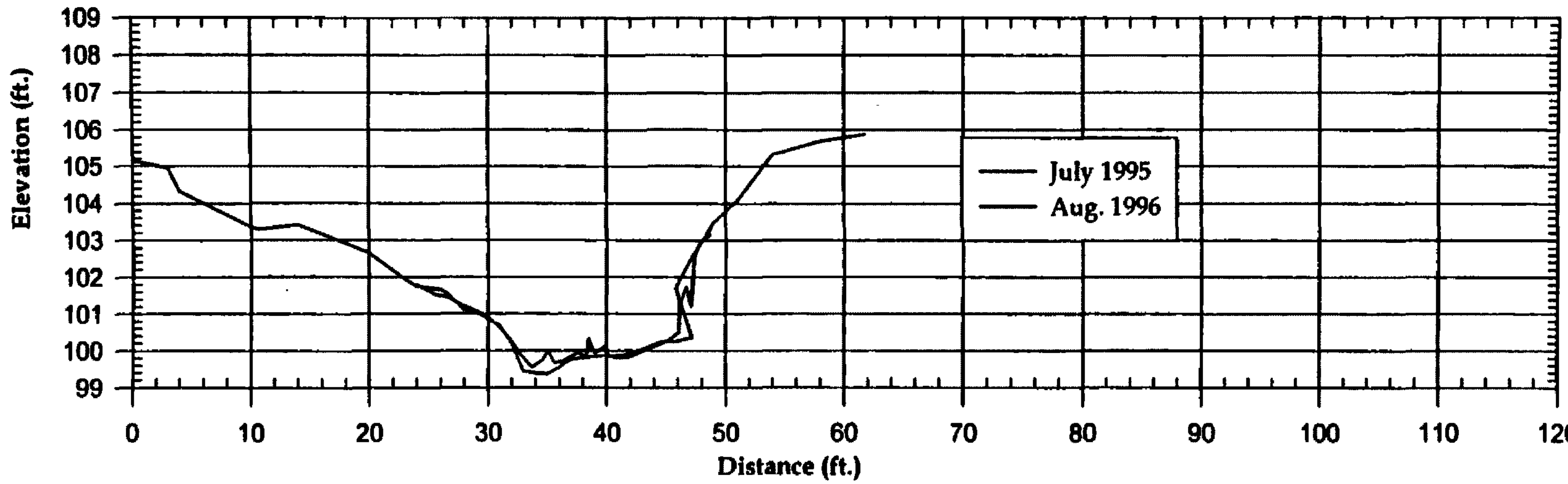
Cross-Section 4.1 - N. F. Dupuyer Creek



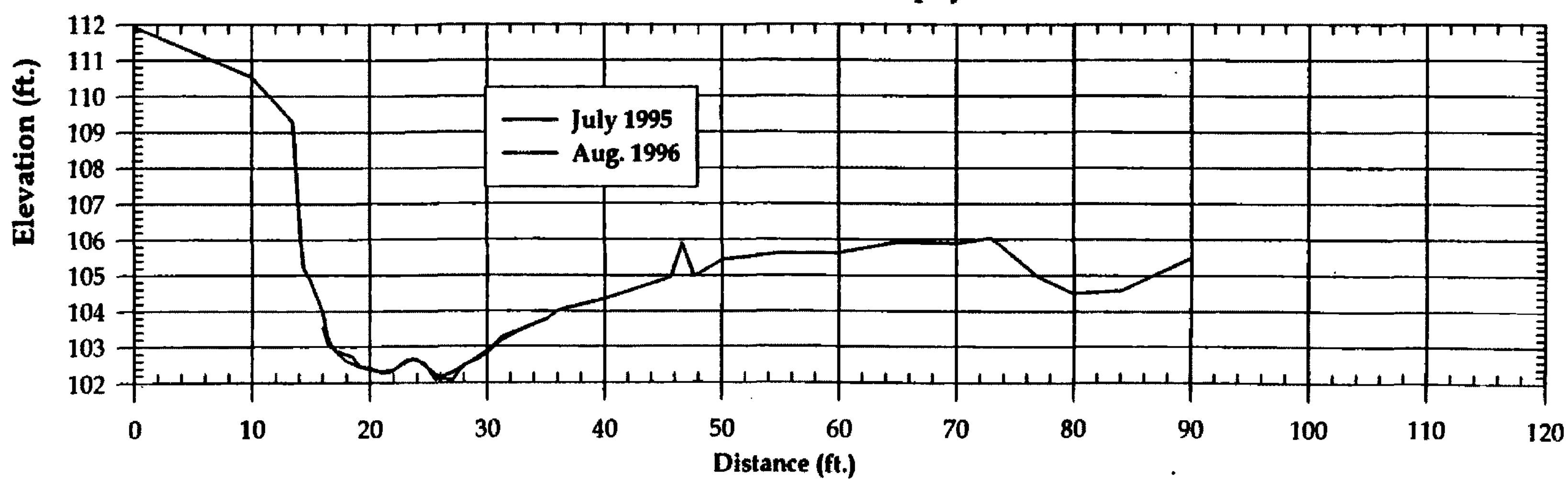

Cross-Section 4.2 - N. F. Dupuyer Creek
Elevation (ft.)
Distance (ft.)
July 1995
Aug. 1996
104
103
102
101
100
99
98
97
96
95
94
0
10
20
30
40
50
60
70
80
90
100
110
120


Cross-Section 4.3 - N. F. Dupuyer Creek
Elevation (ft.)
Distance (ft.)
July 1995
Aug. 1996
108
107
106
105
104
103
102
101
100
99
98
0
10
20
30
40
50
60
70
80
90
100
110
120

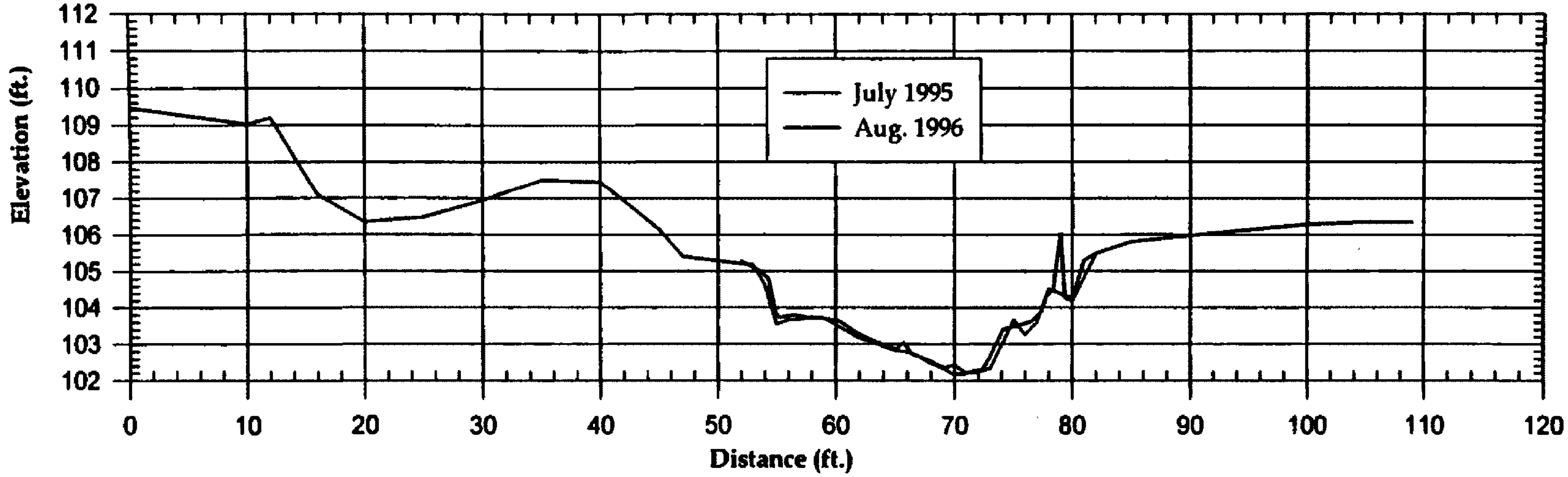
Cross-Section 4.4 - N. F. Dupuyer Creek



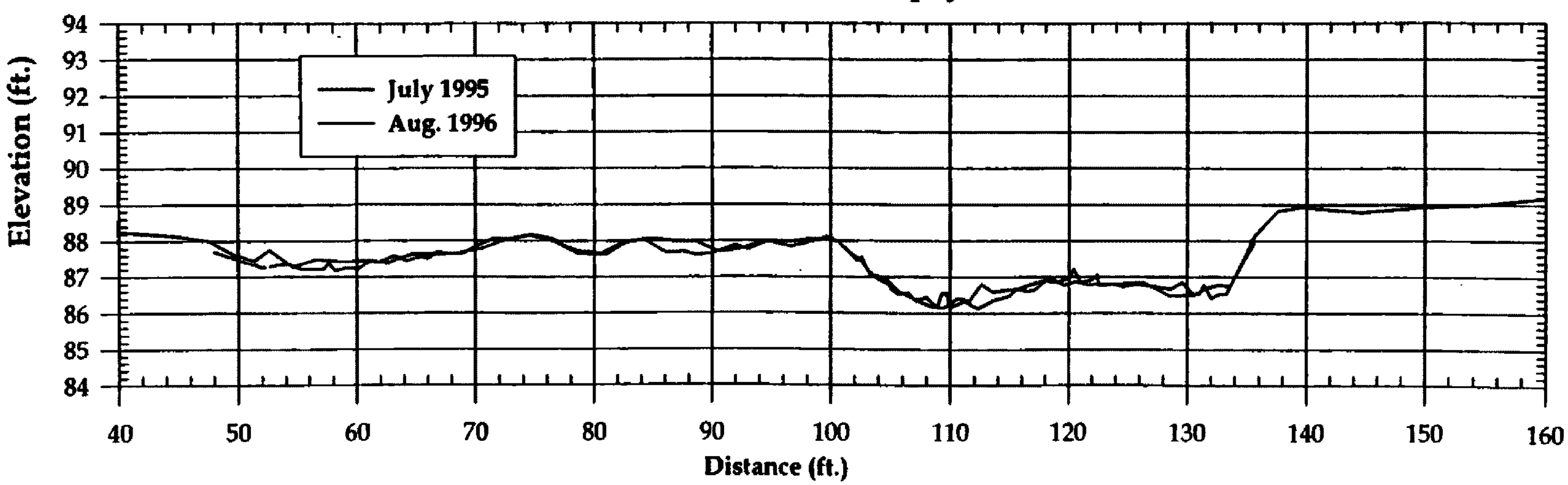
Cross-Section 4.5 - N. F. Dupuyer Creek

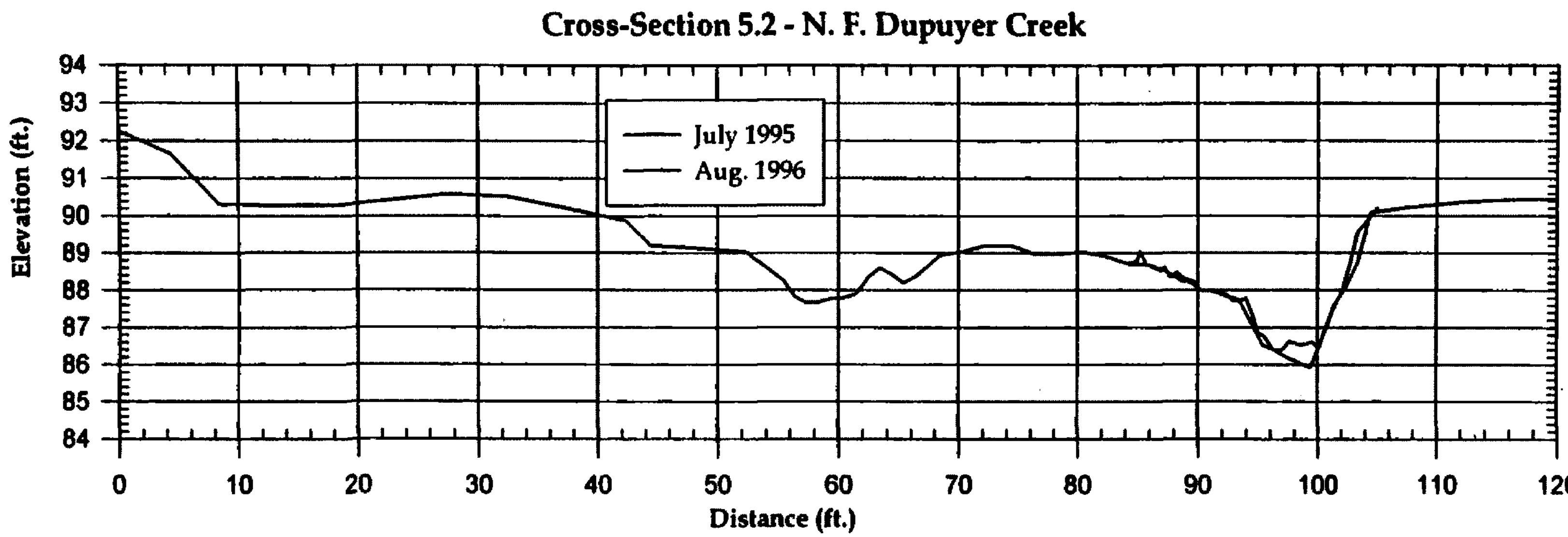


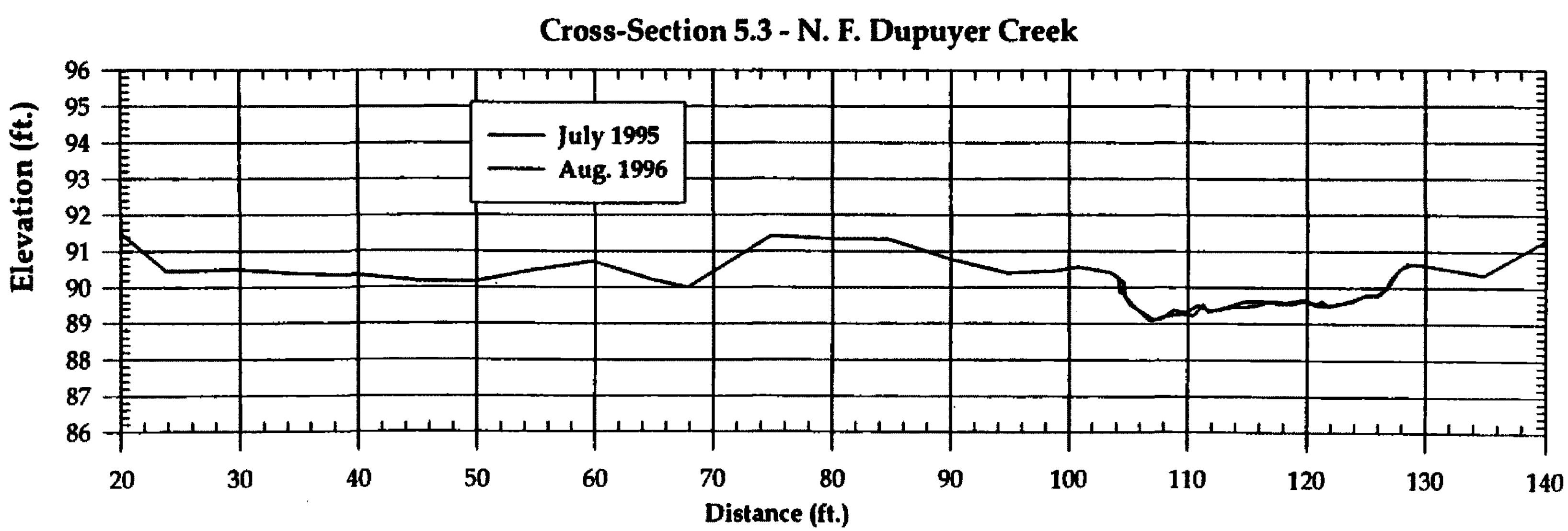
Cross-Section 4.6 - N. F. Dupuyer Creek



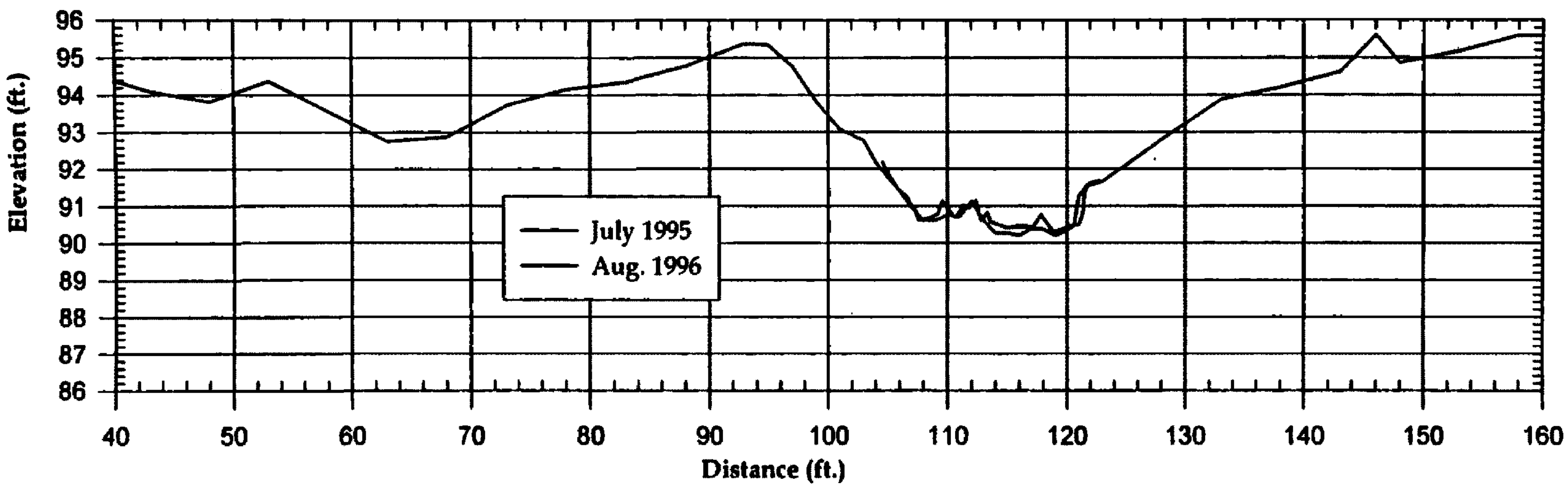
Cross-Section 5.1 - N. F. Dupuyer Creek



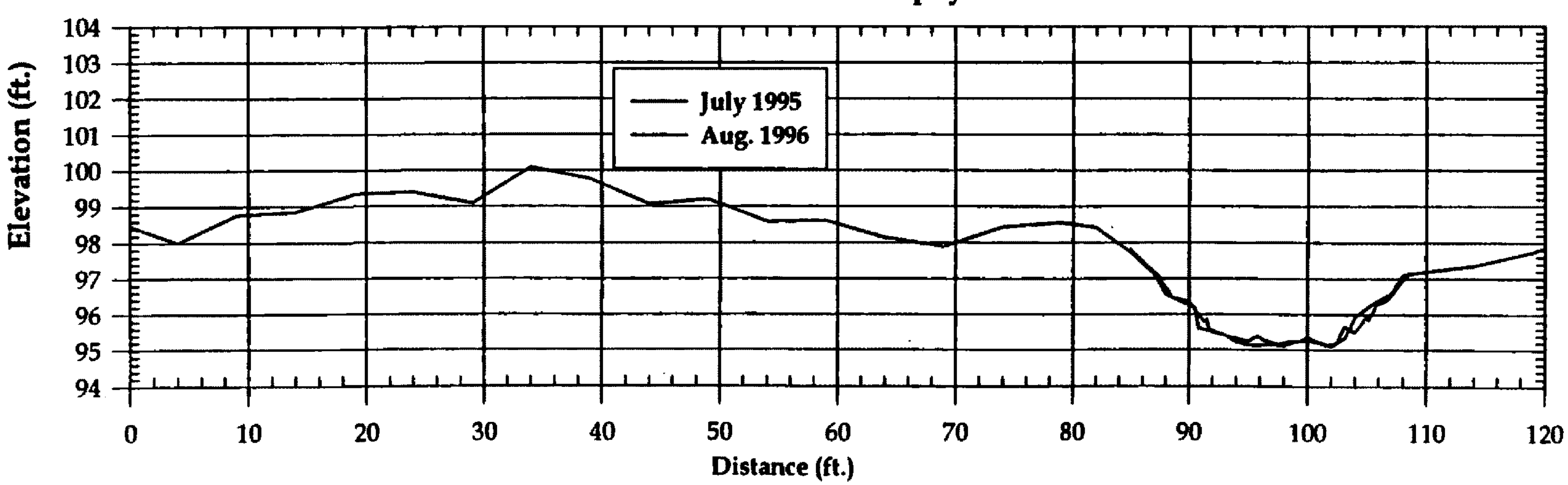

Cross-Section 5.2 - N. F. Dupuyer Creek
July 1995
Aug. 1996
Elevation (ft.)
94
93
92
91
90
89
88
87
86
85
84
0
10
20
30
40
50
60
70
80
90
100
110
120
Distance (ft.)


Cross-Section 5.3 - N. F. Dupuyer Creek
July 1995
Aug. 1996
Elevation (ft.)
96
95
94
93
92
91
90
89
88
87
86
20
30
40
50
60
70
80
90
100
110
120
130
140
Distance (ft.)

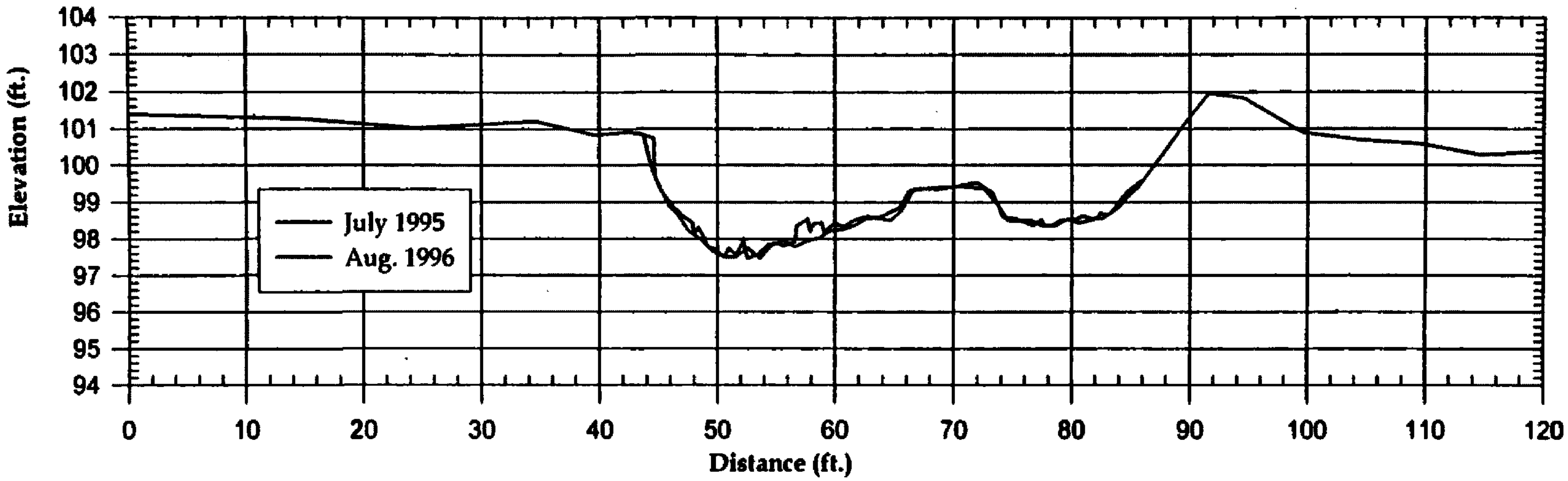
Cross-Section 5.4 - N. F. Dupuyer Creek



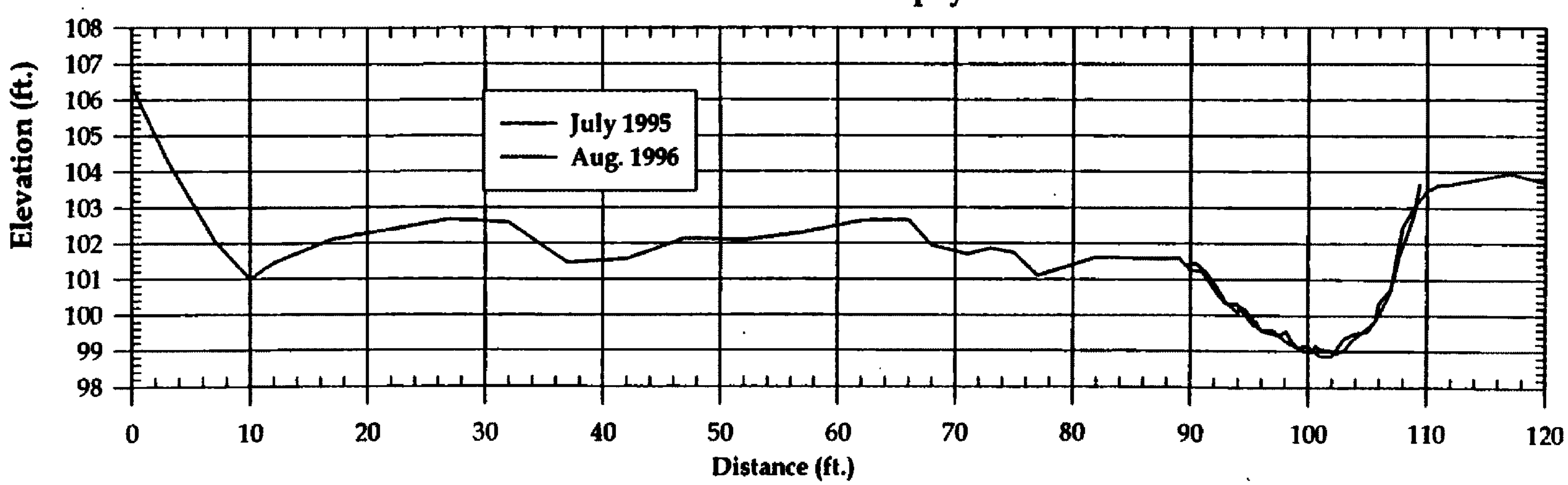
Cross-Section 5.5 - N. F. Dupuyer Creek

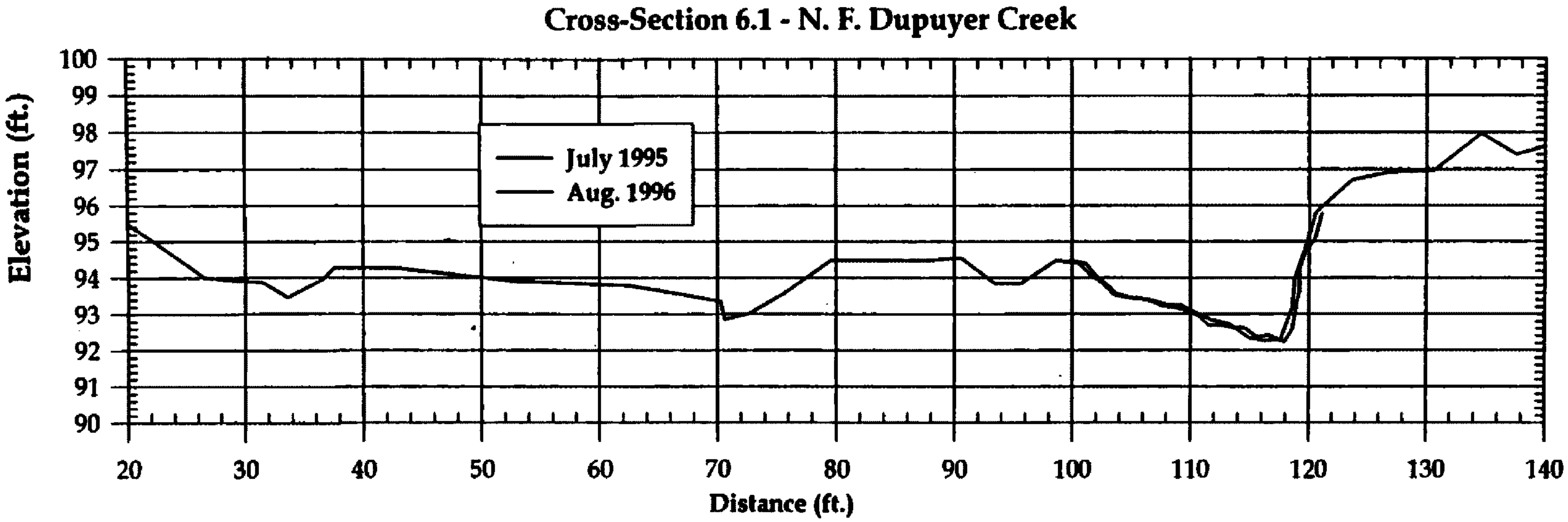


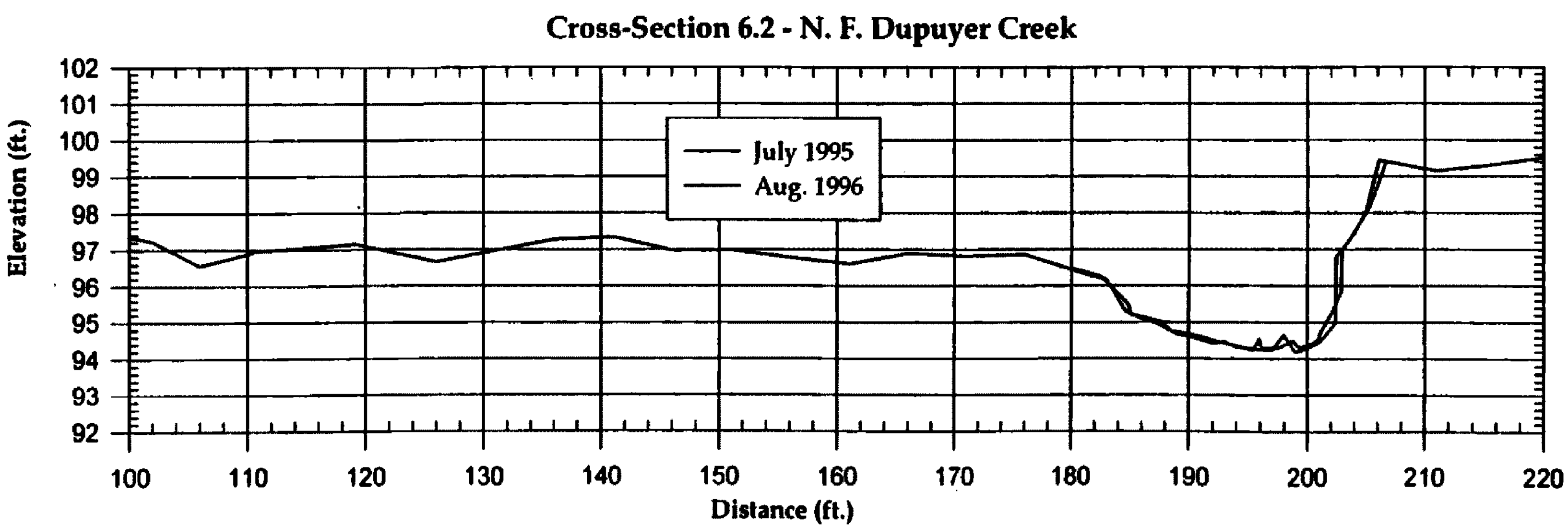
Cross-Section 5.6 - N. F. Dupuyer Creek



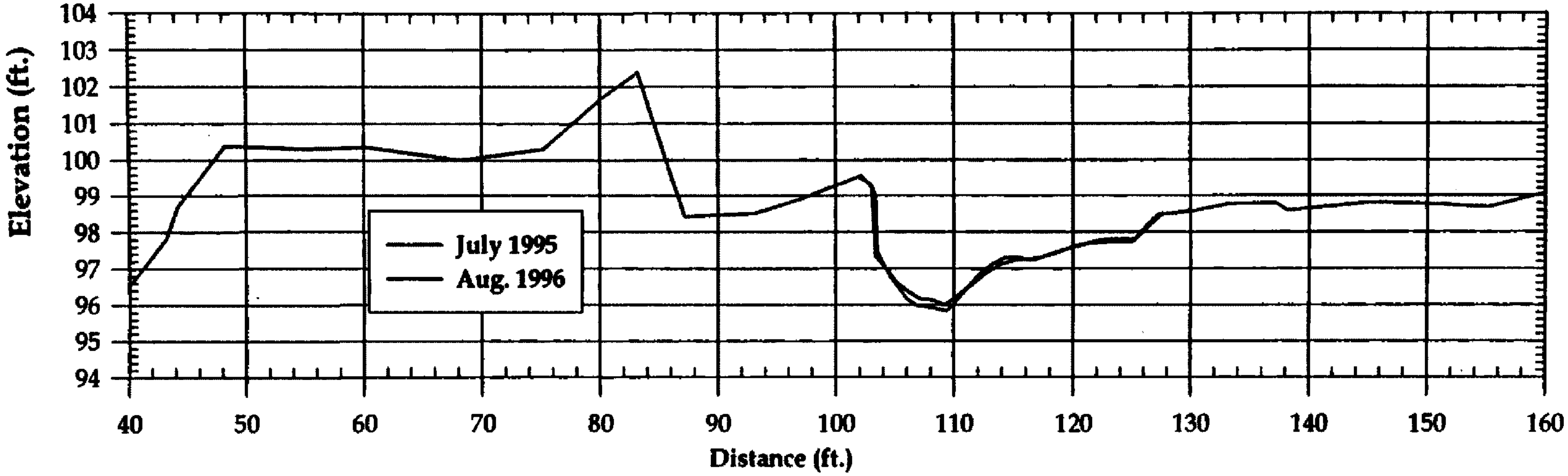
Cross-Section 5.7 - N. F. Dupuyer Creek



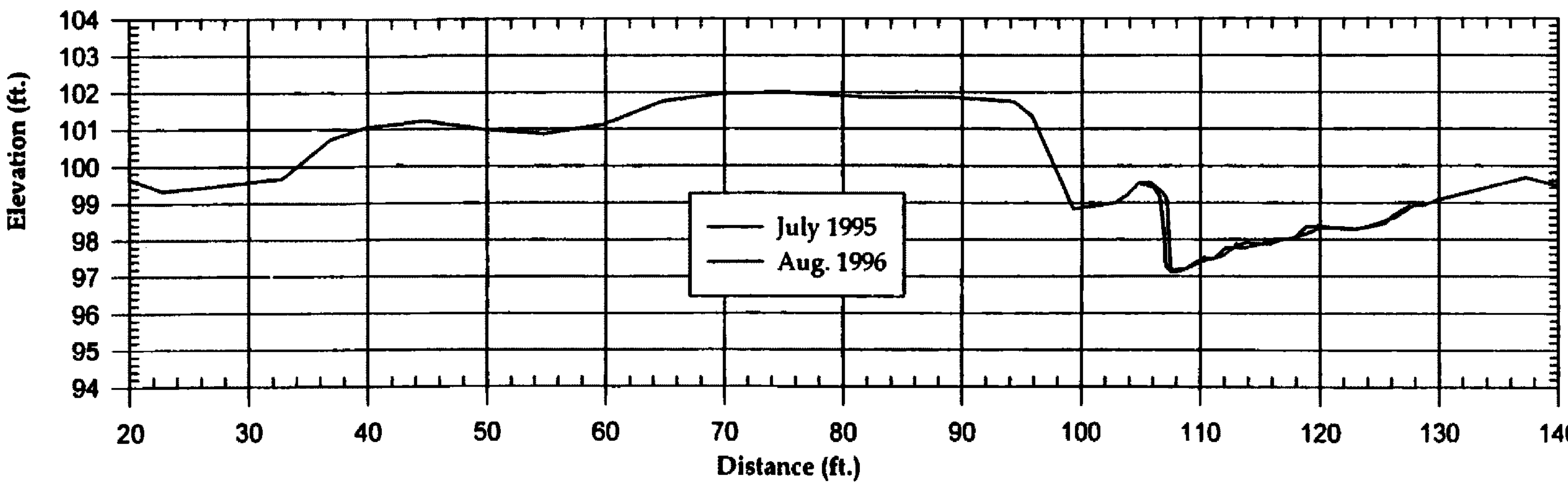

Cross-Section 6.1 - N. F. Dupuyer Creek
July 1995
Aug. 1996
Elevation (ft.)
Distance (ft.)
100
99
98
97
96
95
94
93
92
91
90
20
30
40
50
60
70
80
90
100
110
120
130
140

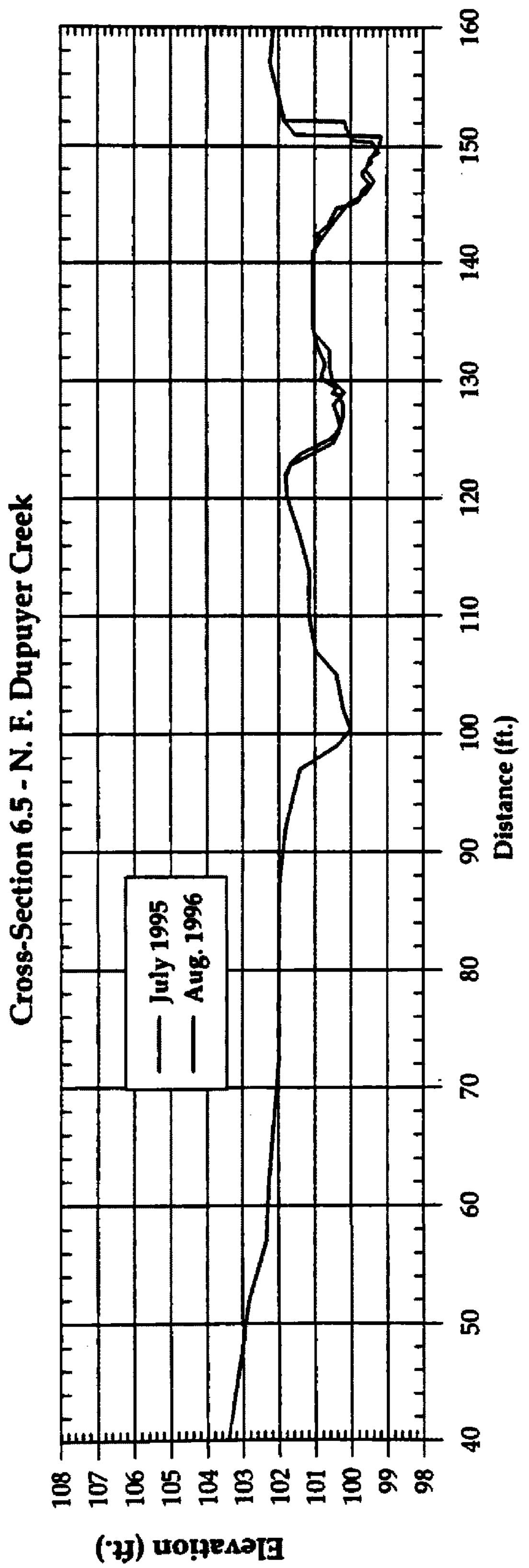

Cross-Section 6.2 - N. F. Dupuyer Creek
July 1995
Aug. 1996
Elevation (ft.)
Distance (ft.)
102
101
100
99
98
97
96
95
94
93
92
100
110
120
130
140
150
160
170
180
190
200
210
220

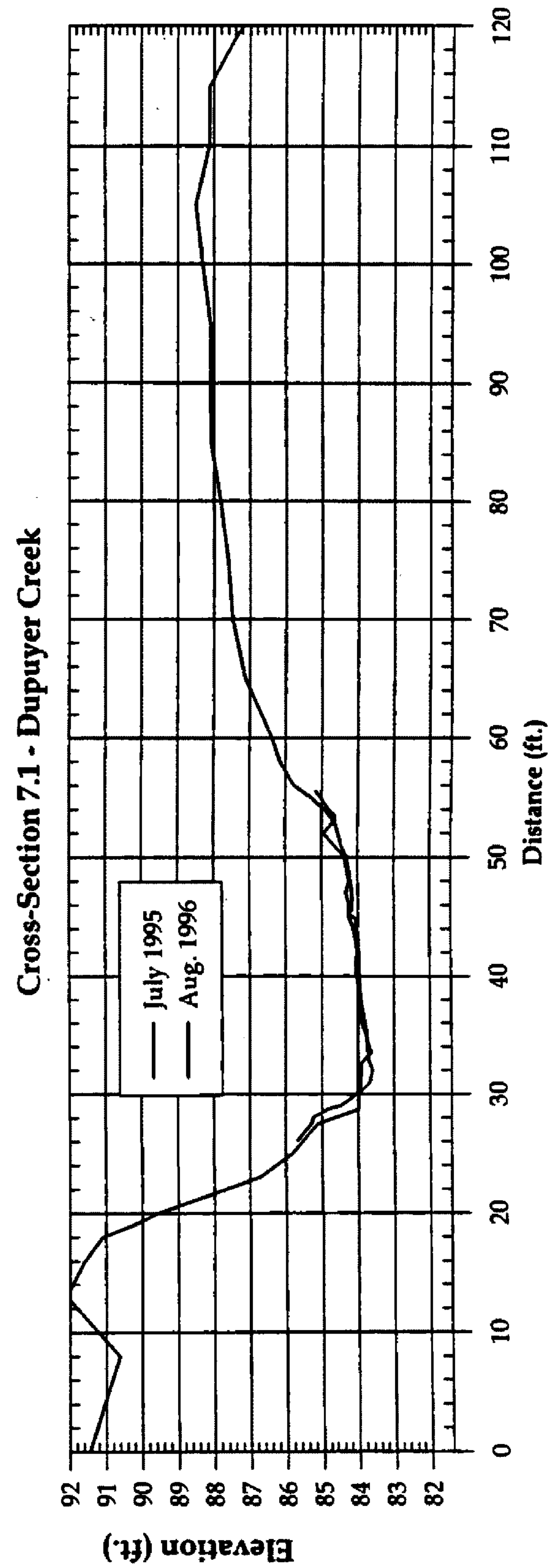
Cross-Section 6.3 - N. F. Dupuyer Creek



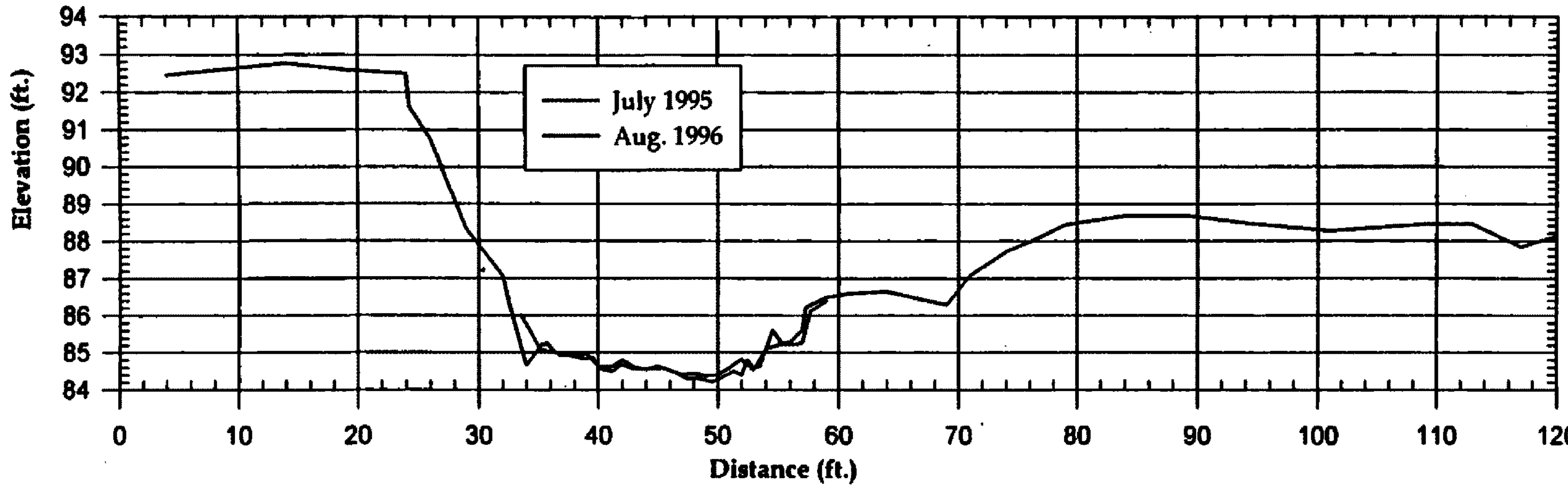
Cross-Section 6.4 - N. F. Dupuyer Creek



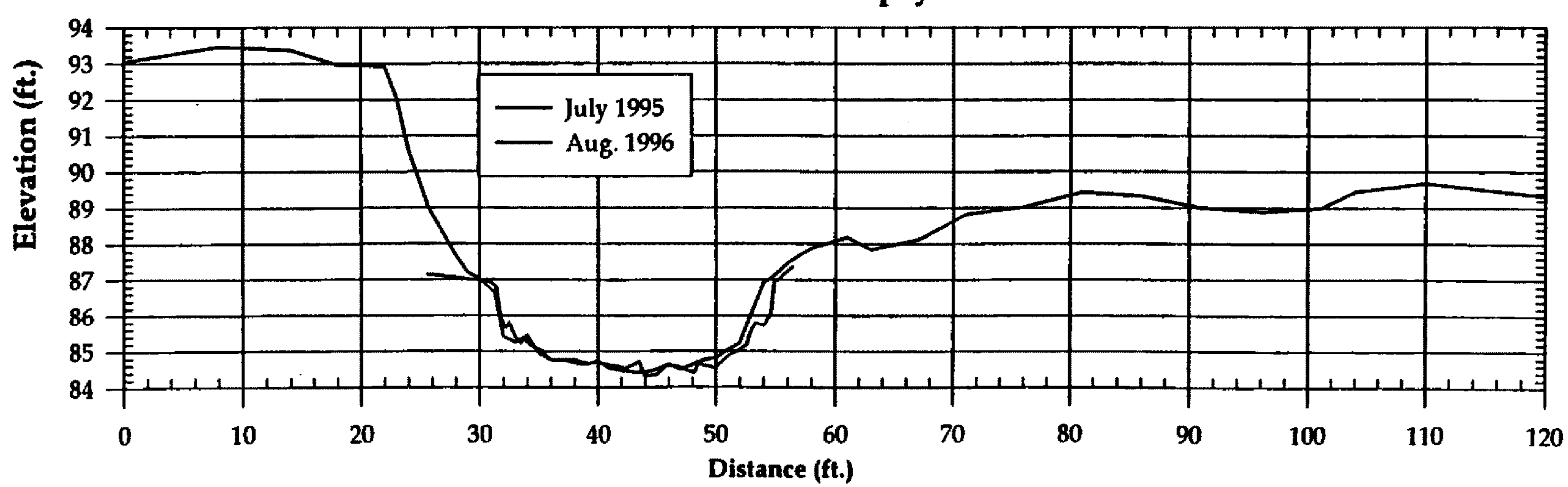

Cross-Section 6.5 - N. F. Dupuyer Creek
July 1995
Aug. 1996
Elevation (ft.)
108
107
106
105
104
103
102
101
100
99
98
Distance (ft.)
40
50
60
70
80
90
100
110
120
130
140
150
160


Cross-Section 7.1 - Dupuyer Creek
July 1995
Aug. 1996
Elevation (ft.)
92
91
90
89
88
87
86
85
84
83
82
Distance (ft.)
0
10
20
30
40
50
60
70
80
90
100
110
120

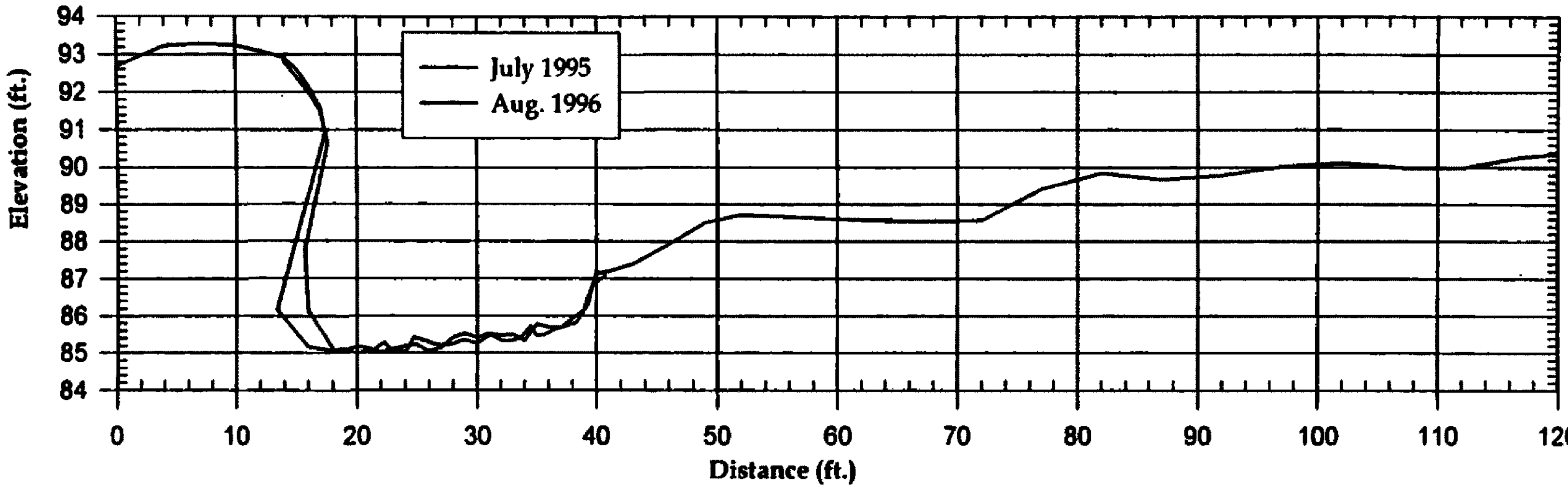
Cross-Section 7.2 - Dupuyer Creek



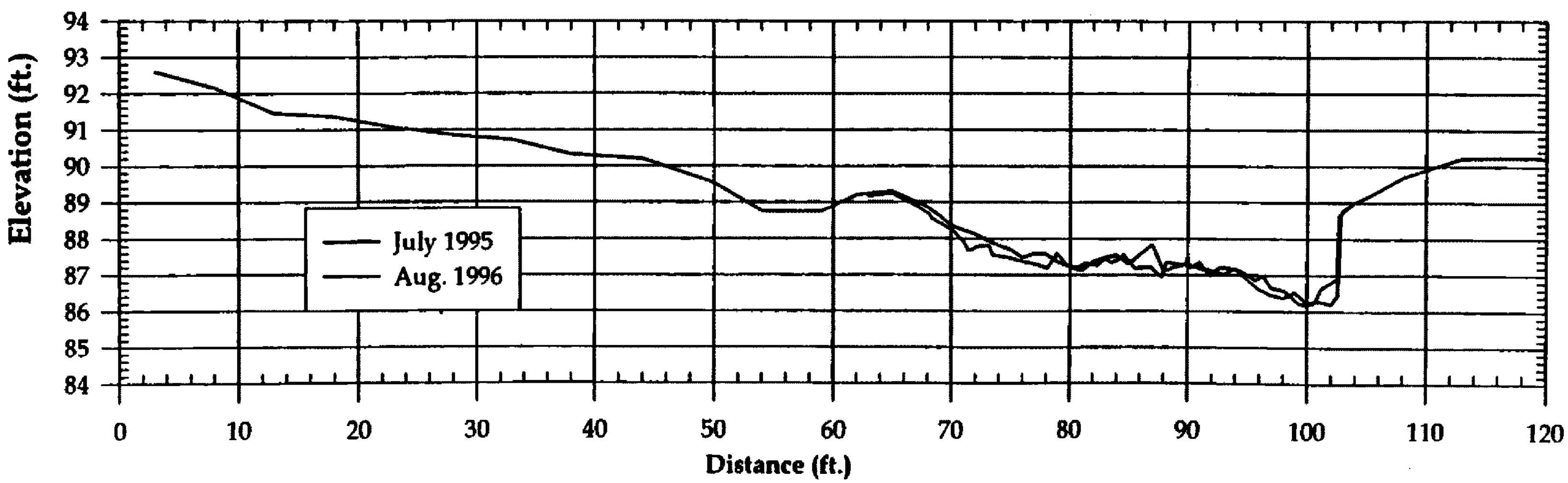
Cross-Section 7.3 - Dupuyer Creek



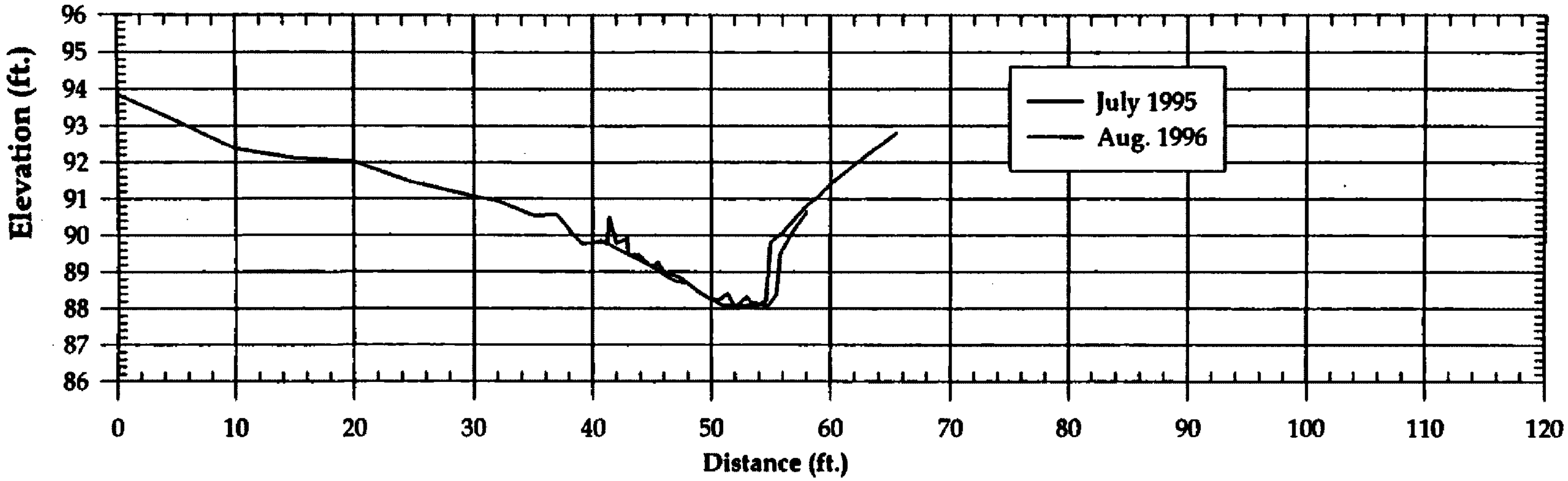
Cross-Section 7.4 - Dupuyer Creek



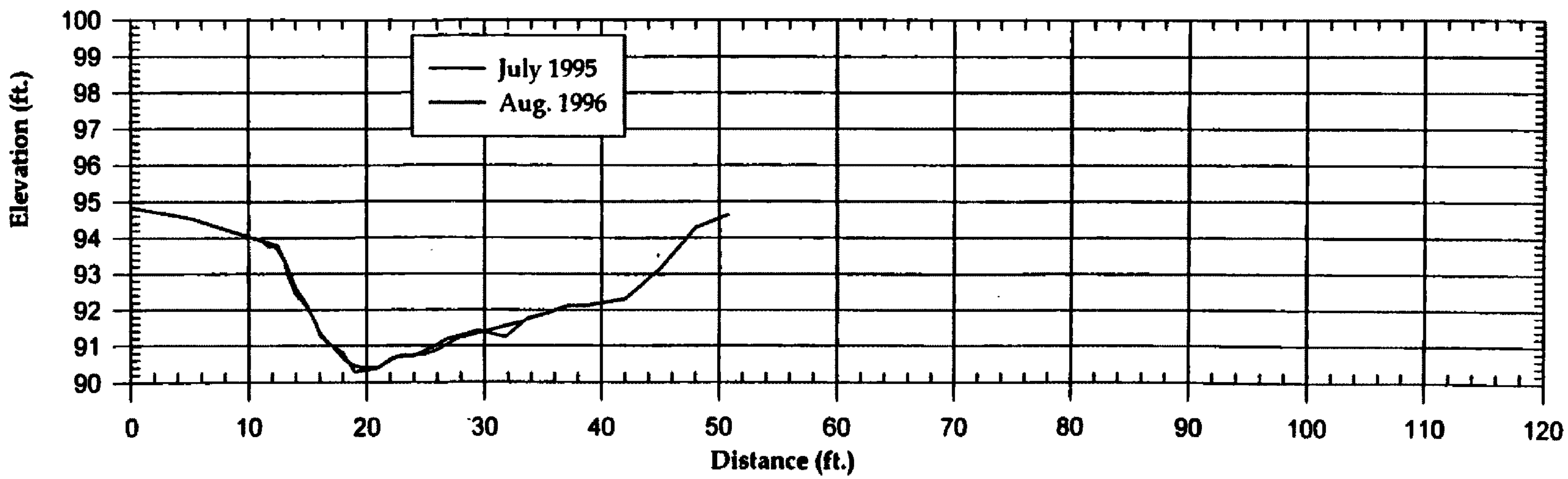
Cross-Section 7.5 - Dupuyer Creek



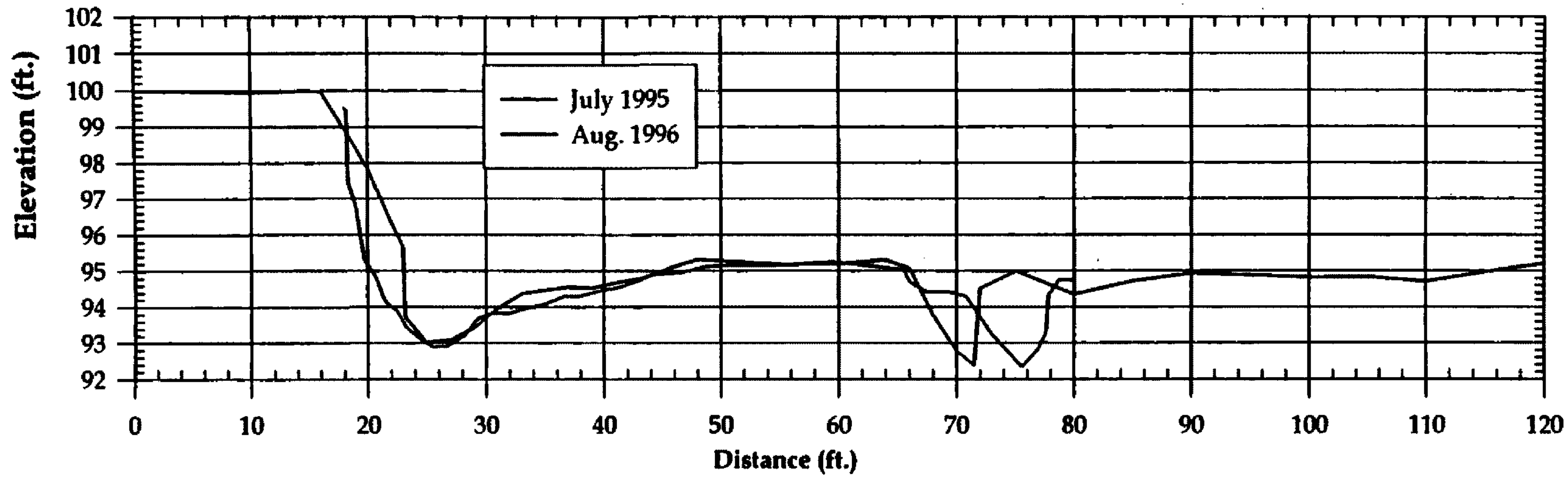
Cross-Section 8.1 - Dupuyer Creek



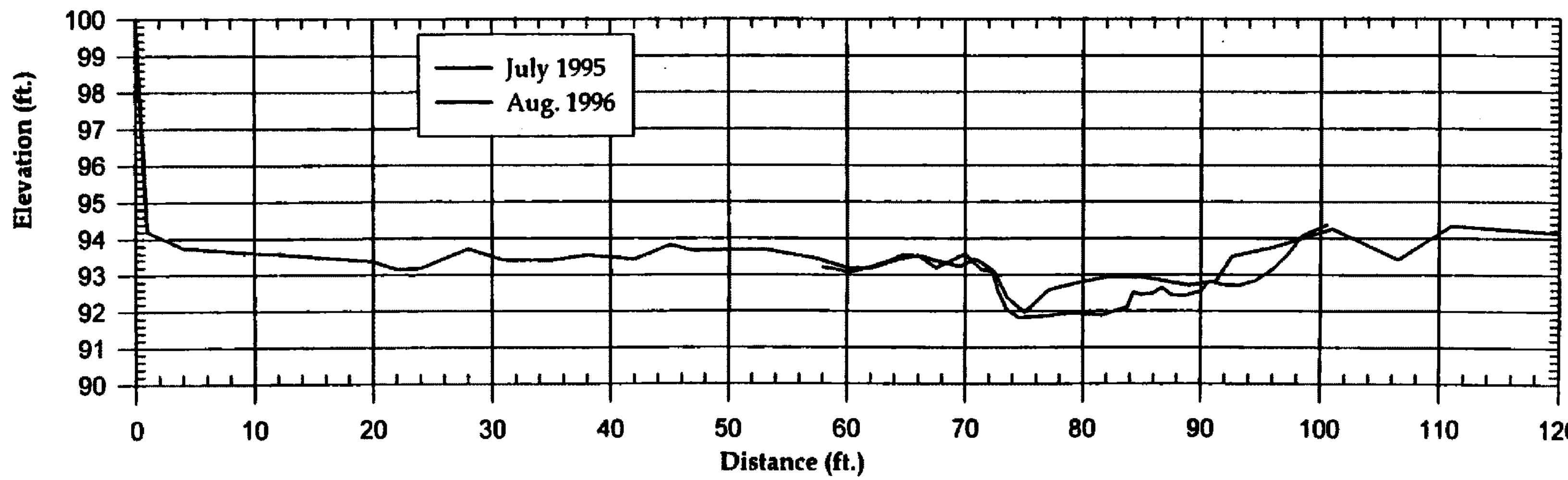
Cross-Section 8.2 - Dupuyer Creek



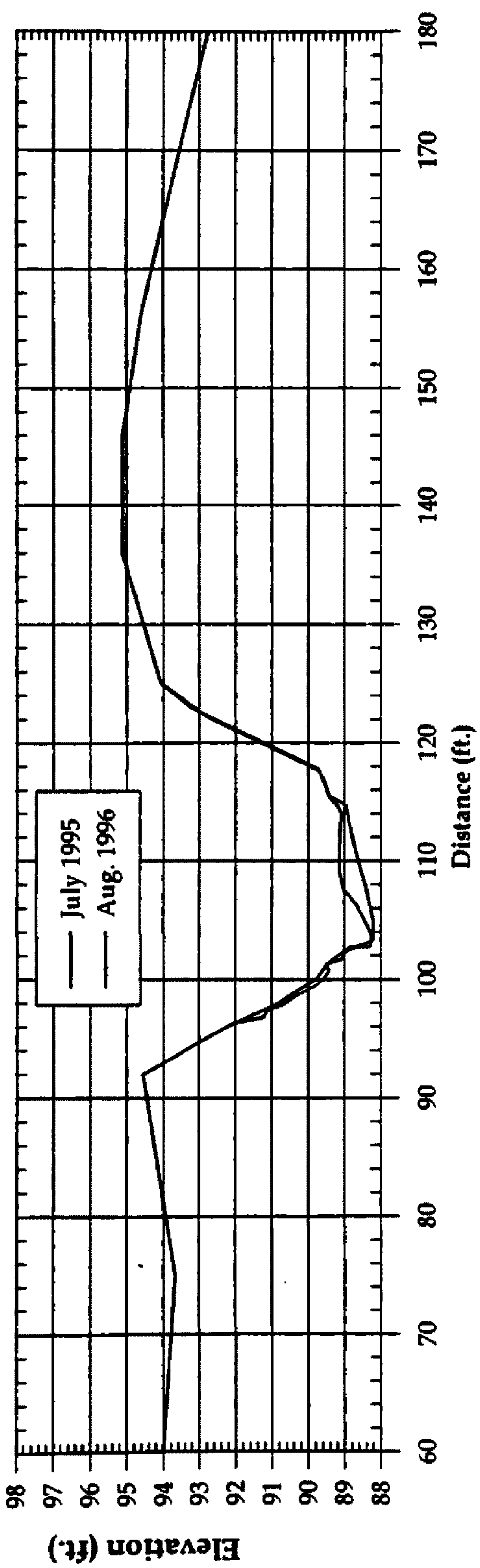
Cross-Section 9.1 - Dupuyer Creek



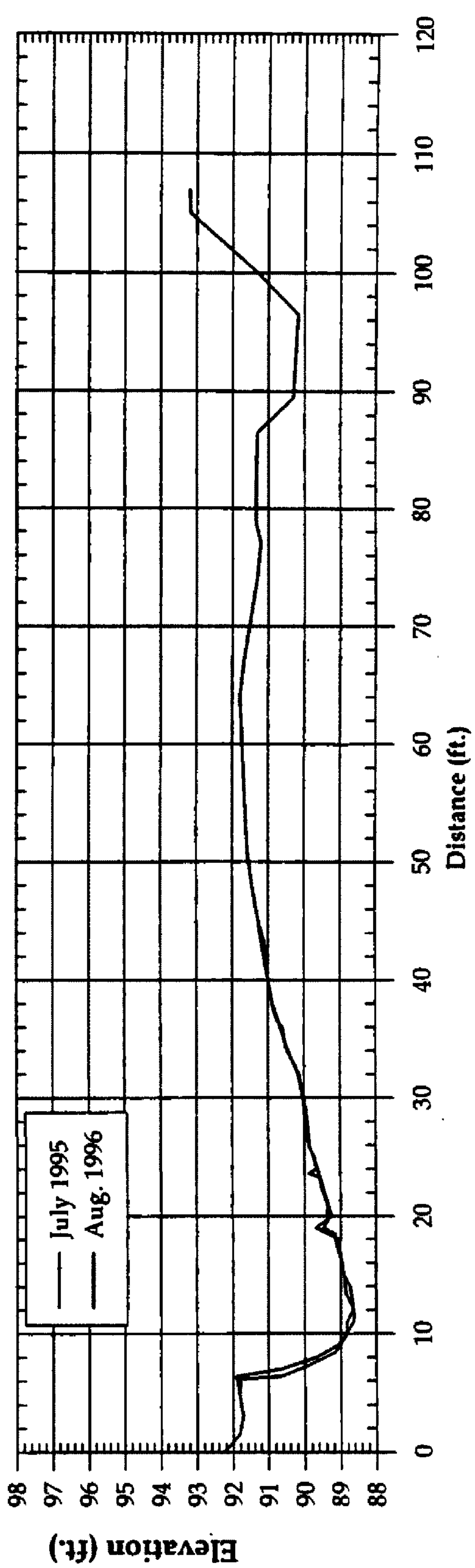
Cross-Section 9.2 - Dupuyer Creek



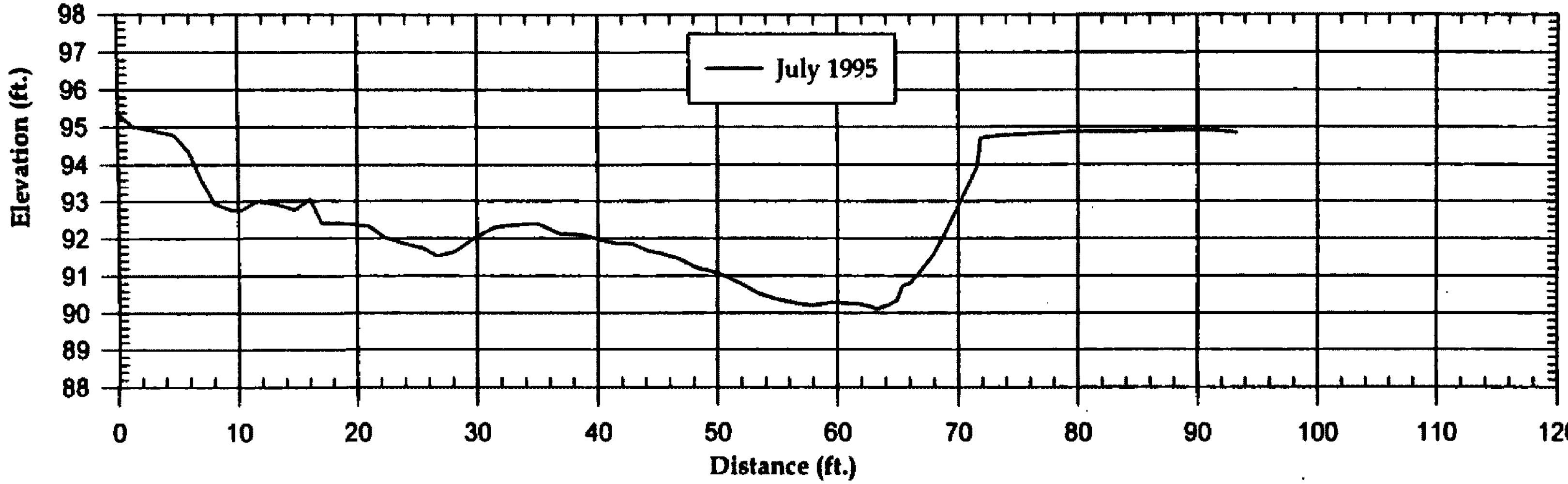
Cross-Section 9.3 - Dupuyer Creek



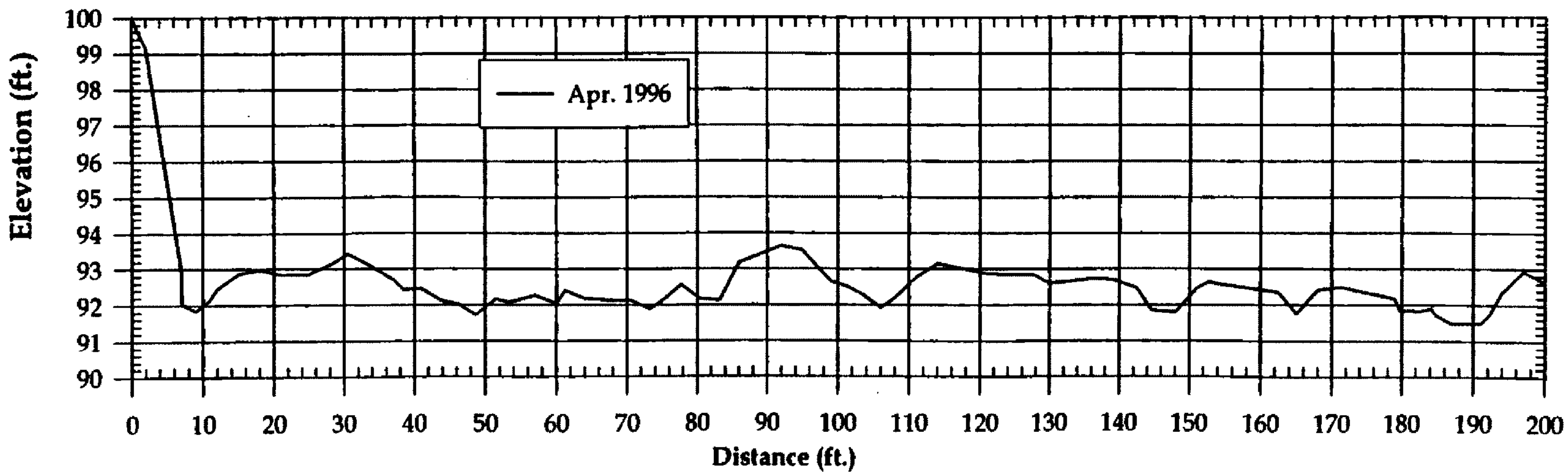
Cross-Section 10.1 - Dupuyer Creek



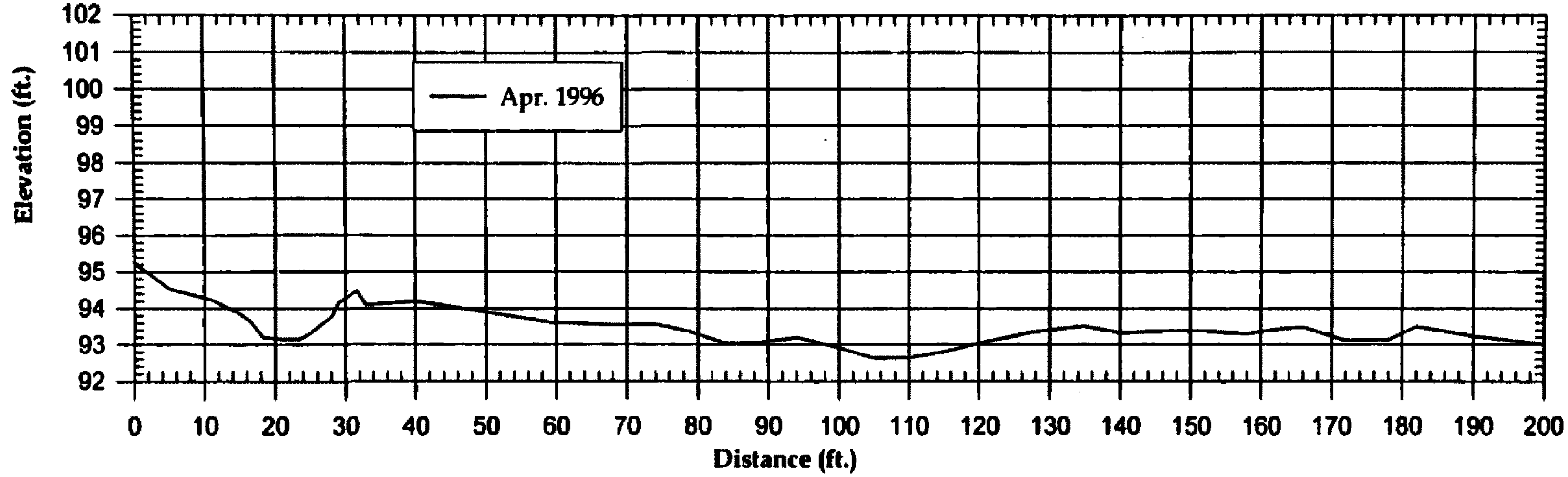
Cross-Section 10.2 - Dupuyer Creek



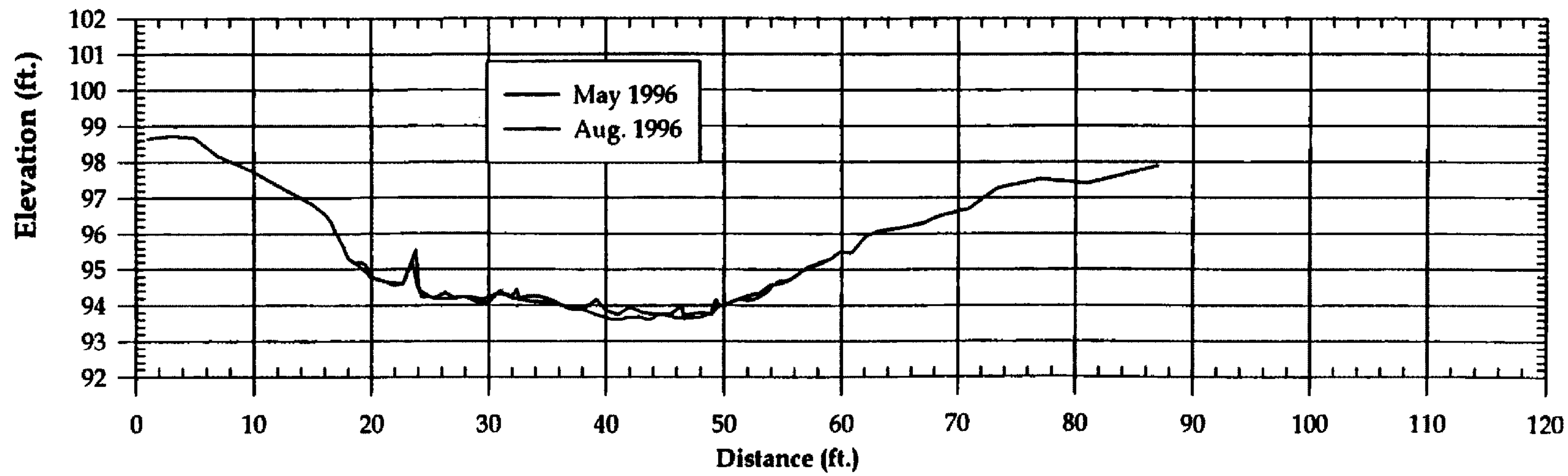
Cross-Section 11.1 - Dupuyer Creek

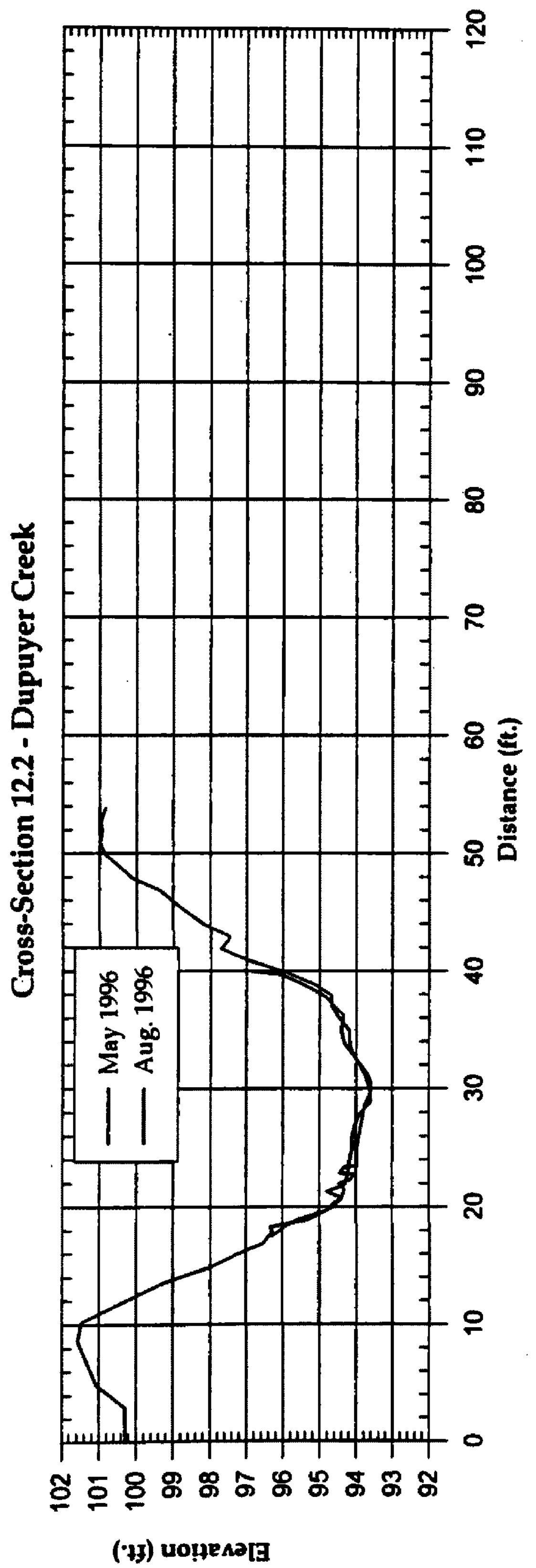


Cross-Section 11.2 - Dupuyer Creek



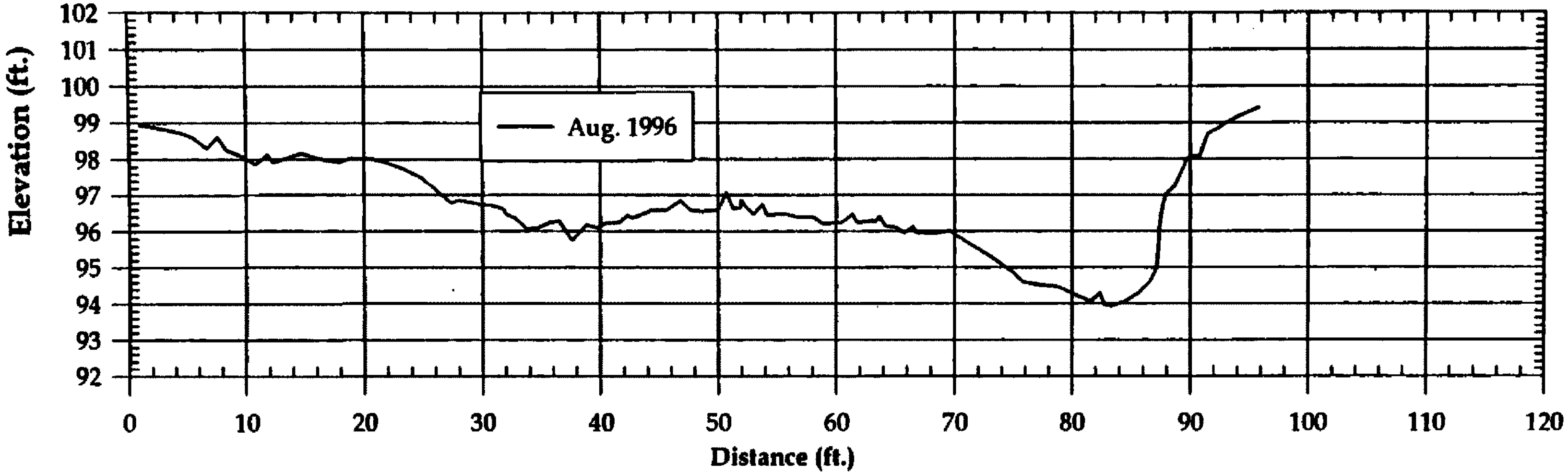
Cross-Section 12.1 - Dupuyer Creek



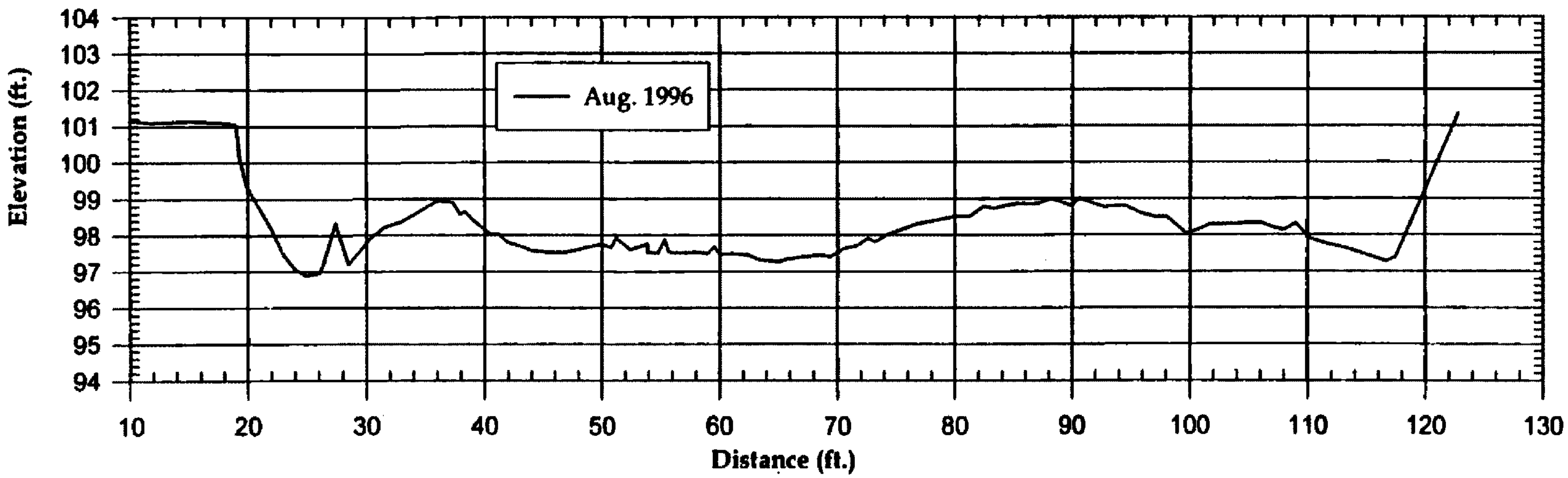


Cross-Section 12.2 - Dupuyer Creek
May 1996
Aug. 1996
Elevation (ft.)
102
101
100
99
98
97
96
95
94
93
92
Distance (ft.)
0
10
20
30
40
50
60
70
80
90
100
110
120

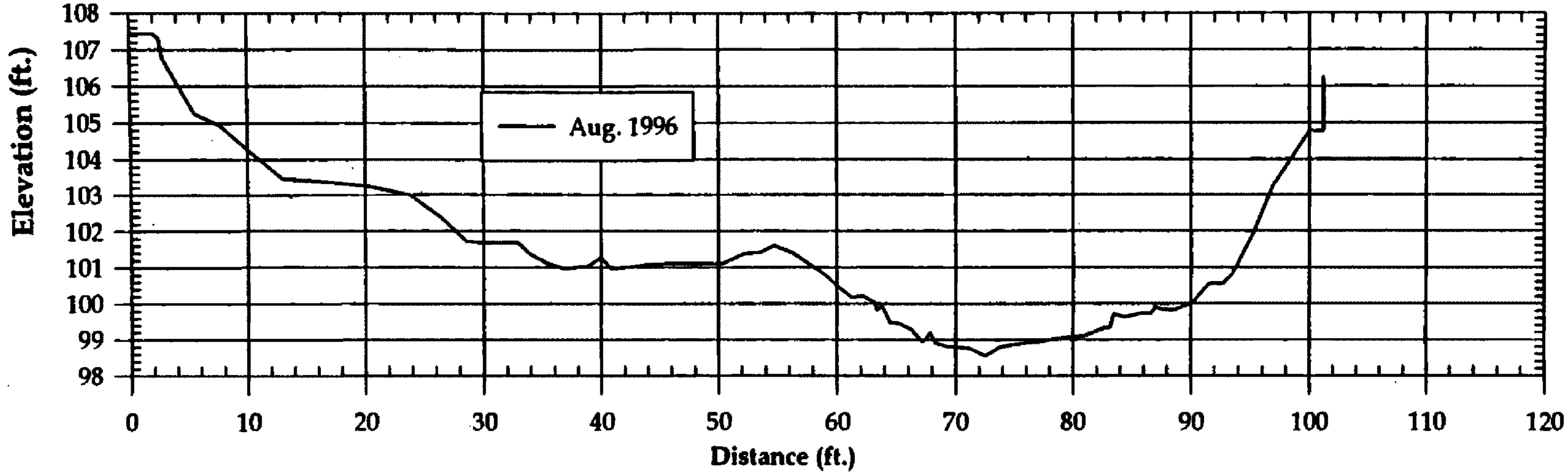
Cross-Section 15.1 - Dupuyer Creek



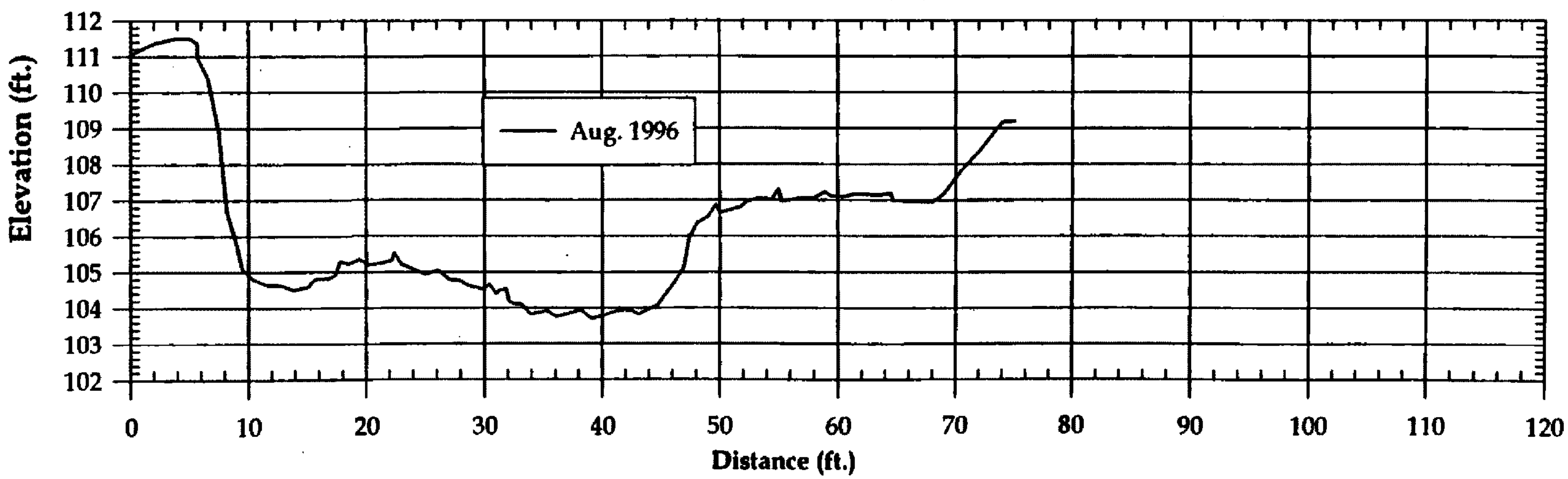
Cross-Section 15.2 - Dupuyer Creek



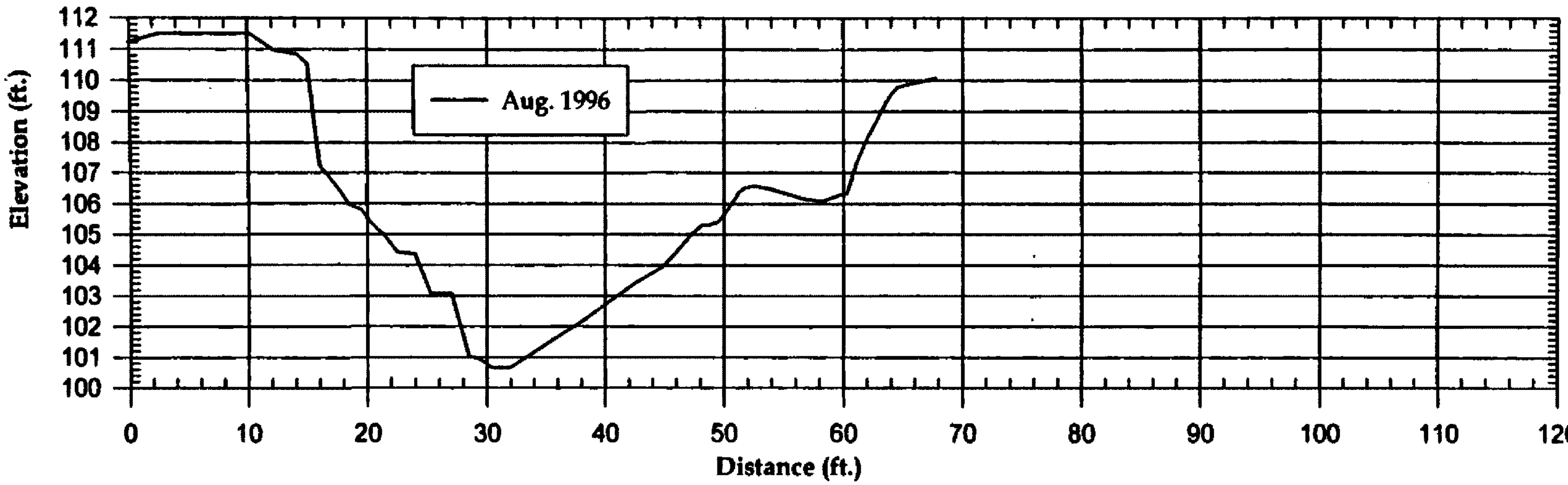
Cross-Section 15.3 - Dupuyer Creek



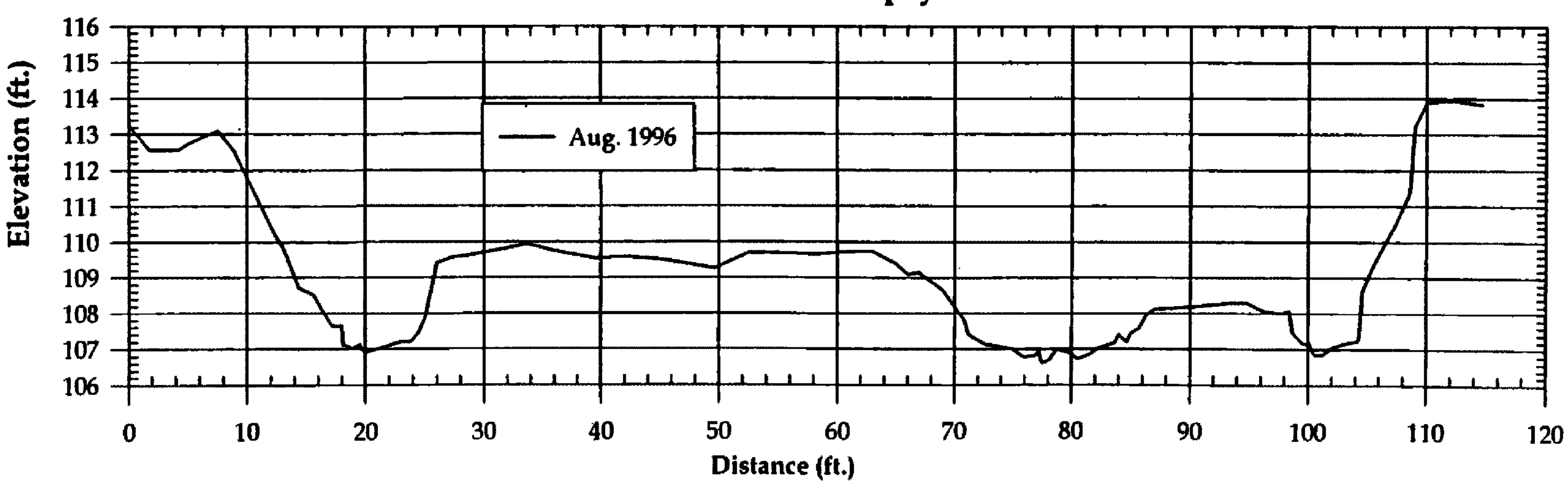
Cross-Section 16.1 - Dupuyer Creek



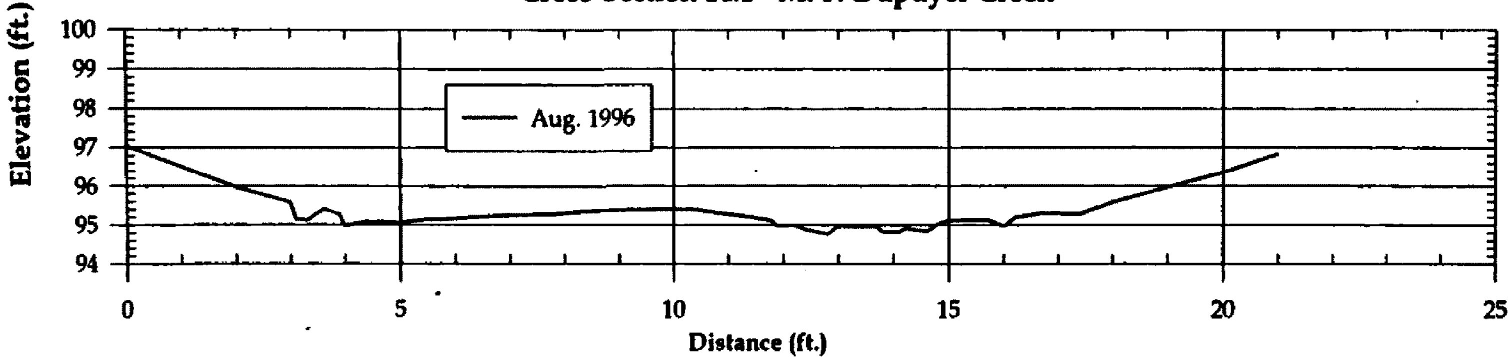
Cross-Section 16.2 - Dupuyer Creek



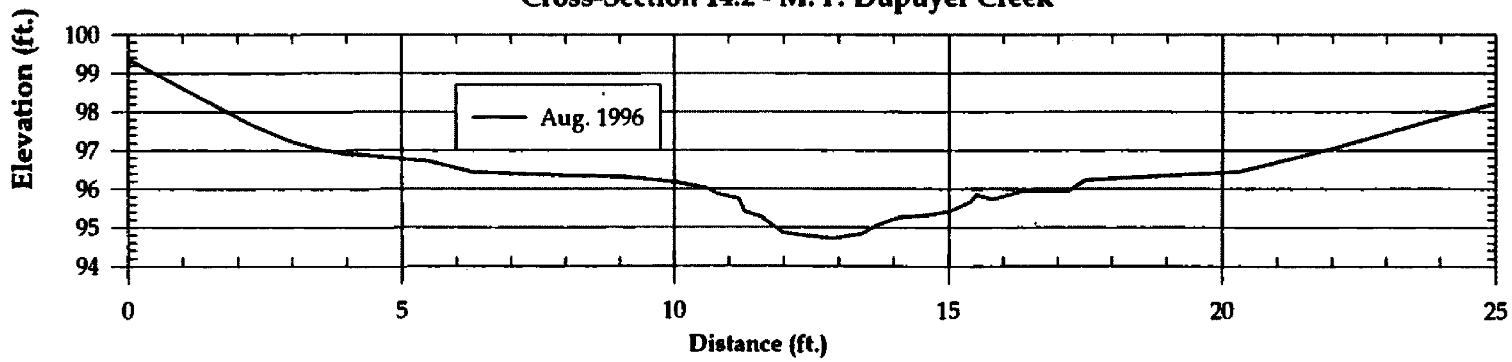
Cross-Section 16.3 - Dupuyer Creek



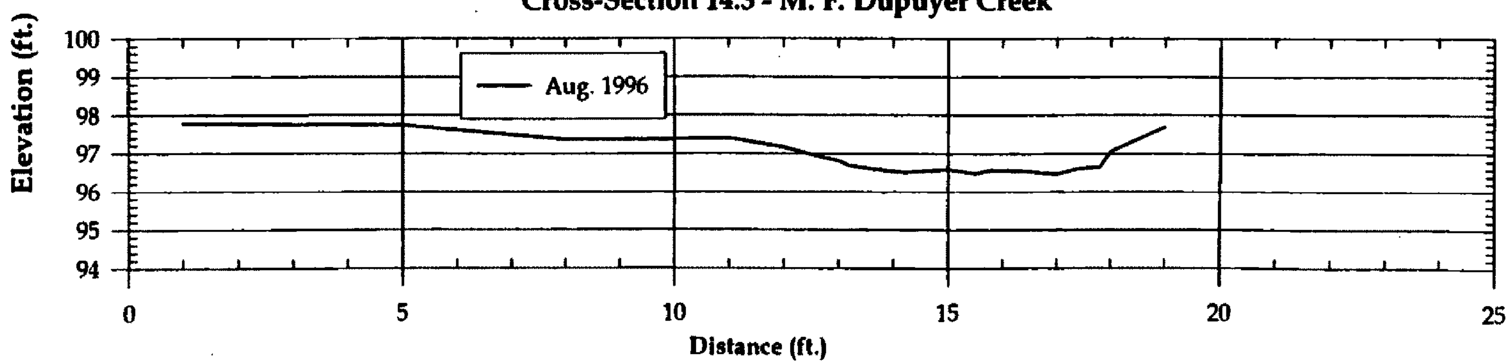
Cross-Section 14.1 - M. F. Dupuyer Creek



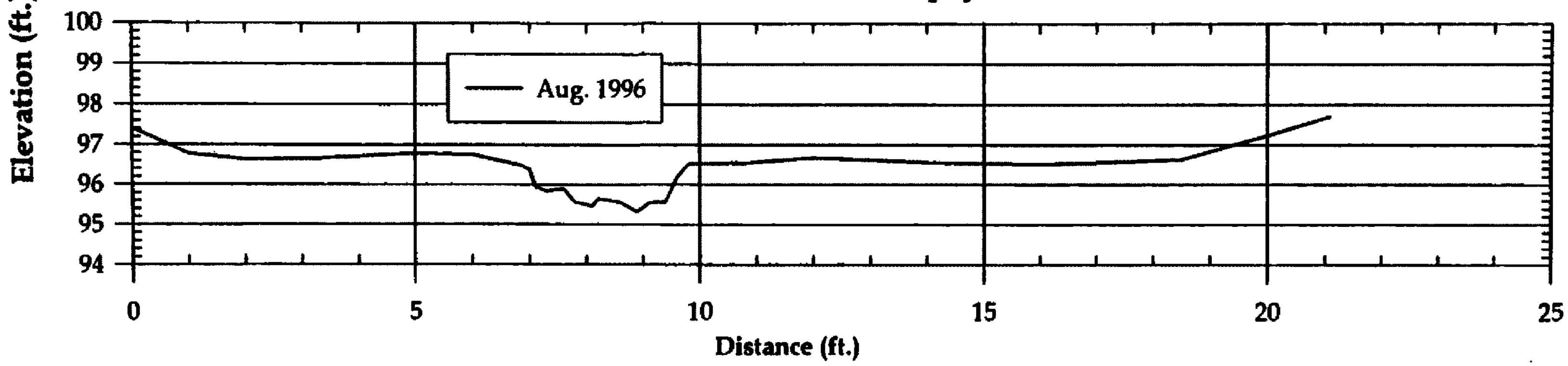
Cross-Section 14.2 - M. F. Dupuyer Creek



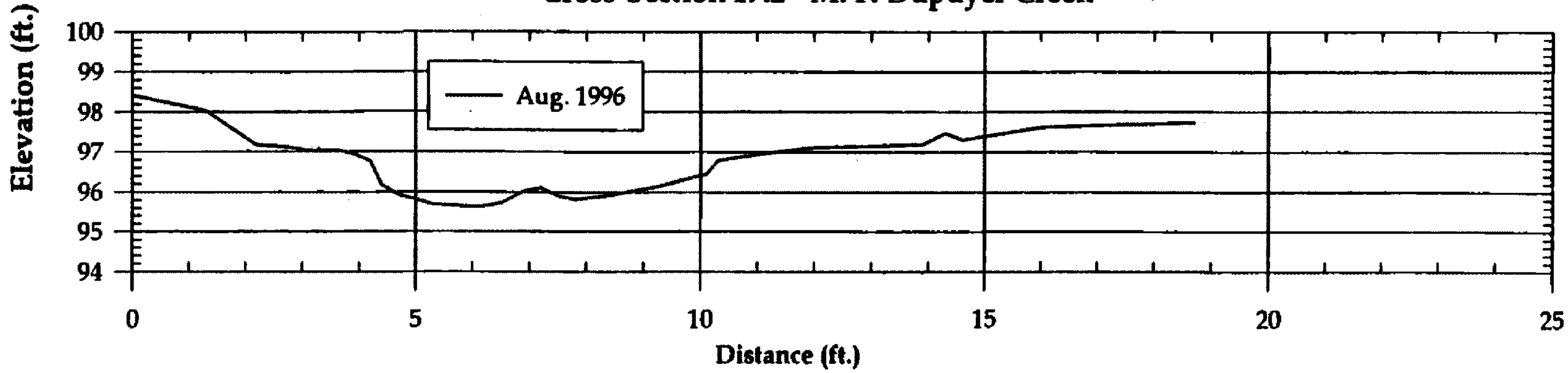
Cross-Section 14.3 - M. F. Dupuyer Creek



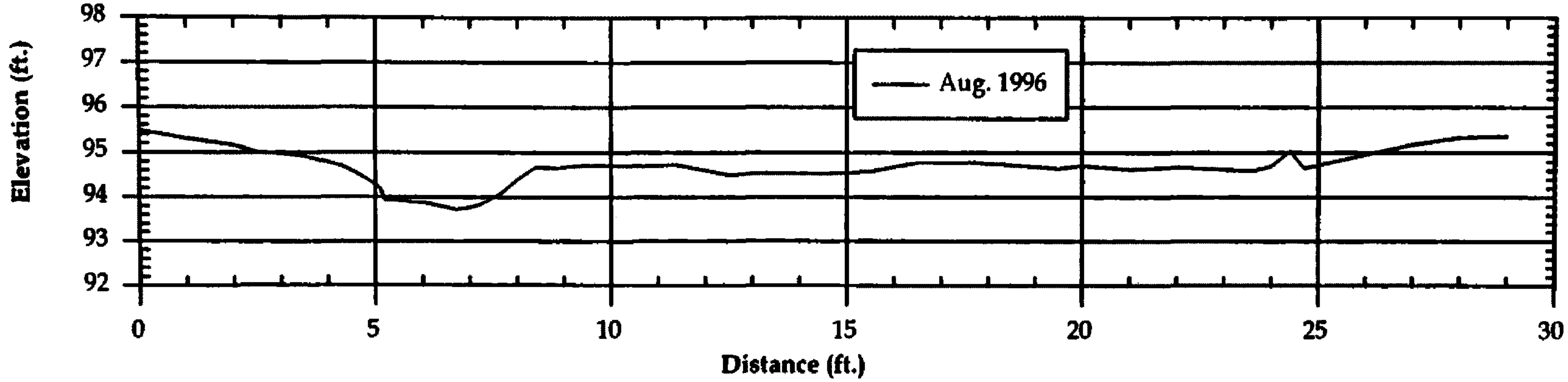
Cross-Section 17.1 - M. F. Dupuyer Creek



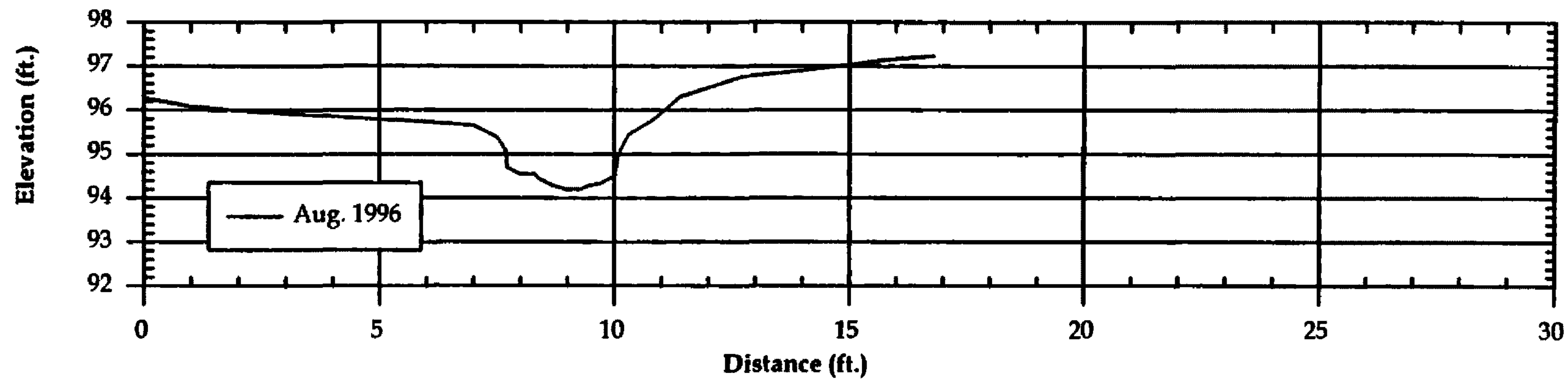
Cross-Section 17.2 - M. F. Dupuyer Creek



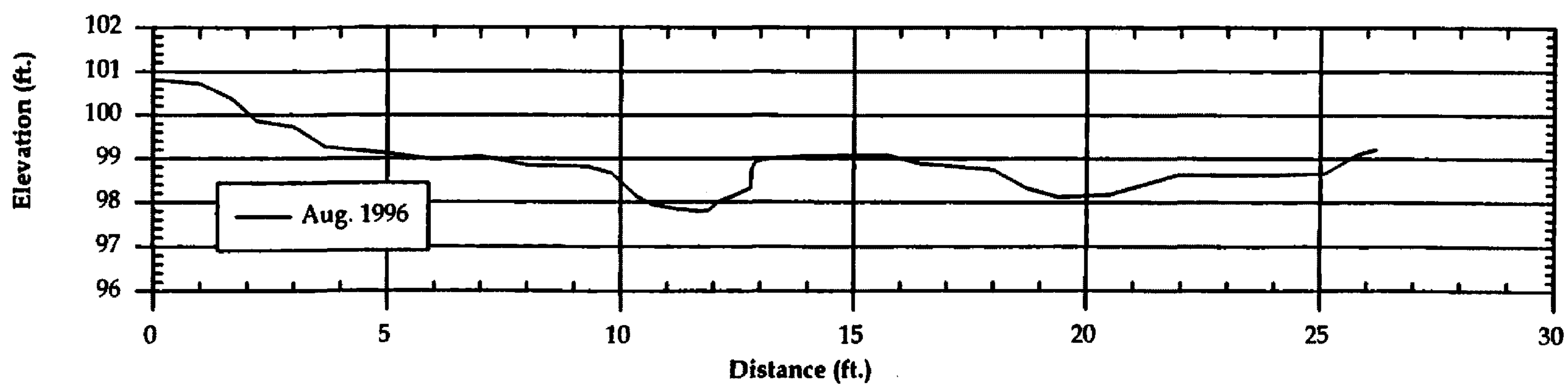
Cross-Section 19.1 - Lenstra Creek Below Cattle Exclosure



Cross-Section 19.2 - Lenstra Creek Cattle Exclosure

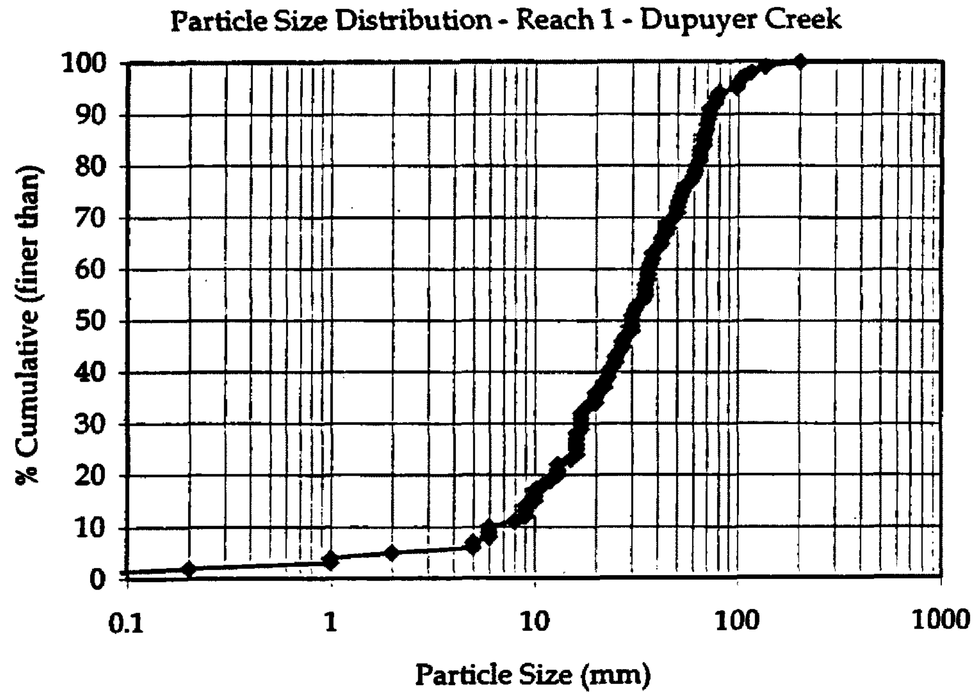


Cross-Section 19.3 - Lenstra Creek Wildlife Exclosure

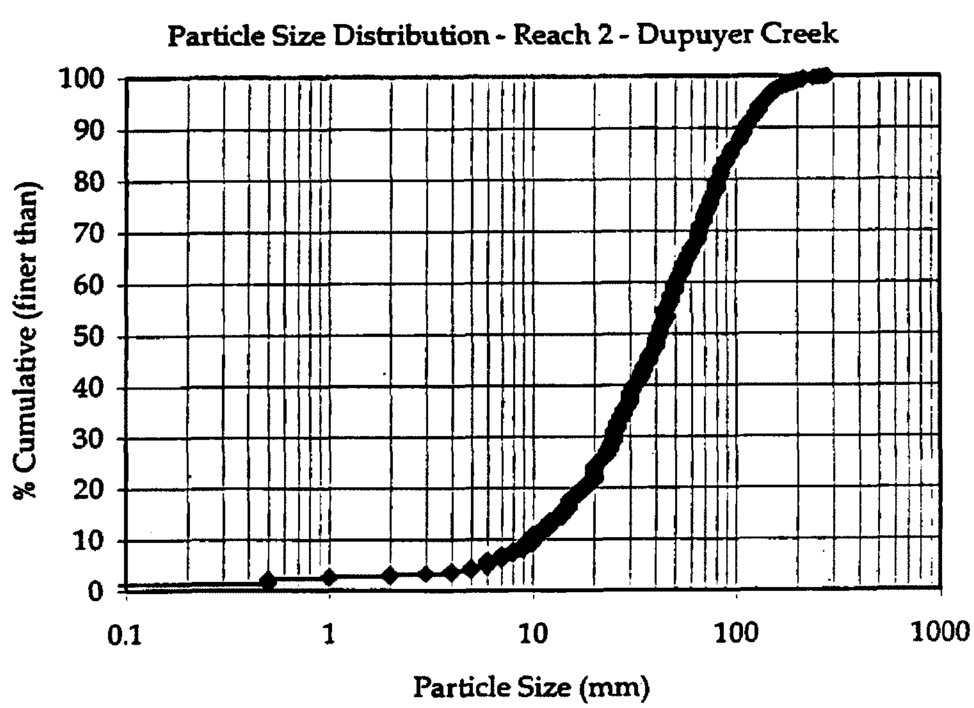


Appendix F

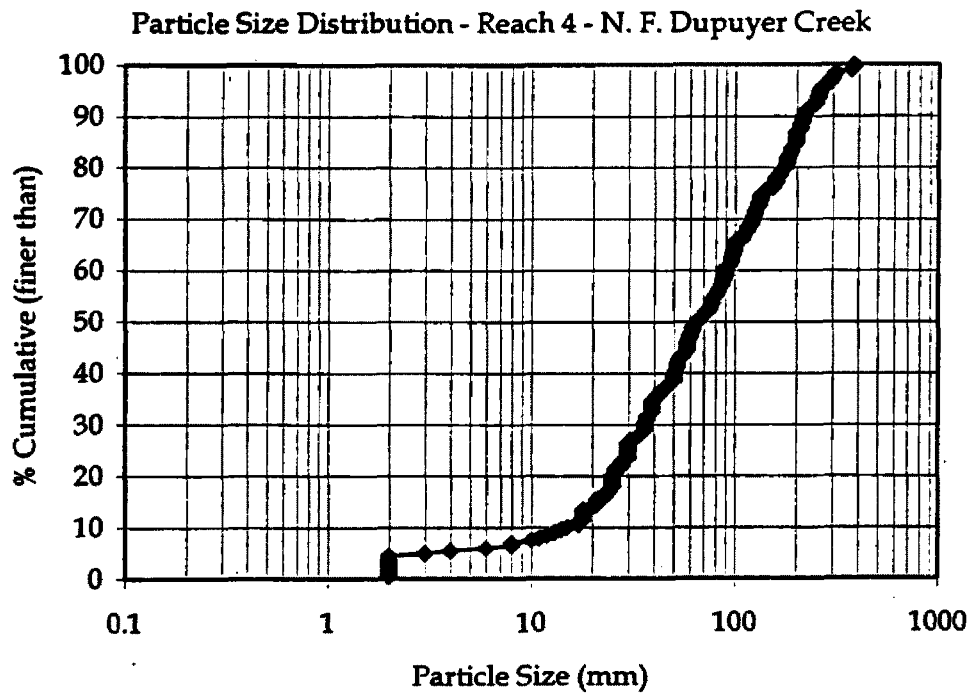
Plots of particle size distributions.

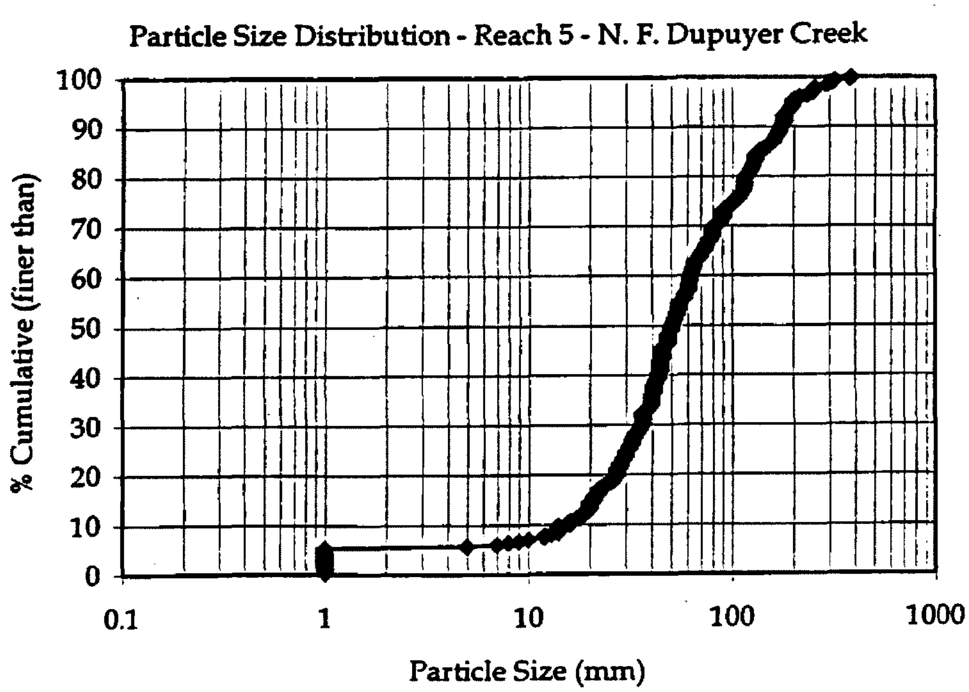


Particle Size Distribution - Reach 1 - Dupuyer Creek
% Cumulative (finer than)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
Particle Size (mm)

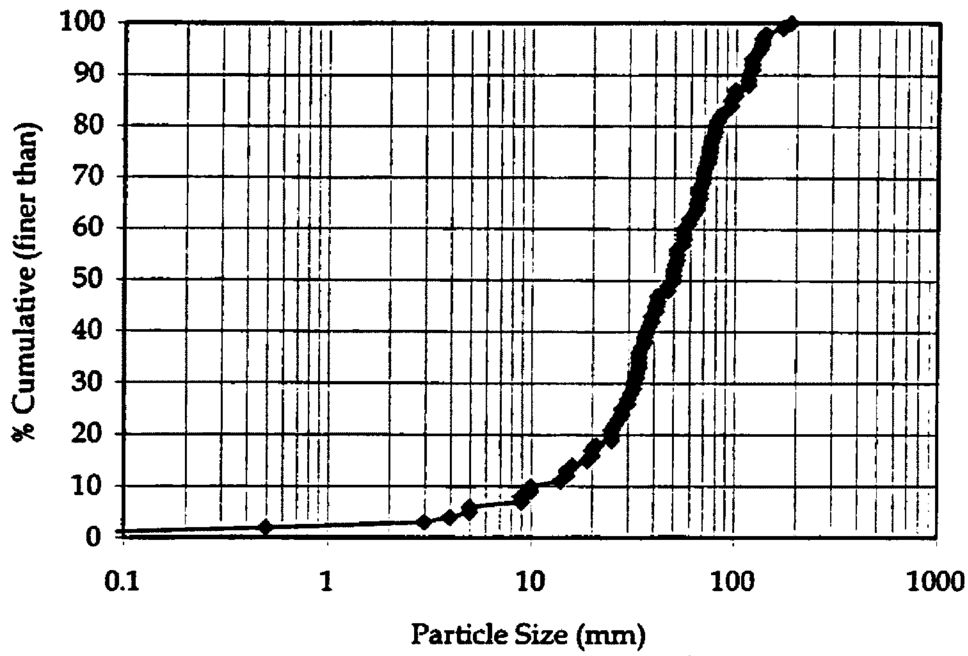


Particle Size Distribution - Reach 2 - Dupuyer Creek
% Cumulative (finer than)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
Particle Size (mm)

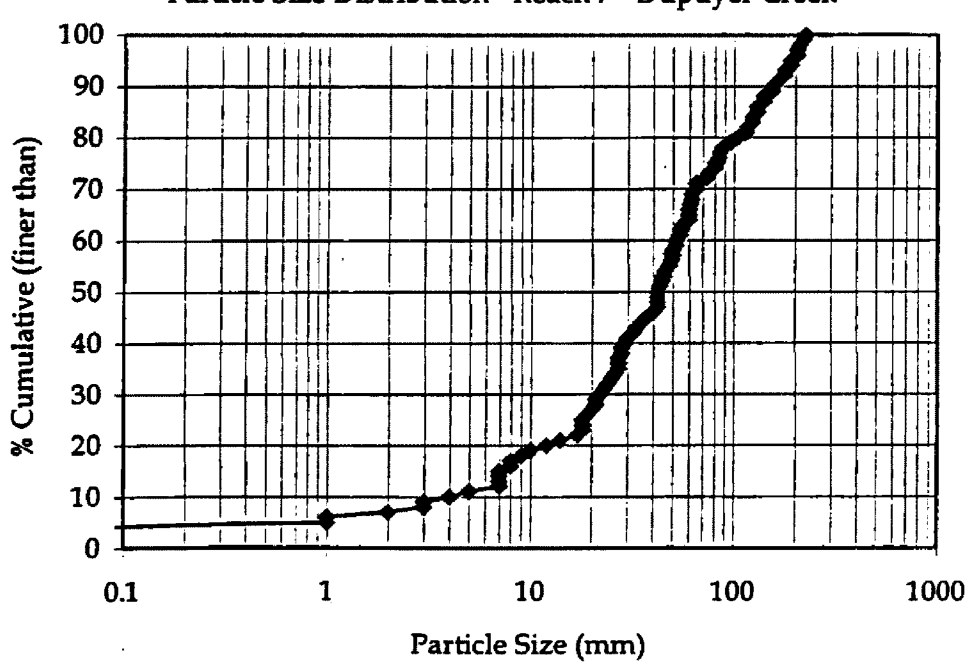

Particle Size Distribution - Reach 4 - N. F. Dupuyer Creek
100
90
80
70
60
50
40
30
20
10
0
% Cumulative (finer than)
0.1
1
10
100
1000
Particle Size (mm)

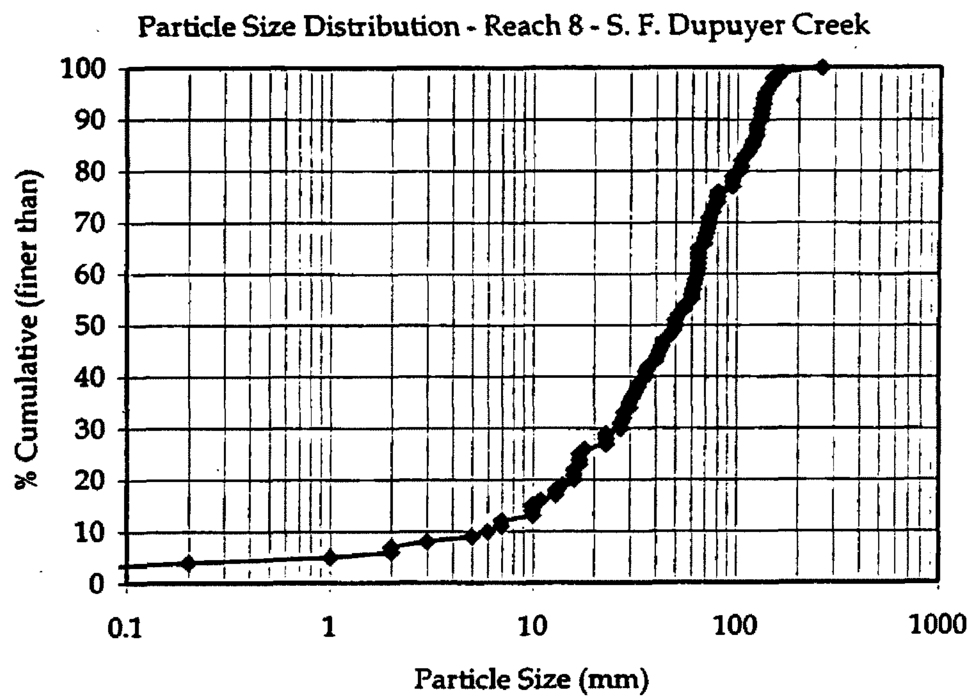

Particle Size Distribution - Reach 5 - N. F. Dupuyer Creek
100
90
80
70
60
50
40
30
20
10
0
% Cumulative (finer than)
0.1
1
10
100
1000
Particle Size (mm)

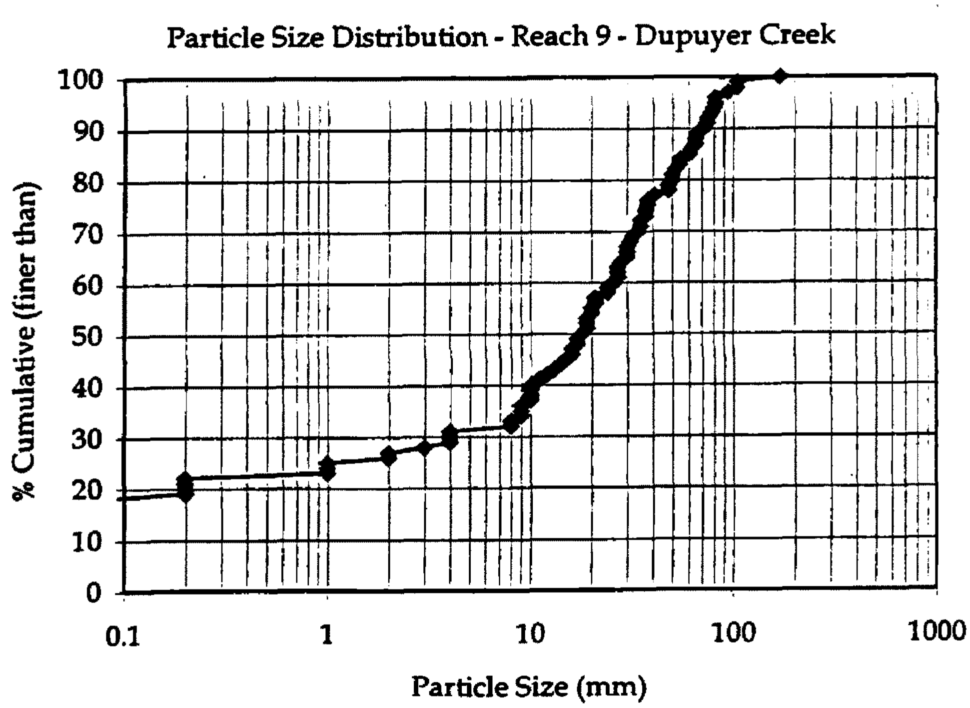
Particle Size Distribution - Reach 6 - N. F. Dupuyer Creek



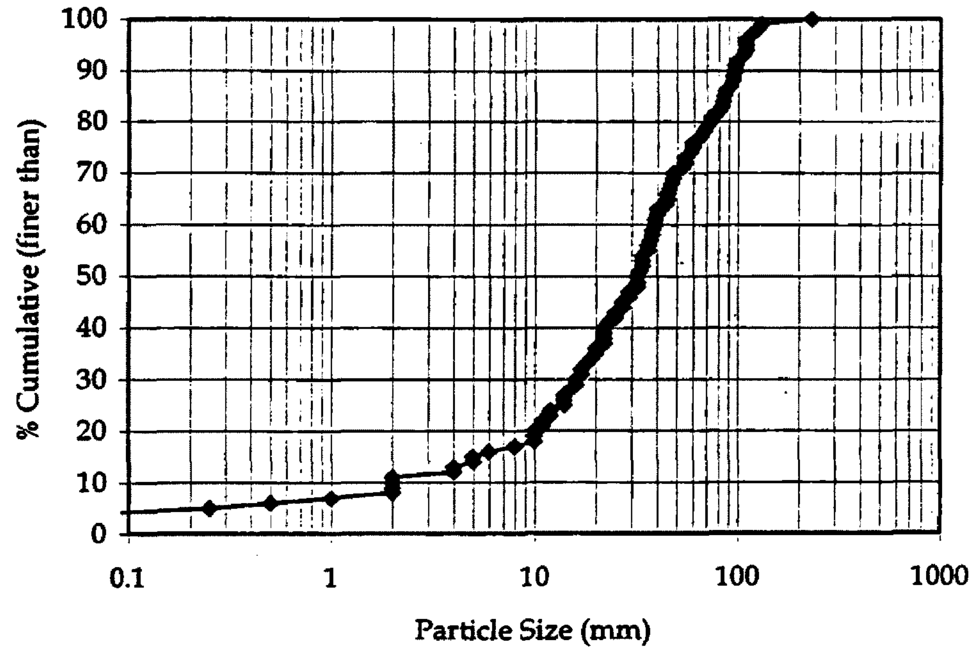
Particle Size Distribution - Reach 7 - Dupuyer Creek



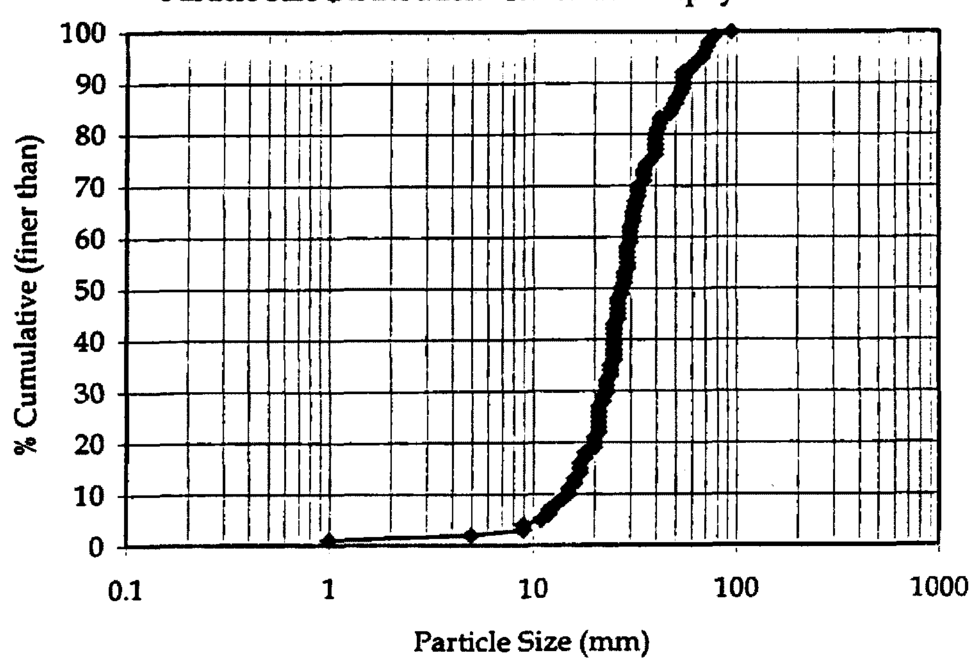

Particle Size Distribution - Reach 8 - S. F. Dupuyer Creek
100
90
80
70
60
50
40
30
20
10
0
% Cumulative (finer than)
0.1
1
10
100
1000
Particle Size (mm)

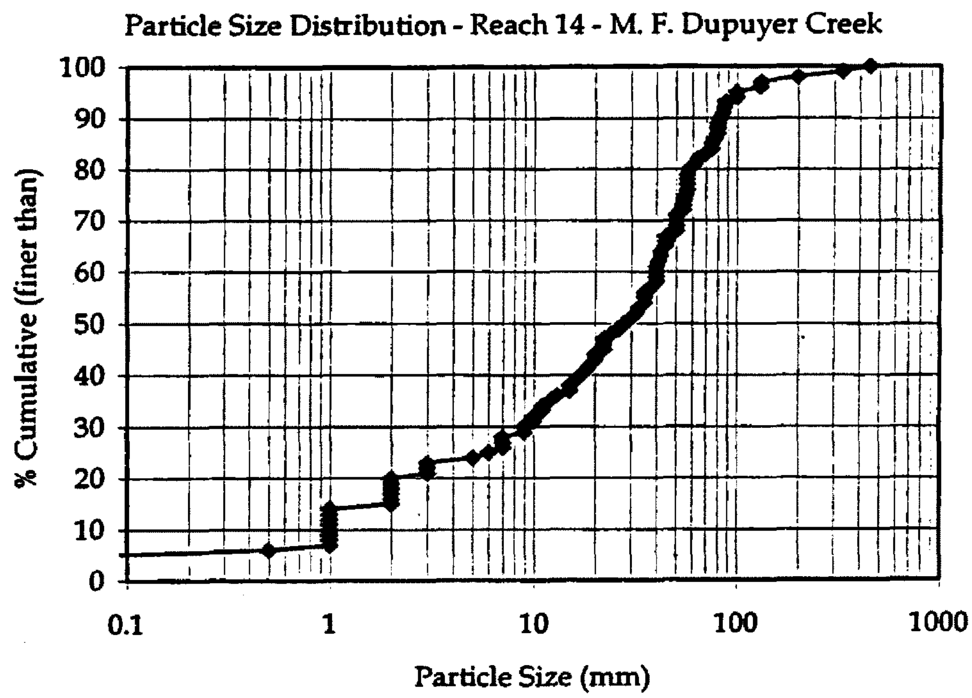

Particle Size Distribution - Reach 9 - Dupuyer Creek
100
90
80
70
60
50
40
30
20
10
0
% Cumulative (finer than)
0.1
1
10
100
1000
Particle Size (mm)

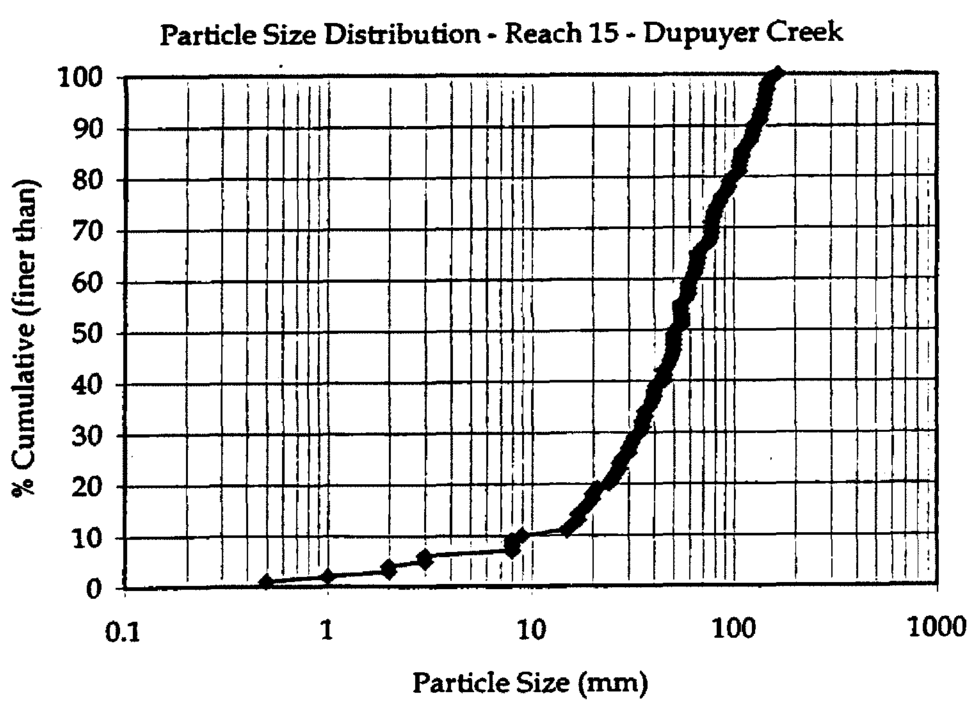
Particle Size Distribution - Reach 10 - Dupuyer Creek

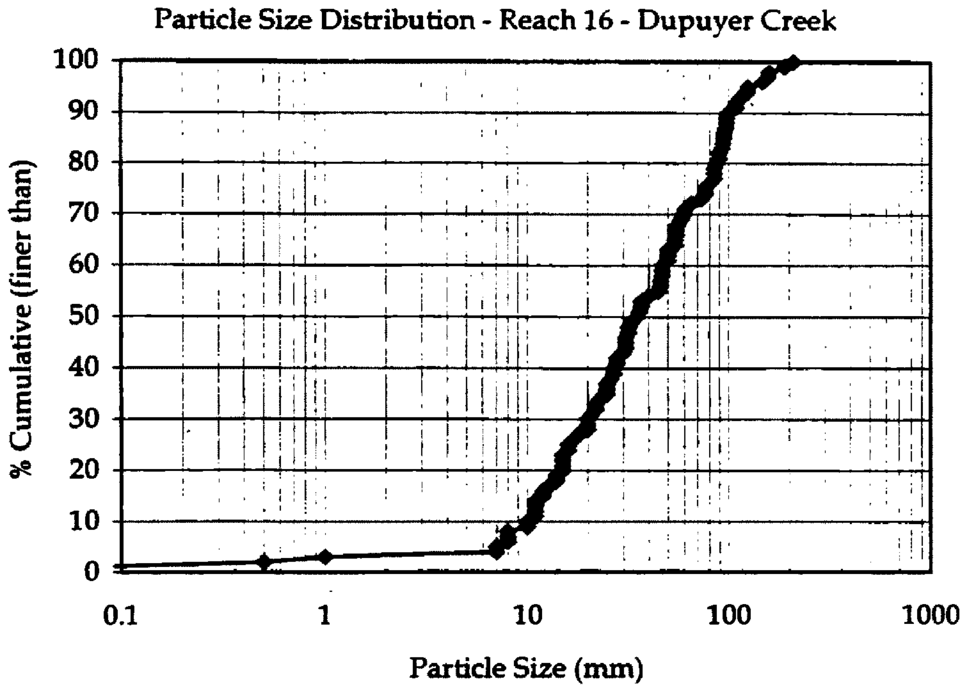


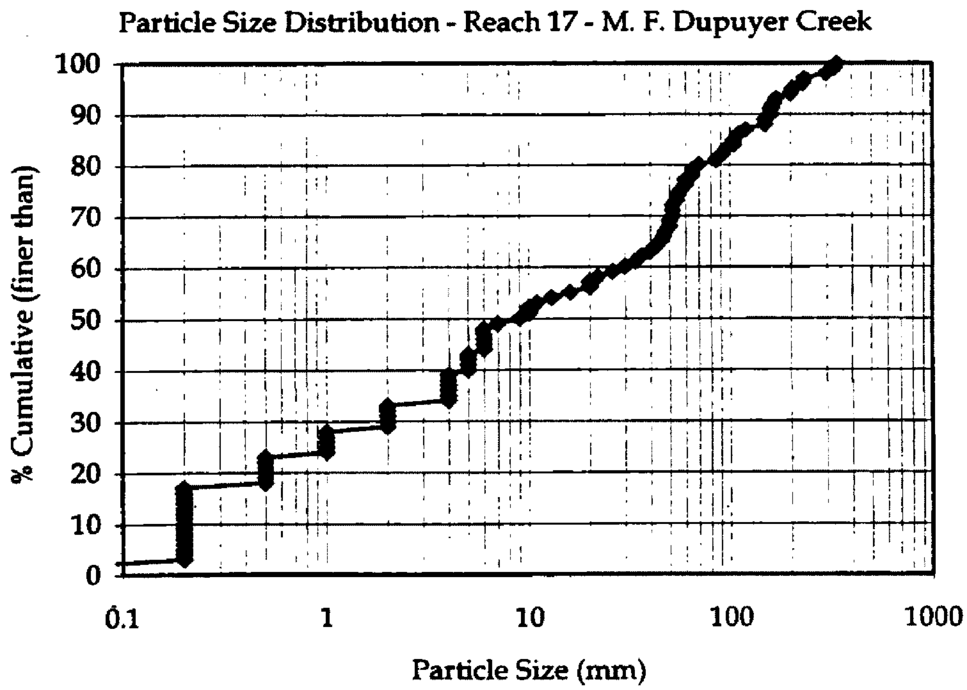
Particle Size Distribution - Reach 11 - Dupuyer Creek




Particle Size Distribution - Reach 14 - M. F. Dupuyer Creek
% Cumulative (finer than)
0
10
20
30
40
50
60
70
80
90
100
0.1
1
10
100
1000
Particle Size (mm)


Particle Size Distribution - Reach 15 - Dupuyer Creek
% Cumulative (finer than)
0
10
20
30
40
50
60
70
80
90
100
0.1
1
10
100
1000
Particle Size (mm)


Particle Size Distribution - Reach 16 - Dupuyer Creek
% Cumulative (finer than)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
Particle Size (mm)


Particle Size Distribution - Reach 17 - M. F. Dupuyer Creek
% Cumulative (finer than)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
Particle Size (mm)

Appendix G

Maps of surveyed cross-sections presented by reach. For general location refer to Figure 3.

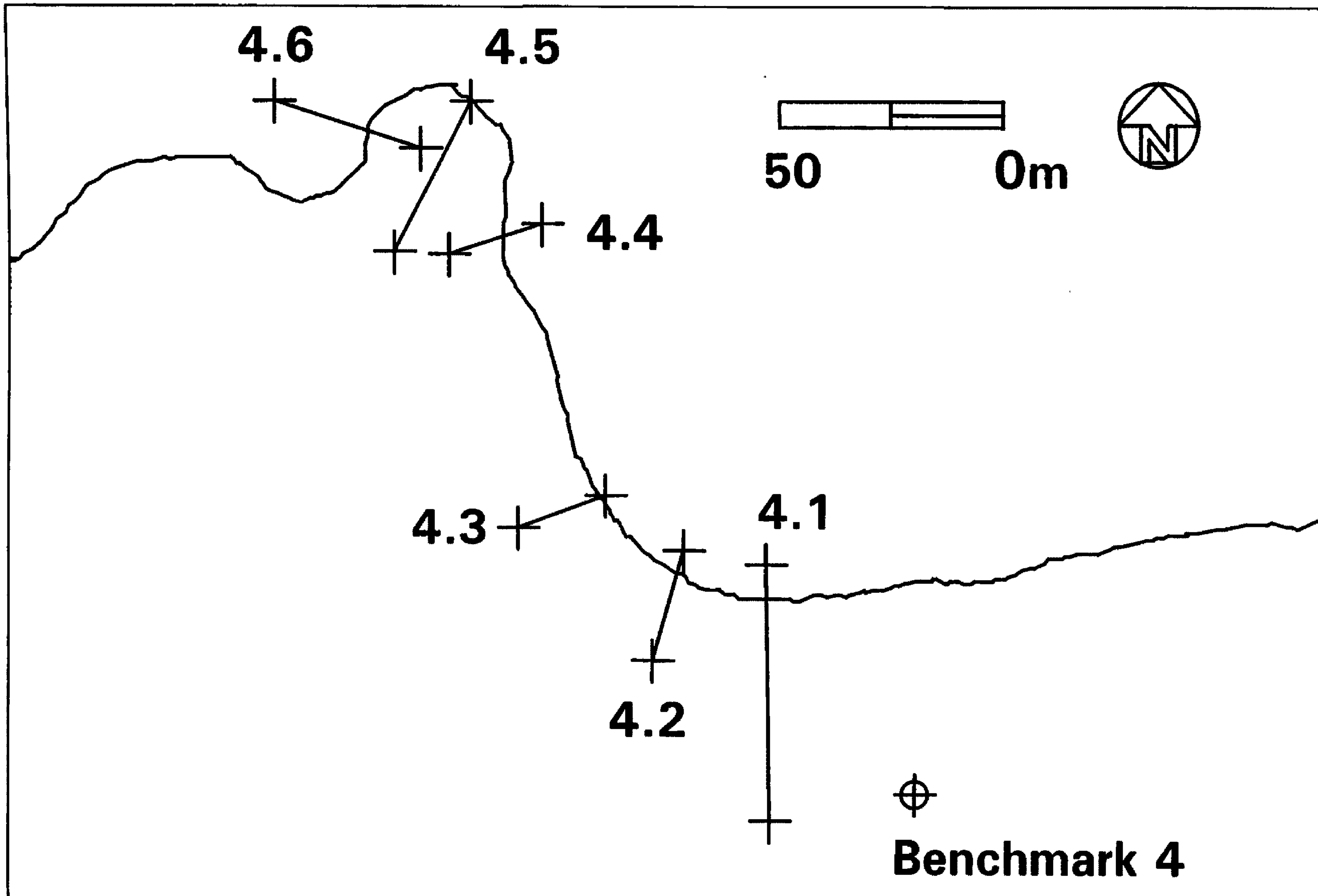


Figure G1. Map of reach 4 cross-sections on North Fork Dupuyer Creek, Anderson Property. Benchmark 4 consists of a stove bolt set in concrete on high terrace.

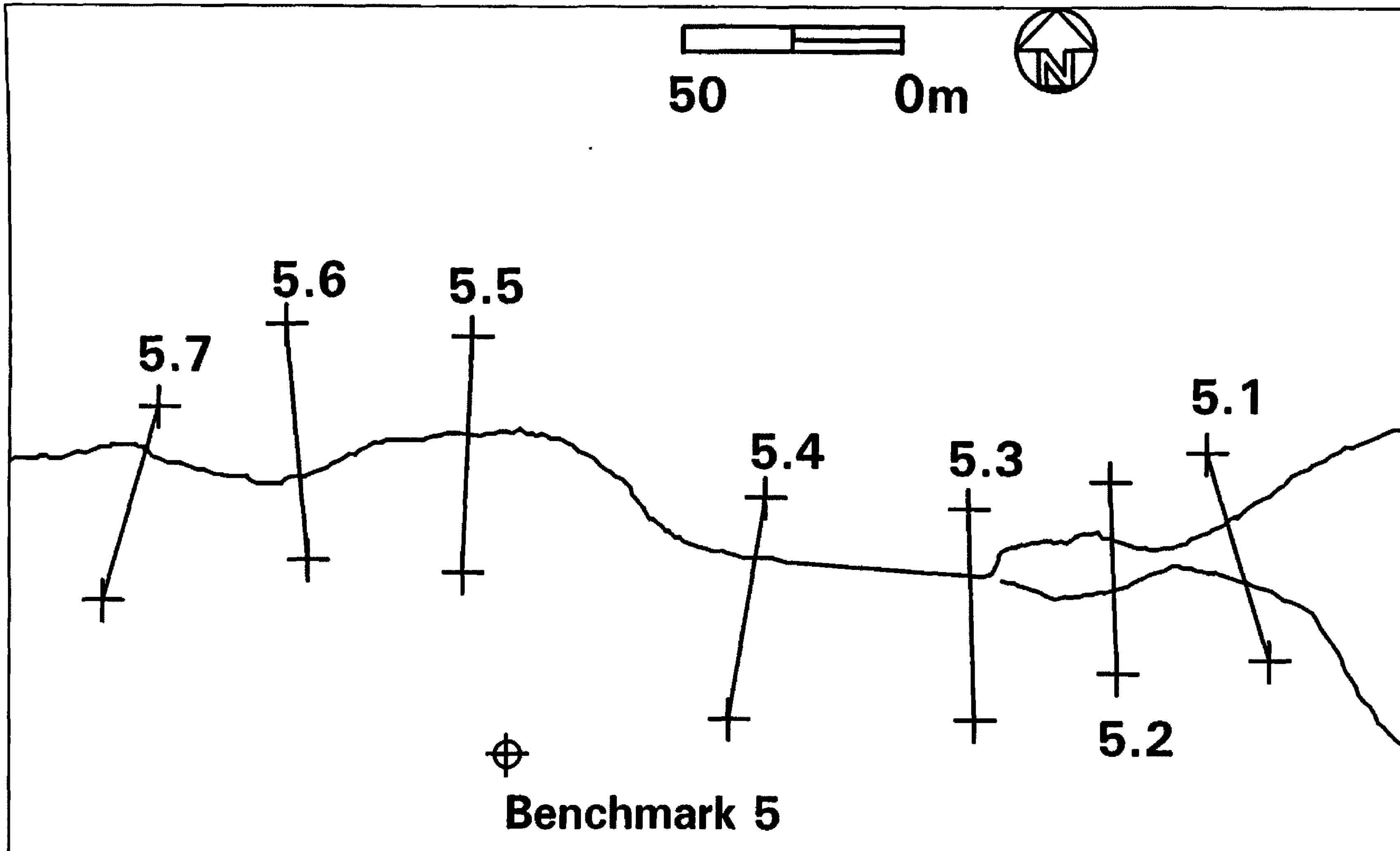


Figure G2. Map of reach 5 cross-sections on North Fork Dupuyer Creek, TRM Ranch. Benchmark 5 consists of a stove bolt set in concrete on high terrace.

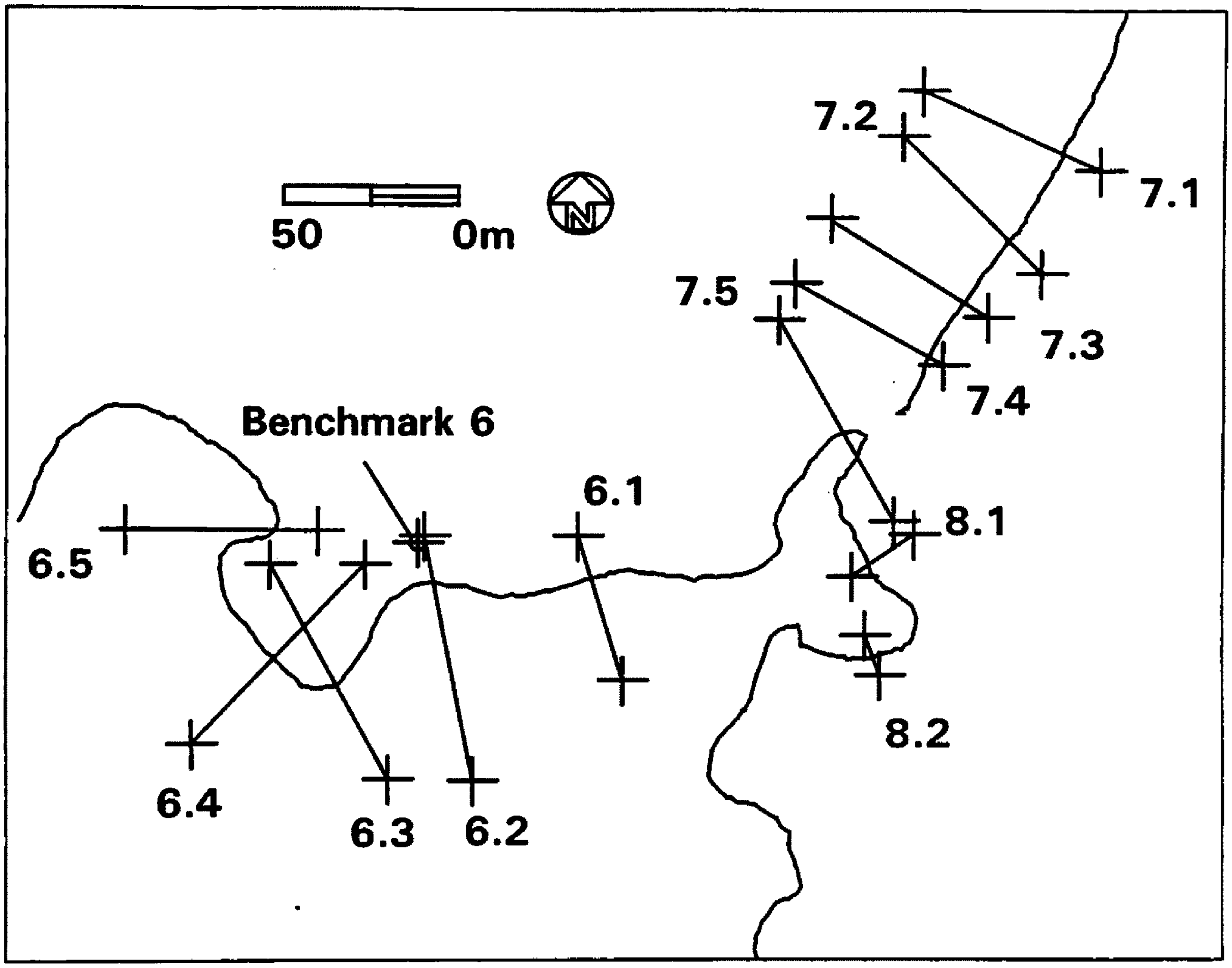


Figure G3. Map of reach 6 cross-sections on North Fork Dupuyer Creek, reach 8 cross-sections on South Fork Dupuyer Creek, and reach 7 cross-sections on Dupuyer Creek, TRM Ranch. Benchmark 6 consists of a stove bolt set in concrete on high terrace, all cross-sections in this map are relative to benchmark 6.

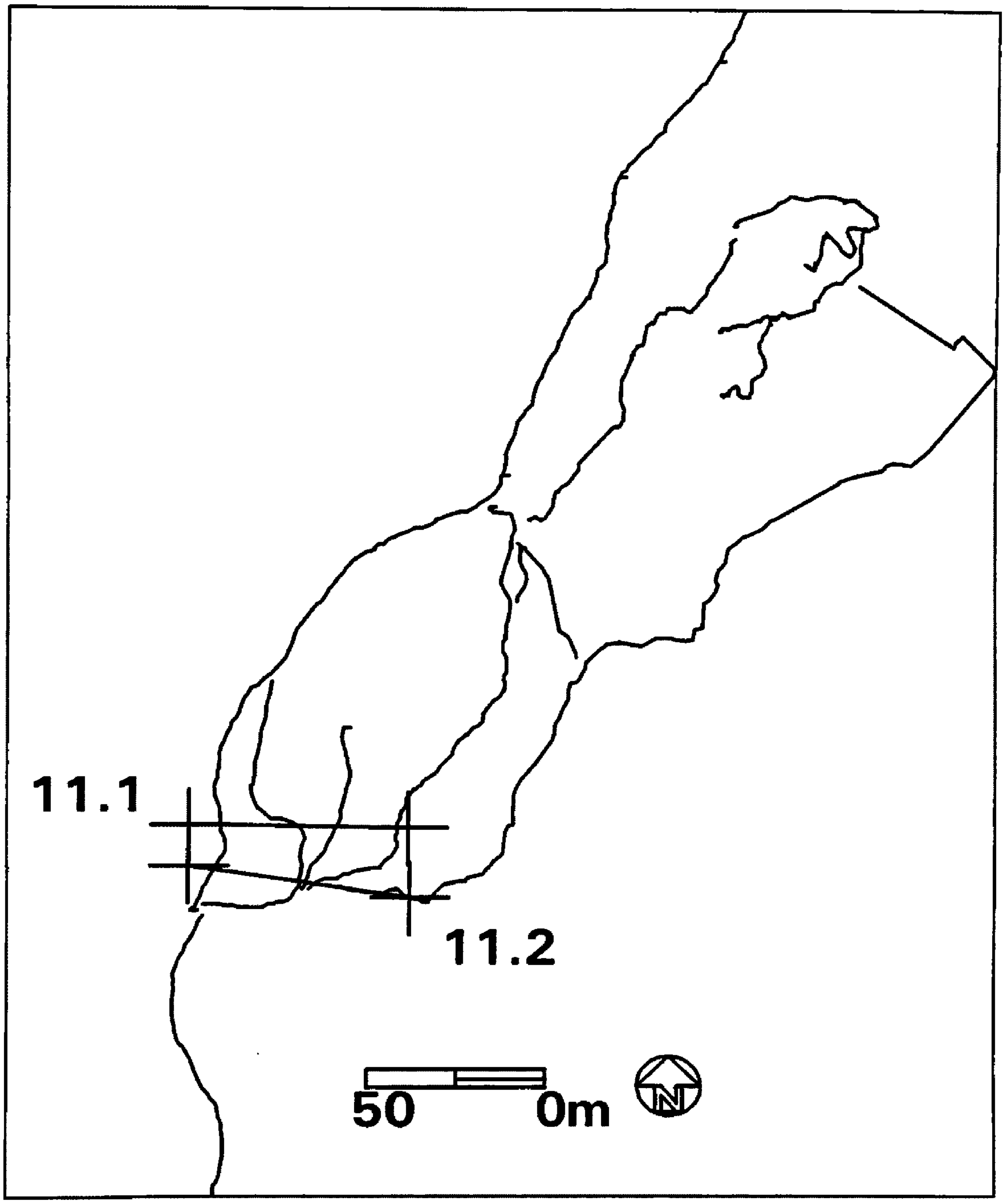


Figure G4. Map of reach 11 cross-sections on Dupuyer Creek, Johnson's Crossing TRM Ranch. No benchmark was established for these cross-sections other than the ends of the cross-sections marked with rebar.

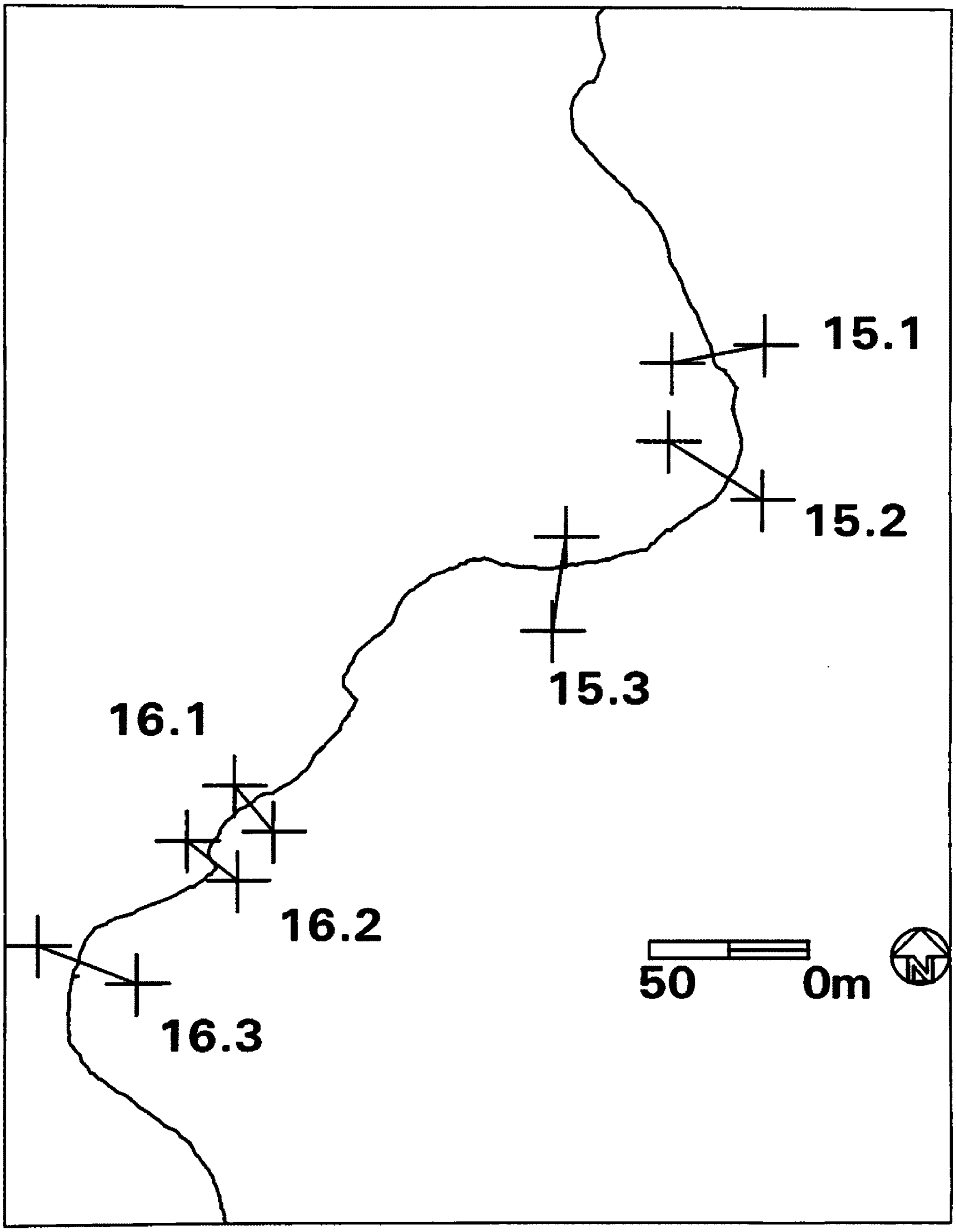


Figure G5. Map of reaches 15 and 16 and associated cross-sections on Dupuyer Creek, TRM Ranch. No benchmark was established for these cross-sections other than the ends of the cross-sections marked with rebar.

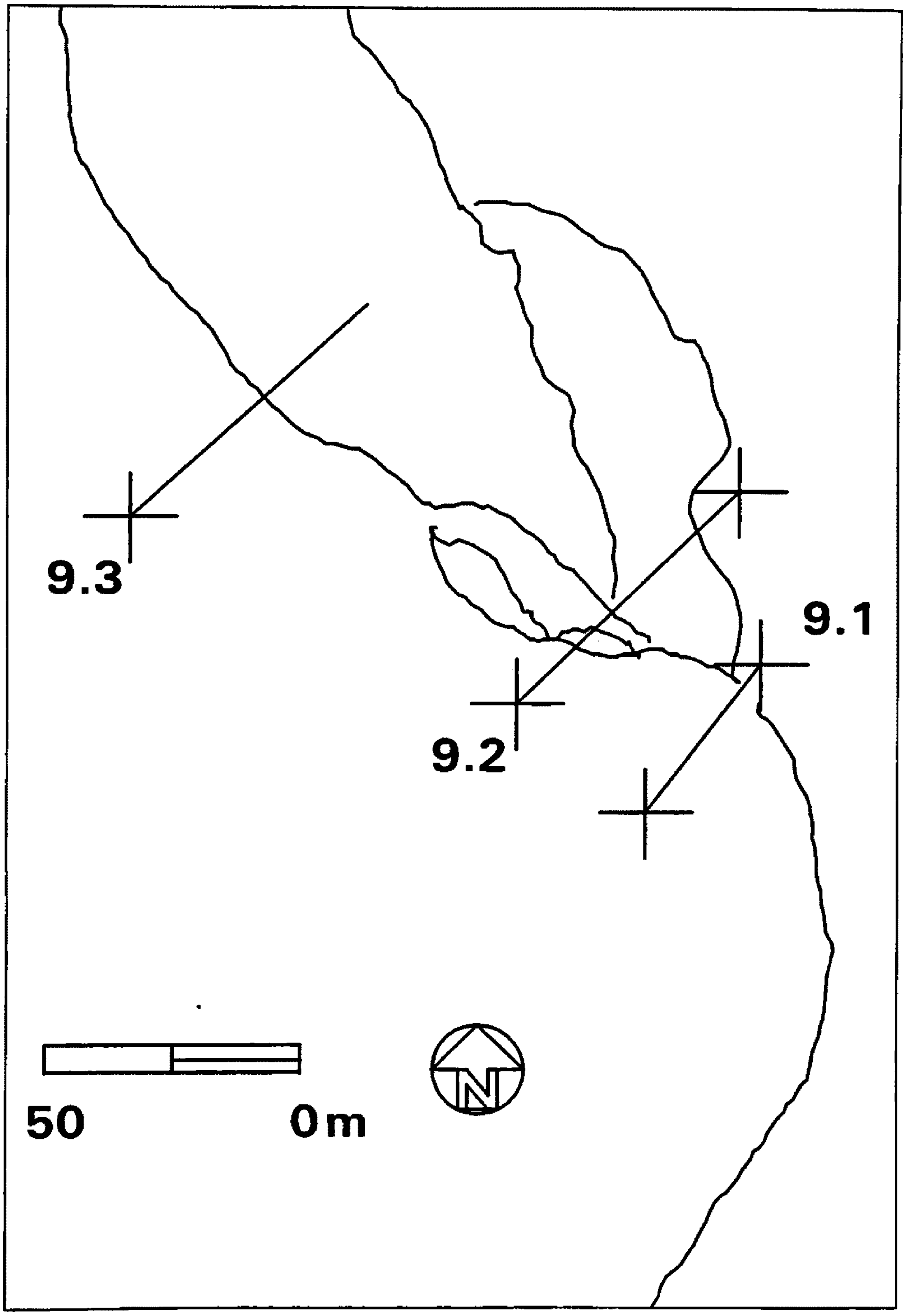


Figure G6. Map of reach 9 cross-sections on Dupuyer Creek, middle crossing on TRM Ranch. No benchmark was established for these cross-sections other than the ends of the cross-sections marked with rebar.

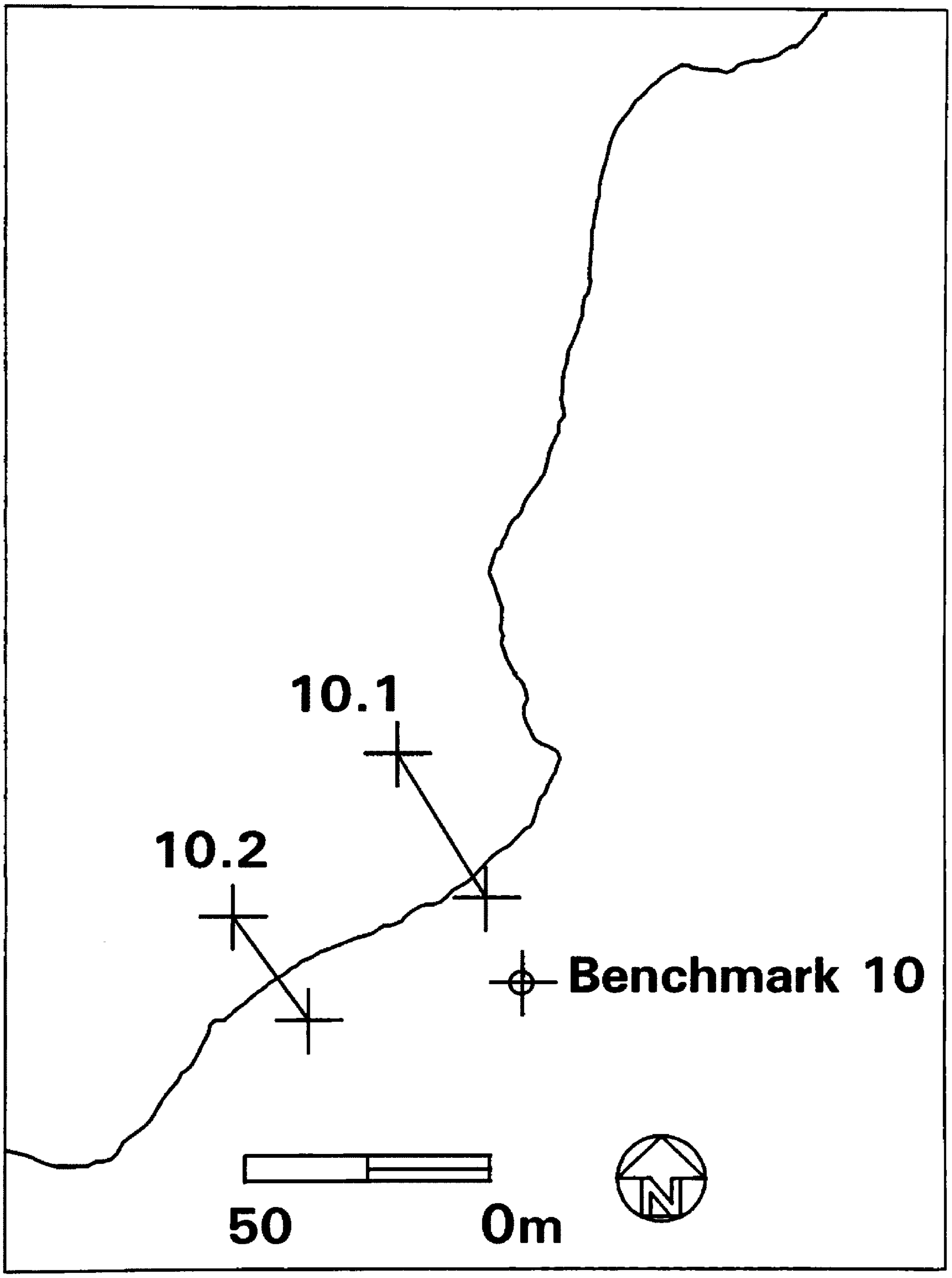


Figure G7. Map of reach 10 cross-sections, Dupuyer Creek cattle exclosure on TRM Ranch. Benchmark 10 consists of rebar set in concrete near Southeast corner of grazing exlosure.

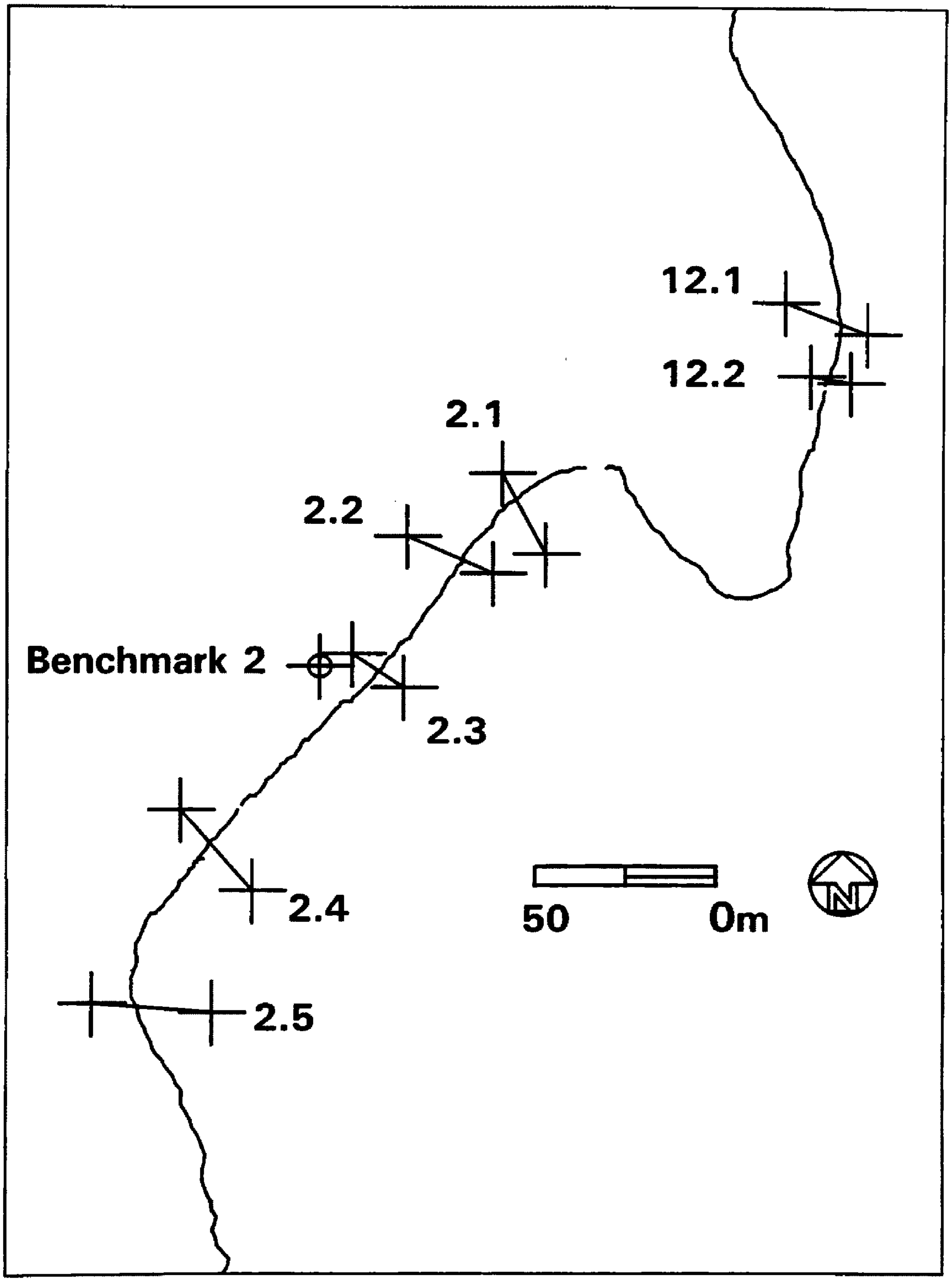


Figure G8. Map of cross-sections for reaches 2 and 12, Dupuyer Creek on TRM Ranch. Benchmark 2 consists of rebar set in concrete near stilling well and footbridge.

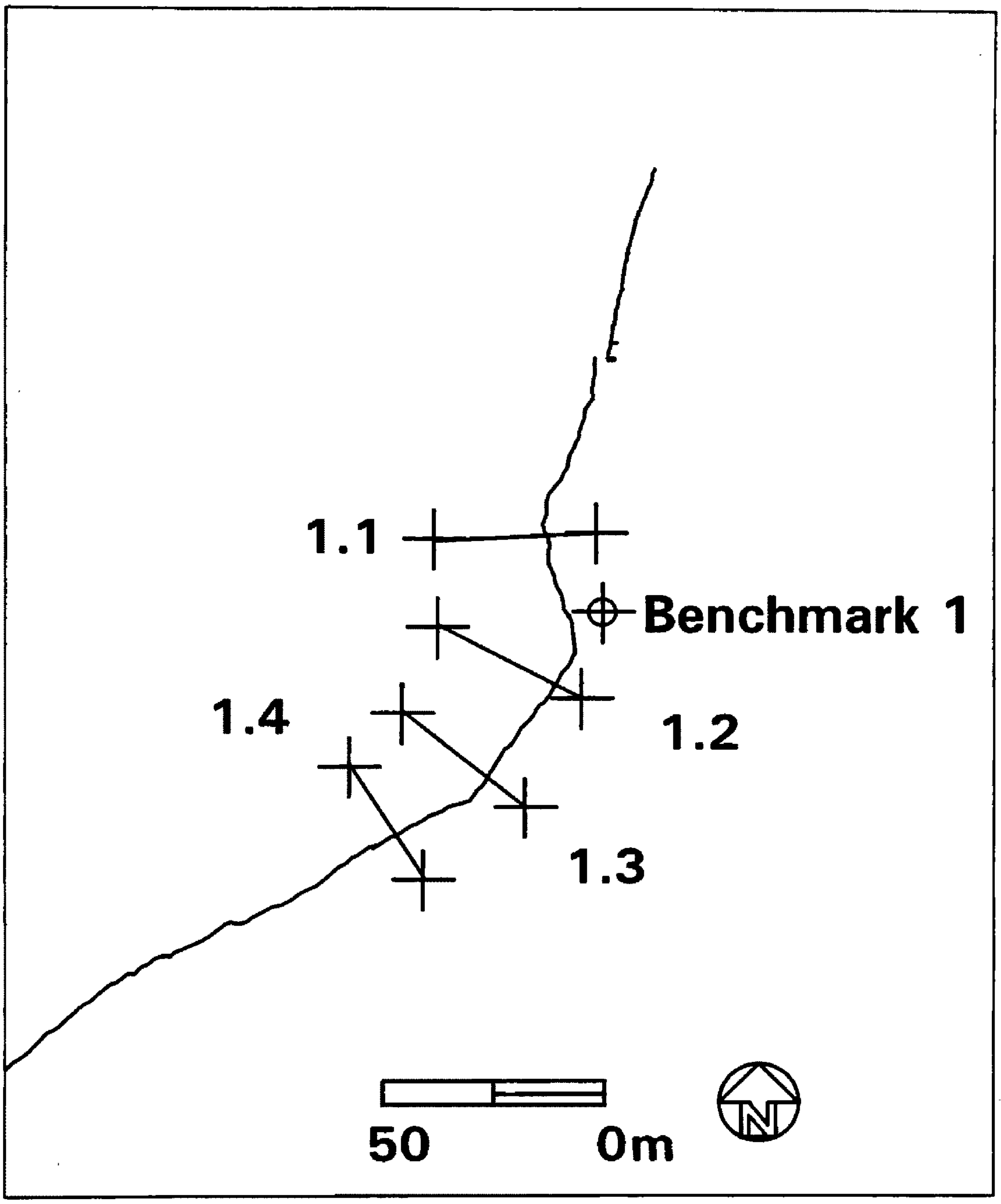


Figure G9. Map of cross-sections for reach 1, Dupuyer Creek on TRM Ranch. Benchmark 1 consists of rebar set in concrete.

Appendix H

UTM coordinates for cross-sections and concrete benchmarks. Note: coordinates for reaches 1, 14, 17, 18, 19, 20 and 21 were not obtained.

Cross-section	x	y
2.1	37551662	533066699
2.1	37550452	533068990
2.2	37550202	533066168
2.2	37547831	533067209
2.3	37546317	533063840
2.3	37547742	533062883
2.4	37543577	533057100
2.4	37541602	533059391
2.5	37542468	533053671
2.5	37539154	533053894
4.1	37178859	532792435
4.1	37178763	532798052
4.2	37176923	532798374
4.2	37176230	532795959
4.3	37175181	532799526
4.3	37173211	532798827
4.4	37173743	532805451
4.4	37171653	532804796
4.5	37172153	532808094
4.5	37170439	532804836
4.6	37167763	532808077
4.6	37171025	532807079
5.1	37240652	532791163
5.1	37242103	532786526
5.2	37238453	532790496
5.2	37238629	532786270
5.3	37235214	532789892
5.3	37235351	532785224
5.4	37230563	532790156
5.4	37229719	532785218
5.5	37223856	532793713
5.5	37223621	532788456
5.6	37220074	532788726
5.6	37219589	532793979
5.7	37215366	532787832
5.7	37216666	532792144
6.1	37407083	532789242
6.1	37405806	532793542
6.2	37402769	532786249
6.2	37401393	532793553
6.3	37400336	532786314
6.3	37396975	532792713
6.4	37394721	532787360
6.4	37399680	532792705
6.5	37392845	532793728
6.5	37398333	532793693
7.1	37420819	532804500
7.1	37415715	532806849
7.2	37419145	532801402
7.2	37415136	532805482
7.3	37417599	532800079
7.4	37416302	532798628
7.4	37412059	532801089
7.5	37414898	532794019
7.5	37411585	532799995
8.1	37415475	532793599
8.1	37413700	532792336
8.2	37414496	532789397
8.2	37414075	532790593
9.1	37488560	532966523
9.1	37490821	532969490
9.2	37486016	532968725
9.2	37490395	532972998
9.3	37478396	532972455
10.1	37500836	533003095
10.1	37502654	533000030
10.2	37499035	532997437
10.2	37497489	532999667
11.1	37429726	532838615
11.1	37423589	532838725
11.2	37429770	532836483
11.2	37423557	532837439
12.1	37560529	533073004
12.1	37558262	533073891
12.2	37560062	533071582
12.2	37558971	533071820
15.1	37477971	532924073
15.1	37475021	532923435
15.2	37477879	532919011
15.2	37474909	532920922
15.3	37471692	532917824
15.3	37471251	532914689
16.1	37461231	532909704
16.1	37462467	532908178
16.2	37461333	532906582
16.2	37459747	532907900
16.3	37455074	532904507
16.3	37458185	532903236

Figure H1. UTM coordinates for cross-section markers.

Benchmark #	x	y
1	37623746	533139508
2	37545426	533063518
4	37182124	532793070
5	37224618	532784412
6	37401202	532793370
10	37503405	532998232

Figure H2. UTM coordinates for concrete benchmarks.